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Design of Waste Plastic Recycling Facilities Based on Campus Scenarios

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ABSTRACT

According to statistics, China's waste plastic recycling rate has been around 30% in recent years. The reason is that the work of sorting and classifying waste plastics from domestic waste with complex compositions relies solely on scavengers and sanitation workers, which is inefficient and costly. This study aims to improve the recycling rate of waste plastics and alleviate plastic pollution by establishing a more reasonable waste plastic recycling system. First, desktop research was conducted through a literature review. Based on the proportion of waste plastics in domestic waste and the difficulty of deploying public facilities, waste plastic recycling facilities in the campus scenario were determined as the research object. The impact of internal and external factors on waste plastic recycling classification behavior was studied respectively. The internal factor study explores conducts sample observations and behavior records of different user groups on campus, and conducts interviews to determine the overall basic functions and function lists of each behavior stage required for the waste plastic recycling process. Use the KJ method to classify functions and summarize function types. Then use the function organization method to draw a function system diagram to discuss the primary and secondary relationships between functions. Research on external factors explores users' willingness and feasibility for recycling and sorting plastic waste in specific scenarios. Semi-structured interviews were conducted through focus groups to study whether plastic sorting and recycling behavior habits can be formed and maintained from various angles. Finally, permutation and combination experiments of each function module were carried out to obtain several scheme ideas, and the schemes were optimized and screened according to the variables of component quantity, unit arrangement, geometric forming method and size until the final product was presented.

Keywords: Campus scene, Waste plastic recycling, Function organization, KJ method

INTRODUCTION

Harmless recycling has become a good way to deal with waste plastics that are difficult to degrade naturally. According to data released by authoritative organizations, in 2021, China produced about 62 million tons of waste plastics, of which only about 31% was recycled, and there is still a lot of room for improvement. The parts that are not recycled were mainly disposed of through low-cost but environmentally harmful methods such as incineration and landfilling.

At present, China's plastic recycling industry is characterized by complex front-end processing links of waste plastic recycling, high manufacturing costs of recycled plastics, and low profit margins of finished products. The main reason for this situation is that the front-end recycling and sorting process is not systematic and the development is not standardized. At present, it is mainly carried out and collected by workers set up at garbage collection points, as well as scavengers. This method is inefficient and costly, and it is difficult to further improve the recycling efficiency of waste plastics.

DESKTOP RESEARCH

The industry reports released by authoritative organizations such as the China Plastic Recycling Association of China National Resources Recycling Association was studied, and calculations and analyzes were conducted based on the data released by the National Bureau of Statistics of China. Analysis of data on China's primary form of plastics, plastic product production, waste plastic production, and waste plastic recycling volume in recent years found that in the four years from 2018 to 2021, China's waste plastic recycling rate fluctuated around 30%, which is at a relatively low level.

In view of the low recycling rate of waste plastics, a literature survey was conducted focusing on the current situation of China's waste plastics recycling industry and waste plastics identification technology. During the literature survey, it was found that the current problems faced by the waste plastic recycling industry include but are not limited to: there is a large demand for plastic products, but no suitable alternative materials have been found; there are relatively few plastic recycling companies and the scale is relatively small… The recycling and regeneration process can be divided into two parts: the collection and sorting link completed in the waste plastic discarding scene and the waste plastic regeneration link. At present, waste plastics in China are generally collected and sorted manually before recycling. The sorting process mainly involves the separation of waste plastics and other domestic waste and the classification of different types of waste plastics. The operation is relatively simple and highly replaceable. Therefore, starting from the sorting and collection process, we try to conduct design research on waste plastic recycling facilities.

In addition, according to the data published in the literature, plastic waste accounts for about 20% of domestic waste in economically developed cities. In the campus scenario, this proportion is around 30%. The campus space is more open than the city, giving public facilities more flexible deployment space, and a higher proportion of waste plastic waste can make waste plastic recycling facilities better pilot application. Therefore, this paper will study the function organization and modeling design of waste plastic recycling facilities in the campus scenario.

INTERNAL PROCESS ANALYSIS - FUNCTIONAL REQUIREMENTS SORTING BASED ON KJ METHOD

The KJ method is a method of sorting out relevant information about unknown problems and using their inherent relationships to sort out ideas from complex phenomena and find solutions. The KJ method is now used to define and organize the functions of waste plastic recycling facilities in campus scenario.

First, four buildings in the campus dormitory area were selected as sample sources based on stratified random sampling in the probability sampling method. Based on the criterion of whether they were carrying waste to be discarded, 5 individuals who walked out of the building were randomly selected as samples, and a total of 20 samples were obtained. Follow and covertly observe the selected individual and decompose the discarding action. In order to prevent the observer's bias, after obtaining the consent of the observed subjects, standardized open interviews were conducted on the causes, timing, discarding actions and other behaviors of their waste disposal behaviors to deepen their understanding of their behaviors. Sort out the covert observation and interview results to obtain the behavior process of users when discarding waste.

Table 1. Waste disposal behavior process analysis.

Behavior process	Carrying waste	Items carried	Open the dormitory door	Go to garbage collection points	Determine the discard location	Throw away waste	Make sure it is securely placed	Leave
Observed behavior	One-hand carry (Smaller bags of household waste)	Carrying back-packs and bags	Push the door with one hand (one- hand carry)	Go as normal	According to garbage classification regulations	Throw in (empty trash can)	Observe whether it is shaking (Place behavior)	Travel to other destinations
	Holding in both hands (Medium-sized carton)	Holding other items	Push the door with your torso (Holding in both hands and drag)	Walk carefully (When the waste carried affects road observation)	Empty bottles, cartons, foam boxes, etc. are stacked separately.	Place (full trash can)	Observe whether it falls or shifts (dropping behavior)	Return the same way
	Drag (Large carton)	No items brought	Push the door with your feet and knees		Staff at the drop-off point intervene	Throw away	Leave directly	

According to covert observation and interview results, it was found that the type and size of waste directly determines the user's discarding behavior. At the same time, the discarding process may require a small learning cost - when users discard wastes with recycling value such as cartons and empty bottles, the drop-off point staff will usually intervene and tell them to drop the relevant items to a dedicated stacking point. Most users' waste disposal behavior is an additional behavior of going out (going to class, dining), and only a few users will make a special trip from the building to discard waste. In addition, it was noted through observation that when the waste drop-off point is not on the same route as the user's other destinations, a moderate detour is acceptable. Generally speaking, the behavior process of waste disposal is a relatively mechanical process that requires little mental thinking.

By splitting and sorting out the behavior process and analyzing the behavioral actions at each stage, the overall basic function of the plastic recycling facility was determined - waste plastic classification and recycling. And the functions of each stage are abstracted, quantitative, and the form of the verb-object structure is defined, and 11 stage functions are obtained by providing inlets, pretreating waste plastics, identifying plastics, classifying plastics, storing plastics, providing outlets, transporting plastics, providing guidance, conveying environmental protection information, integrating into the use environment, and conforming to user aesthetics, and summarizing them as second-level demand indicators. Then, based on the results of behavior observations and interviews, we diverged our thinking around the definition of each function, and refined the goals that each second-level demand indicator needs to achieve as the third-level demand indicator. Obtained 31 demand indicators such as the safety of the waste plastic pretreatment process and the identification of plastic types covering a wide range of plastic types. At the same time, the KJ method was used to further summarize four first-level demand indicators for the defined functions: physical function, cognitive function, symbolic function and aesthetic function. From this, a product function list of waste plastic recycling facilities in the campus scenario is established.

Table 2. Function list of waste plastic recycling facilities in campus scenario.

First-level demand indicators	Second-level demand indicators	Third-level demand indicators
Physical function	Providing inlets	1. Easy to open; 2. Convenient to put in; 3. Safe in the putting process;
	Pretreating waste plastics	1. The pretreatment process is safe; 2. The output is usable; 3. The output is easy to store;
	Identifying plastics	1. Low technology cost; 2. Low application threshold; 3. Wide coverage of plastic types; 4. Efficient identification; 5. No negative impact;
	Classifying plastics	Effectively classify according to identification results;
	Storing plastics	1. Sufficient space; 2. Easy to recycle;
	Providing outlets	1. The outlet is easy to open; 2. Recycling is convenient; 3. The recycling process is safe;
	Transporting plastics	1. Safe transportation process; 2. Efficient transportation; 3. Reduce the impact on traffic;
Cognitive function	Providing guidance	1. Simple and easy to understand; 2. Reasonable scale; 3. Audio-visual combination;
Symbolic function	Conveying environmental protection information	1. Rational shape; 2. Soft color matching; 3. Use of clean energy;
	Integrating into the use environment	The shape conforms to the public's perception of public facilities;
Aesthetic function	Conforming to user aesthetics	1. Reasonable size; 2. Unobtrusive shape and color matching; 3. No noise impact; 4. Beautiful shape and color matching.

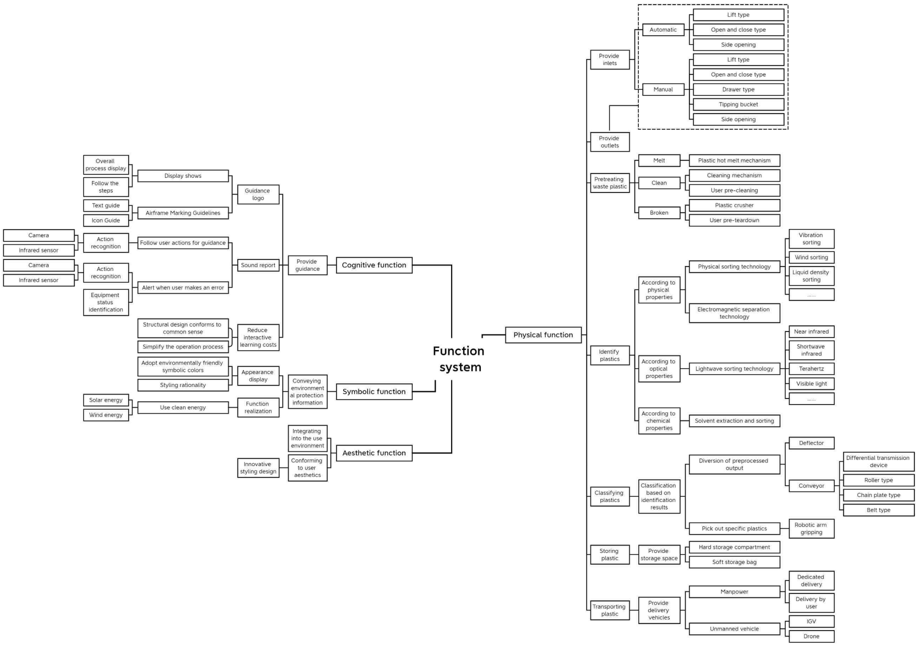

Figure 1: Function system diagram.

After defining each function through the functional requirements list and clarifying their respective functional indicators, a function series connection diagram is drawn using abstract functions and specific implementation methods as the purpose and means of each other. Use this to find possible implementation methods for each function, sort out the primary and secondary relationships and system structure relationships between each function, and integrate the functional connection diagram to form a complete function system diagram.

EXTERNAL SITUATION ANALYSIS - FEASIBILITY ANALYSIS OF WASTE PLASTIC CLASSIFICATION AND RECYCLING IN CAMPUS SCENES

Considering that the waste plastic classification and recycling behavior requires a small amount of additional operation and physical and mental expenditure by users. Therefore, it is necessary to explore the feasibility of classifying and recycling waste plastics in campus scenario to ensure that plastic recycling facilities in campus scenario can achieve their design purposes in actual use. Focusing on the cognitive attitude towards waste plastic classification, the possibility and convenience of hardware facility design, and the correlation mechanism that combines short-term and long-term incentives, semi-structured interviews were conducted using focus group methods on some of the objects of covert observation and interview. Explore users' willingness and operability to participate in plastic classification and recycling behavior in campus scenario.

Table 3. Compilation of interview results.

Question type	Question	Answers	
Waste sorting behavior	Do you usually sort garbage? What are the reasons for doing/not doing garbage sorting?	Do 1. Classification is obligatory and not complicated; 2. Failure to classify will result in penalties; 3. Garbage station staff are required to sort;	Do not 1. Garbage station staff will divide; 2. Weak awareness of classification among those around you;
	How do you usually deal with recyclable waste such as cartons and plastic bottles?	1. Discard it with other recyclable garbage; 2. The garbage station sanitation union asks for help; 3. Pile it next to the garbage station with other people; 4. Throw it away or sell it according to the actual situation;	
Willingness to sort waste plastics	What impact do you think separate sorting of waste plastics will have on daily littering?	1. It is not much different from ordinary garbage classification; 2. It will be necessary to sort out the plastic separately, which is more troublesome; 3. An additional step will be added when discarding;	
	If public facilities could be provided for dedicated plastic recycling, would you be willing to participate in waste plastic recycling?	1. Yes, it should not be much different from throwing garbage normally; 2. It will be participated in just like normal stacking; 3. Hope it coincides with the moving line of garbage disposal as much as possible; 4. Will participate if required by the school or dormitory;	
	Would it change your willingness to participate if it could return you actual benefits after you recycle the plastic correctly, but require you to sort or simply dismantle the plastic before recycling?	1. It feels more troublesome, not as convenient as throwing away garbage.; 2. If the operation is not particularly troublesome, you will participate; 3. Willing to participate if it can be popularized; 4. Make a decision based on the actual benefits;	
	What are your expectations for incentives?	1. Establish a red list and black list system; 2. Points redemption; 3. Special supervision and reminder; 4. Those who do not comply will be fined and photographed.	

The interview results showed that in the opinions of the interviewees, the behavior of discarding waste is a relatively simple process without strict requirements and restrictions. The interviewees are willing to recycle without requiring users to make too much extra mental or physical effort, but they also put forward more design requirements for hardware facilities. Incentive mechanisms can promote users to classify and recycle waste plastics to a certain extent, but interviewees also mentioned that the type and intensity of incentive mechanisms will also affect their decision-making to participate in waste plastic classification and recycling behaviors. Therefore, reasonable hardware facility design combined with appropriate incentive mechanisms can realize the classification and recycling of waste plastics in campus scenario.

FUNCTIONAL SOLUTION INTEGRATION AND MODELING DESIGN

Combining the results and requirements of internal and external factor analysis, arrange and combine the physical functional links, and sort out the implementation process of functional requirements in hardware facility design based on the characteristics of the input and output factors of the functional links to form a function flow chart. Based on this, we proposed an overall solution concept, conducted permutation and combination experiments on the functional solutions proposed in the function system diagram, and comprehensively considered the four independent variables of the number of hardware components, economy, implementation conditions and hardware facility size. And combined with the current popularity and application level of each technology, the best functional concept solutions are selected for hardware facility design.

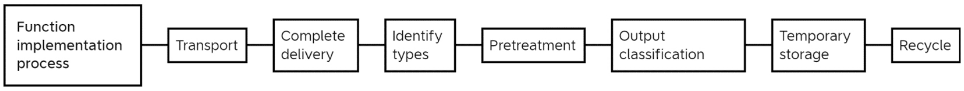

Figure 2: Functional flow chart.

Table 4. Function solution.

Function	Implementation				
	1	2	3	4	5
Transport	Delivered by user	Dedicated delivery	Igv	Drone	
Put in	Lift type	Open and close type	Tipping bucket	Drawer type	Side opening
Identify	Physical sorting	Lightwave sorting	Electromagnetic separation	Solvent extraction and sorting	
Pretreatment	Plastic crusher	Cleaning mechanism	Plastic hot melt mechanism		
Sorting	Rely on identification technology	Conveyor	Deflector	Robotic arm gripping	
Storage	Storage box + partition	Multiple storage bags	Multiple independent storage boxes		

In order to reduce the physical expenditure of users during the delivery process and reduce the impact on traffic, drones are added to transport waste plastics on the basis of users placing waste plastics themselves, and containers are set up to store waste plastics during drone delivery. The inlet adopts a lifting mechanism with a simple structure to achieve the purpose of easy opening and safe delivery. Light wave identification technology has a relatively low threshold for use among current plastic identification technologies, covers a wider range of plastic types, and is more suitable for identifying waste plastics in campus scenario. Considering the availability of the output, a crusher is used to crush the plastic after identification, and a guide plate combined with a conveyor is used to classify the waste plastic fragments. Due to the randomness of the composition and quantity of plastic types, storage boxes are used for storage and movable partitions are deployed in them to store and separate the plastic fragments.

After determining the implementation method of each function module, conduct spatial arrangement experiments. Use modeling software to simplify each function module into blocks of different colors. Based on the function implementation process, conduct spatial arrangement experiments on the function modules in the software interface to determine the functional structure layout within the final hardware design.

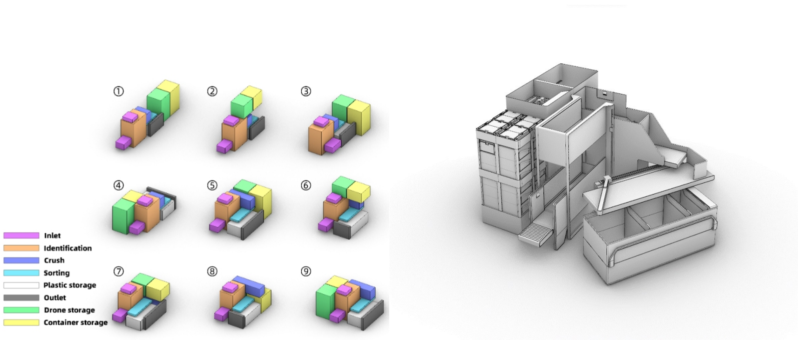

Figure 3: Function module arrangement experiment and function module layout modelling.

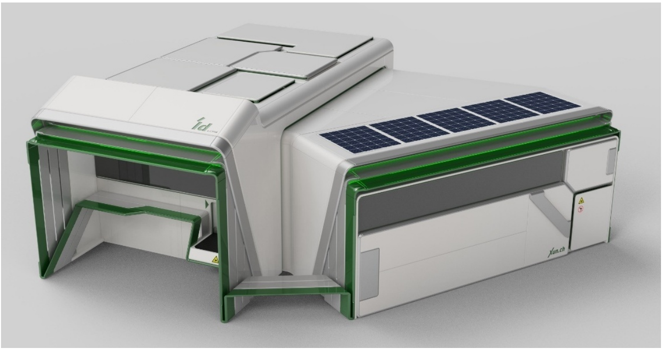

Figure 4: Modeling design of waste plastic recycling facilities.

During the spatial arrangement experiments, four independent variables - number of builds, unit arrangement, geometric shaping method and size - were varied to obtain different functional layout solutions and evaluated. Use this as a clue to optimize the spatial layout until the final functional structure layout is determined, and use this as a basis for further hardware modeling design.

CONCLUSION AND OUTLOOK

This paper explored the impact of internal process factors and external situation factors on recycling and sorting behavior. The study of internal process factors uses the KJ method to analyze waste disposal behavior and arrange the functions of hardware facility design. External situation factors explore the possibility of plastic recycling facility in specific scenarios through user interviews. Finally, the research results of the two were combined to design a plastic recycling device in a campus scenario. It is hoped that this design can improve the current situation of low recycling rate of waste plastics. It is also hoped that this study can provide more ideas for sustainable design.

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