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Original Article

Proposal for the Service Design of a Waste Sorting and Recycling System of Public Residential Districts in Shanghai: Focusing on Waste Sorting and Recycling Bins

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ABSTRACT

Objectives: This study uses service design to improve waste sorting participation and accuracy among residents in Shanghai's public housing communities by developing a user-centered, modular, and intelligent recycling system. **Methods**: A mixed-methods approach was adopted, including analysis of current practices in Shanghai, case studies from South Korea and Japan, and service design tools such as user journey mapping to identify key touchpoints and user pain points. **Results**: Findings show a gap between policy measures and residents' everyday needs, leading to low engagement. Challenges include unclear signage, inconvenient bin placement, and poor system interaction. **Conclusions**: A service-design-based solution is proposed: an intelligent, modular recycling system that integrates human-centered design and smart technology, aiming to increase usability, participation, and long-term compliance in waste sorting.

Keywords: Public residential districts, Recycling bins, Service design, Shanghai of china

1. Introduction

1.1. Research background and objectives

Since 2019, when Shanghai initiated pilot waste sorting programs in some public residential districts, most waste is still "mixed and unsorted", with low compliance rates for proper classification. The fundamental issue of sorting waste at the source remains unresolved. Problems such as incomplete regulations, lack of public awareness, underdeveloped recycling products, and low efficiency in waste processing continue to persist.

As main spaces for residents' daily activities and the primary sites for household waste generation and disposal, the management of household waste in public residential districts plays a decisive role in determining both the quality of life and lifestyle of residents. Currently, there are numerous issues with waste sorting in these areas in Shanghai, such as inaccurate waste disposal, overflowing waste bins leading to littering, and complex waste management systems, etc.. Waste sorting and recycling in public residential districts mainly rely on policies and enforced measures from the government and society to compel residents to sort their waste. However, this approach overlooks residents' actual thoughts and inconveniences regarding waste disposal, ultimately failing to achieve the desired outcomes.

In response to these challenges, this paper seeks to optimize

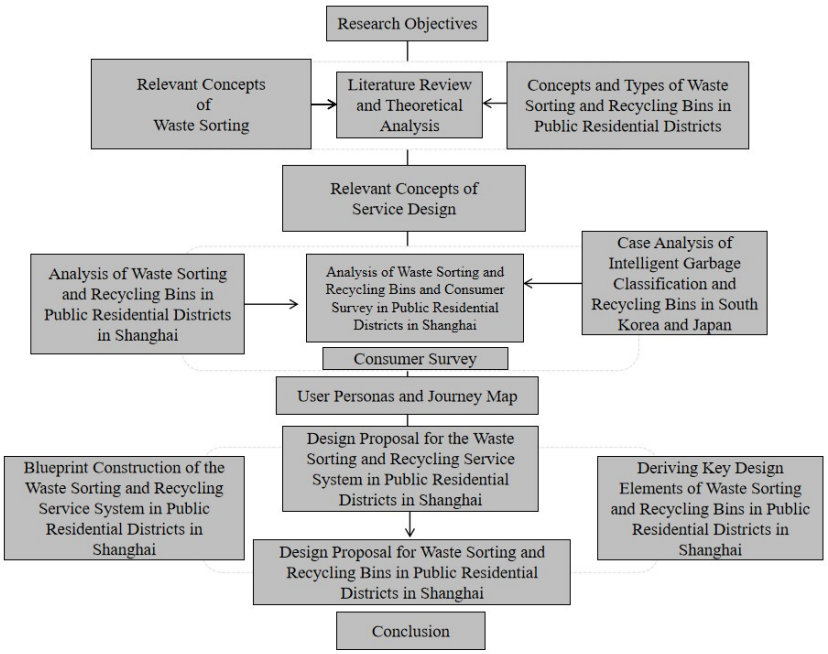


Fig. 1. Research famework

the structure and functionality of waste sorting and recycling bins in public residential districts in Shanghai through the lens of service design concepts and tools. By applying the theoretical framework of service design, intangible services are made tangible. Through investigating the actual needs of target users, the waste sorting and recycling process is optimized, as well as a waste sorting and recycling service system is constructed for public residential districts. This aims to provide users with a better experience during the waste sorting and disposal process. In doing so, the negative attitudes of some residents towards waste sorting can be reversed, and the design of the waste sorting and recycling system in public residential districts can be improved, helping to encourage residents to sort waste at the source, increase recycling rates, and effectively reduce treatment costs.

1.2. Research methodology

This study is divided into four stages: First, it examines the relevant concepts and processes related to waste classification, Public Residential community garbage bins, and service design in Shanghai. Second, through field research on garbage classification and recycling bins in three residential communities in Pudong New Area, Shanghai, combined with the analysis of best practices from South Korea and Japan, as well as a consumer survey, the study develops target user personas and user journey maps. Next, based on the analysis of user journey maps, it identifies service touchpoints, uncovers user needs and pain points, proposes service design strategies, and optimizes key touchpoints. Finally, it constructs an optimization direction for the waste classification and recycling service system in Public Residential communities in Shanghai, proposing design elements and directional suggestions for garbage classification and recycling bins, as well as the user-end application. The research framework is illustrated in Fig. 1.

2. Theoretical Analysis

2.1. Waste sorting in Shanghai

A detailed explanation of Shanghai's waste sorting categories, along with examples, is shown in Table 1. Recyclables refer to waste suitable for recycling and resource recovery, such as used plastics, old newspapers, glass, metals, etc.. Hazardous waste includes items like used batteries, expired medications and so on. Wet waste, or food waste, includes

Table 1. Detailed explanation and examples of household waste classification in Shanghai

Category	Content	Classification Standard
Recyclable Waste	plastic bottles metal, glass, paper, etc.	Waste that can be recycled and utilized as a resource
Hazardous Waste	mercury thermometers, cosmetics, batteries, medications, etc.	Waste that poses direct or potential harm to human health or the natural environment
Wet Waste	leftover food, spoiled food, etc.	Waste produced from daily life food processing and food services
Dry Waste	shells, residue, tiles, hoses, etc.	Household waste that does not fall under recyclables, hazardous waste or wet waste

items such as food scraps, leftovers, expired food, and biodegradable kitchen waste like fruit peels and seeds. Dry waste, also known as other waste, refers to all household waste that does not fall under the categories of recyclables, hazardous waste, or wet waste.

2.2. Types of waste bins in public residential districts

Following the enforcement of mandatory waste sorting policies, small and open-lid type waste bins have gradually been phased out. Currently, the predominant waste collection tools in public residential districts are still waste bins, which can be categorized into the following three types: (1) Single-bin Waste Bins: These are the most commonly used waste collection tools. They are typically made from high-density polyethylene or polypropylene through single injection molding. They offer advantages such as corrosion resistance and strong weather ability. The smooth surface facilitates easy waste disposal and minimizes residue. These bins can be combined in multiple units for easier transport and use. They are specifically categorized based on their operational mechanism into swing-lid type, flip-lid type, and pedal type. These bins are cost-effective and widely used for various waste collection environments. A typical single-bin waste bin is illustrated in Fig. 2.

(2) Waste Sorting and Recycling Bins: After implementing the waste sorting policy, most cities in China adopted the four-category waste sorting method. Existing plastic bins were differentiated by color and labeling, and single-bin waste bins were upgraded to a more structured bin design. These upgraded bins include rain shelters and are accompanied by four-color bins and information boards to facilitate proper waste sorting in public residential districts, as shown in Fig. 3.

(3) Smart Waste Sorting Bins: Smart waste collection equipment represents an upgrade of the traditional four-category waste bins in the context of modern technological advancements. Utilizing technologies such as the Internet, big data, the Internet of Things (IoT), and artificial intelligence (AI), the "smart recycling" model is employed to carry out front-end waste sorting and recycling, unified transportation at the terminal stage, and centralized processing at the final stage (Chen, 2019 [1]) The content is shown in Fig. 4.

2.3. Concepts related to service design

2.3.1. Definition of service design

The concept of combining "service" and "design" was first introduced by G.L. Shostack [7]. in 1984. Service design was formally discussed in 1991, with its development closely linked to advances in science and technology, as well as design theory [4]. Service design refers to the effective planning and organization of activities aimed at improving service quality and enhancing the interaction between service providers and recipients. It involves the coordination of various elements such as people, infrastructure, communication, and materials, all with the goal of optimizing the service experience, improving service quality, and enhancing user satisfaction through systematic planning [9].

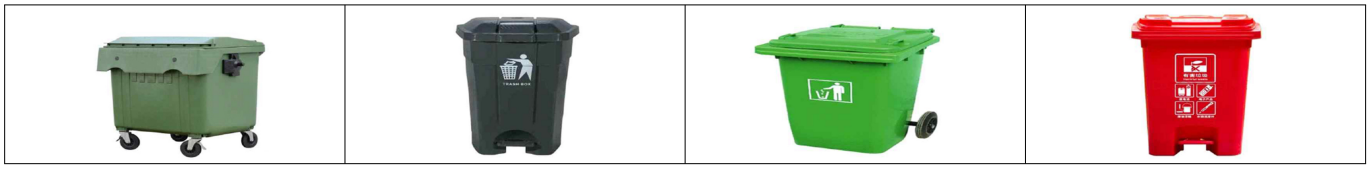


Fig. 2. Single-bin waste bins

Fig. 3. Waste sorting and recycling bins

Fig. 4. Smart waste sorting bins

2.3.2 Service design process

This study adopts the Double Diamond model published by the Design Council (UK), which illustrates that the design process involves continuous cycles of divergent and convergent thinking. It consists of four stages: Discover, Define, Develop, and Deliver [3].

(1) Discover: In this stage, relevant literature is reviewed to understand the current situation of waste sorting and recycling in public residential districts. Surveys are conducted to identify the issues users face when recycling or interacting with the relative products.

(2) Define: This stage involves analyzing product cases, developing user personas to clarify the characteristics of target users, and mapping user journeys through behavioral analysis. This allows for a deep understanding of user needs throughout the waste sorting process.

(3) Develop: The focus is on building a recycling service system using service design tools and service blueprints. The service design direction for these waste sorting and recycling bins is explored from the perspectives of functionality, structure, form, and human-machine interaction.

(4) Deliver: In the final stage, scenarios are constructed and user validation is carried out to minimize errors and discrepancies.

3. Investigation and Analysis of Waste Sorting and Recycling Bins of Public Residential Districts in Shanghai and Consumer Survey

3.1. Analysis of waste sorting and recycling bins of public residential districts in Shanghai

This study conducted field investigations from July 28th to July 31st, 2024, selecting three of the first pilot residential districts for waste sorting in Shanghai: Hangyun Community, Caojiayan Public Residential Complex, and Yaojiang Public Residential Complex. A total of 8 waste sorting bins were examined in detail, The content is shown in Table. 2. focusing

Table 2. Research and analysis of waste sorting and recycling bins in the public residential districts in Shanghai

Image	Dimensions	Material	Color	Location	Features
	2900× 800× 2400 (㎜)	Galvanized, plastic		East Gate	Four categories, with promotional slogans, a handwashing sink on the left, and the ability to increase bin capacity based on disposal quantity
	2900× 1200× 1900 (㎜)	Galvanized, plastic		parking lot	Four categories with foot-operated lids.
	2500× 900× 2100 (㎜)	Galvanized, plastic		Unit 2 Hallway	Four categories, hazardous and other waste bins overlap, unclear sorting labels
	2700× 800× 2100 (㎜)	stainless steel, plastic		Left of Bicycle Storage	Four categories, all bins are the same color, distinguished only by image colors
	3700× 1200× 2000 (㎜)	stainless steel		Southwest Gate Exit	Four categories, increased the number of food and general waste bins
	2400× 900× 2200 (㎜)	plastic		Fitness Center	Four categories, flip-top design for the disposal opening
	2900× 800× 2400 (㎜)	Galvanized, plastic		East Gate	Four categories, with promotional slogans, a handwashing sink on the left, and the ability to increase bin capacity based on disposal quantity
	3200× 1000× 2300 (㎜)	s steel, Galvanized, plastic		erground Parking Exit	upward disposal design, with an increased number of general waste bins

on their dimensions, materials, colors, and features. A summary was conducted, and the detailed content is presented in Table 3.

Table 3. Survey results of waste sorting and recycling bins in public residential districts in Shanghai

Survey Results	
Function	The bins can accommodate the disposal of four types of waste. The lid opening methods vary, including foot-operated, smart-operated, and pull-string designs. Some bins also have handwashing stations attached on the side.
Material	Most single-bin waste containers are made of plastic, while integrated or smart bins would combine other materials such as aluminum alloy and galvanized steel.
Shape	The overall design is predominantly rectangular.
Color	The majority of the bins use red, green, blue, and gray as primary colors to help distinguish and remind users of the different waste categories.

The survey identified the following issues with the waste sorting and recycling bins in three public residential districts in Pudong New Area, Shanghai: (1) Lack of Standardization: The waste sorting and recycling bins are not uniform and can be categorized into three main types: a. Multiple single-bin combinations. b. Integrated bins, where single bins are embedded in aluminum alloy structures. c. Smart integrated bins, which require QR code scanning for waste disposal. (2) Fading Labels: Due to prolonged outdoor exposure or infrequent cleaning, the sorting labels on plastic bins have become unclear. (3) Small Openings: The openings on integrated bins are often too small, causing waste to spill outside. (4) Insufficient Capacity: The waste sorting and recycling bins frequently reach capacity, leading to overflow.

3.2. Case analysis of intelligent garbage classification and recycling bins in South Korea and Japan

Since 2013, Seoul Metropolitan City has introduced RFID (Radio Frequency Identification) technology to enhance the efficiency of food waste management as shown in the Fig. 5 By embedding RFID chips in food waste bins, the system can accurately record the amount of waste disposed of each time, achieving digital management and fair billing. This approach significantly reduces errors and management loopholes associated with manual operations. In practice, each resident is issued a personalized RFID card, which is used to open the garbage bin automatically when swiped. After food waste is deposited, the system automatically weighs it and links the data to the resident's account in real time, charging fees based on the amount of waste. This intelligent management system not only improves the accuracy of waste classification but also makes the fee collection process fairer and more transparent.To ensure the system operates efficiently, Seoul has enacted legislation that clearly defines the responsibilities of all stakeholders, establishing a multi-level accountability system involving residents, property management, and waste disposal companies. Moreover, to encourage public participation, Seoul has implemented a set of incentive and punitive measures: residents and units that actively participate in garbage classification receive rewards, while those who fail to comply face penalties.In addition to RFID-based management, Seoul promotes a food waste reduction policy and enforces the Extended Producer Responsibility (EPR) system for electronic waste, requiring manufacturers to take greater responsibility in waste management. The comprehensive implementation of these measures has significantly improved the accuracy of garbage classification and has driven the sustainable development of urban environmental governance.

3.3. Intelligent garbage bin "SmaGO" in Japan

The SmaGO garbage bin, developed by Forcetec, represents an innovative approach to waste management in Japan. as shown in the Fig. 6 Powered by solar panels, SmaGO utilizes IoT (Internet of Things) technology and a 3G network to monitor waste accumulation in real time. When the bin reaches full capacity, the system automatically compresses the waste, increasing the bin's capacity by 5 to 6 times. This not only significantly improves collection efficiency but also reduces operational costs. One of the notable features of the SmaGO bin is its non-contact, foot-operated lid-opening mechanism, which effectively prevents users from touching the bin handle directly,

Fig. 5. Korean RFID-based food waste bin

Fig. 6. Japanese SmaGO smart trash bin

Table 4. Case analysis of intelligent garbage classification and recycling bins in South Korea and Japan

Case Region	Key Features	Insights
South Korea	• RFID-based identity recognition and weight-based billing system • Supporting legislation and reward-penalty mechanism	• Introduction of RFID identity cards and weight measurement modules enables a traceable and fair incentive system • Establishment of a reward-penalty mechanism linked to sorting behavior enhances enforcement effectiveness
Japan	• Smart bins with IoT connectivity and automatic compression function • Real-time overflow monitoring and data uploading	• Equipped with overflow sensors and networked alert systems to optimize waste collection scheduling • Use of real-time sensor data to improve maintenance and management efficiency

especially when their hands are dirty from handling waste. This thoughtful design greatly enhances user convenience and hygiene. The smart compression system accurately tracks the volume of garbage and optimizes collection scheduling, thereby reducing the frequency of waste collection. This contributes to lower labor and transportation costs, while also minimizing the environmental impact associated with waste logistics.

Shanghai can enhance its waste sorting system by adopting South Korea's RFID-based billing model with legislative support and incentive mechanisms to boost fairness and participation, while also integrating Japan's IoT smart bin technologies — such as automatic compression and real-time monitoring — for more efficient, digitalized waste management as shown in the Table 4.

3.4. Consumer questionnaire survey

This study employed an online distribution method for data collection through a professional online survey platform (Questionnaire Star). The research subjects were permanent residents from the central urban areas of Shanghai, including Huangpu District, Changning District, Xuhui District, Jing'an District, Putuo District, and Hongkou District. These areas, being the first batch of pilot regions for waste classification in Shanghai, feature a comprehensive range of community types and high population density, which helps ensure the representativeness of the sample and the validity of the data. To obtain general and universally applicable conclusions, this study adopted a simple random sampling method. Through random distribution and invitation via an online survey platform, every potential respondent had an equal chance of being selected, thereby reducing selection bias and enhancing the scientific validity and generalizability of the sample. A total of 450 questionnaires were distributed, and 407 valid responses were collected, achieving a valid response rate of 90.4%. The distribution of valid responses was as follows: Huangpu District (114), Changning District (43), Xuhui District (69), Jing'an District (61), Putuo District (76), and Hongkou District (44). The questionnaire design consists of two parts: the first part covers basic information (gender, age, occupation, residential area, and community type) as shown in the Fig. 7; the second part contains 12 structured questions as shown in the Table 5. addressing aspects related to the garbage classification environment in Public Residential communities, human factors, recycling facility factors, and incentive mechanisms. The collected data were statistically analyzed using SPSS 27.0 to systematically examine the impact and influence pathways of various factors on garbage classification behavior. The study aims to provide theoretical foundations and practical guidance for improving garbage classification policies through empirical analysis.

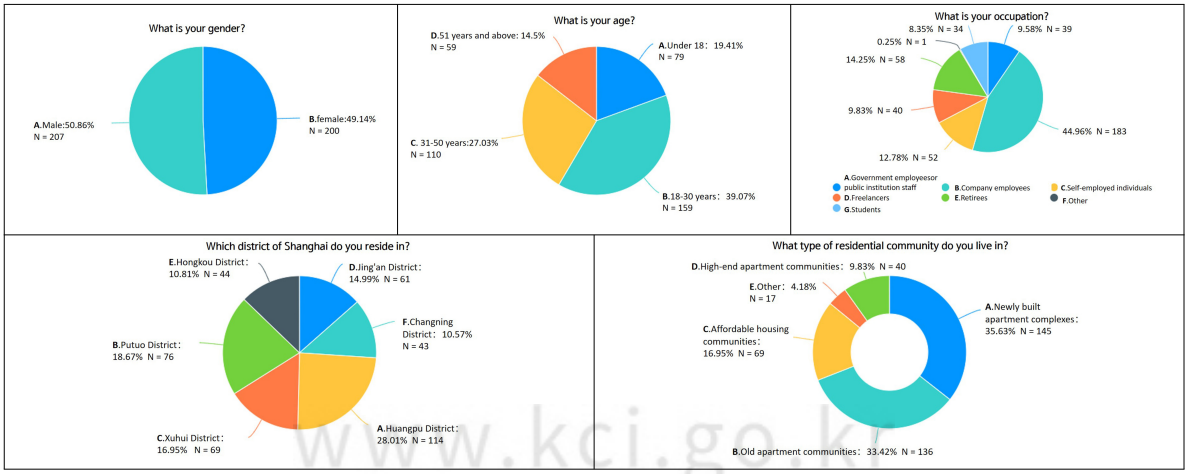


Fig. 7. Questionnaire survey related content

The survey shows a balanced gender distribution among respondents, with 50.86% males and 49.14% females. The age structure leans toward younger demographics, with 39.07% aged 18 to 30, 27.03% aged 31 to 50, 19.41% under 18, and 14.5% aged 51 and above. Occupationally, company employees form the largest group at 44.96%, followed by retirees at 14.25%, self-employed individuals at 12.78%, freelancers at 9.83%, government or public institution staff at 9.58%, and students at 8.35%, while the "other" category accounts for 0.25%. Regarding residential area distribution, most respondents reside in Huangpu District at 28.01%, followed by Putuo at 18.67%, Xuhui at 16.95%, Jing'an at 14.99%, Hongkou at 10.81%, and Changning at 10.57%. In terms of residential community types, newly built public residential districts constitute the largest proportion at 35.63%, followed by old Public Residential communities at 33.42%, affordable housing communities at 16.95%, and high-end Public Residential communities at 9.83%, with the "other" category making up 4.18%.

This consumer survey focuses on the service design of the waste sorting and recycling system in Public Residential communities in Shanghai. It aims to understand residents' satisfaction with waste sorting bins, their acceptance of smart facilities, and suggestions for improvement. The survey

Table 5. Questionnaire survey related content

1. How satisfied are you with the current waste sorting and recycling bins?				
A. Very satisfied	B. Satisfied	C. Uncertain	D. Dissatisfied	E. Very dissatisfied
9.09%	6.63%	16.22%	36.61%	31.45%
2. How willing are you to accept smart waste sorting facilities in the future? (Including the model where traditional and smart systems coexist)				
A. Very willing	B. Willing	C. Uncertain	D. Reluctant	E. Completely unwilling
35.38%	31.7%	17.44%	7.37%	8.11%
3. Do you think it is necessary to design waste sorting and recycling bins with smart and humanized features?				
A. Very necessary	B. Necessary	C. Indifferent	D. Not necessary	E. Absolutely unnecessary
26.76%	39.25%	16.95%	12.86%	4.18%
4. Is the supervision and management of waste sorting in your Public Residential District strict?				
A. Very strict	B. Strict	C. Average	D. Not strict	E. Very lax
7.62%	5.9%	17.44%	31.94%	37.1%
5. How often do you receive guidance on waste sorting?				
A. Never	B. Occasionally	C. Frequently	D. Always	E. Do not need guidance
36.12%	31.45%	14.99%	8.85%	8.6%
6. Do you think a reward system (such as points or cash) would improve your waste sorting habits?				
A. Definitely yes	B. Yes	C. Uncertain	D. No	E. Definitely no
42.86%	27.55%	13.56%	9.42%	6.61%
7. What is your preferred method to obtain waste sorting guidance?				
A. Bin graphics	B. Mobile app guidance	C. Community outreach activities	D. Online training videos	E. Do not need guidance
30.22%	32.19%	19.41%	7.37%	10.81%
8. What do you think is the most significant problem with the current waste sorting facilities?				
A. Inconvenient operation	B. Untimely waste removal	C. Unclear classification labels	D. Insufficient number of facilities	E. Poor hygiene
35.63%	33.42%	16.95%	4.18%	9.83%
9. Do you feel the need to clean your hands immediately after disposing of waste?				
A. Definitely yes	B. Yes	C. Indifferent	D. No	E. Definitely no
29.24%	24.32%	17.94%	12.78%	15.72%
10. What smart facility function do you value the most? (Multiple choices allowed)				
A. Sorting guidance	B. Remaining capacity alert	C. Point rewards	D. Hygiene and cleaning	E. Lid opening method
36.03%	33.34%	28.92%	20.97%	20.74%
11. How do you think the waste sorting reward mechanism should be measured?				
A. By weight	B. By classification type	C. By the number of times	D. By accuracy	E. No reward needed
38.57%	31.45%	15.97%	8.35%	5.65%
12. To improve the precision of waste sorting, would you accept a paid semi-transparent garbage bag with an RFID tag?				
A. Strongly accept	B. Accept	C. Uncertain	D. Do not accept	E. Strongly do not accept
22.68%	43.72%	21.56%	9.56%	2.48%

Table 6. Consumer questionnaire survey summary

Consumer Questionnaire Survey Summary	
User Inconvenience Points	The main issues are centered around operational convenience, waste removal efficiency, lack of guidance, and insufficient management.
Improvement Directions	Provide intelligent classification guidance, capacity monitoring, reward points, and cleaning functions.
Facility Optimization	Enhance user satisfaction and active participation by integrating intelligence, visualization, and incentive mechanisms.
Management Enhancement	Strengthen community management and classification supervision by combining intelligent devices for real-time monitoring and guidance.
Education and Promotion	Popularization of classification knowledge, promotion of Public Residential Districts activities, personalized guidance, and a sustainable publicity mechanism.

results indicate that the current satisfaction with waste sorting bins is relatively low, with 68.06% of respondents expressing dissatisfaction or strong dissatisfaction. Regarding the introduction of smart waste sorting facilities in the future, residents generally hold a positive attitude, with 67.08% indicating a willingness or strong willingness to accept this change. Additionally, 66.01% of respondents believe that it is necessary or very necessary to improve the design of waste sorting bins to be more intelligent and user-friendly. However, the supervision and management of waste sorting remain inadequate, as 69.04% of respondents feel that the management in their communities is not strict or very lax. Moreover, the coverage of waste sorting guidance is insufficient, with 36.12% of respondents reporting that they have never received guidance.

Respondents generally believe that implementing a reward system, such as points or cash incentives, can effectively encourage better waste sorting habits, with 70.41% expressing support for this approach. In terms of preferred methods for receiving waste sorting guidance, mobile application guidance 32.19% and waste bin illustrations 30.22% are the most popular choices. As for the problems associated with existing waste sorting facilities, respondents mainly point out inconvenience in operation 35.63% and untimely waste collection 33.42%. Additionally, 53.56% of respondents feel the need to clean their hands immediately after disposing of waste. When it comes to expectations for smart facility functions, sorting guidance 36.03% and remaining capacity indication 33.34% are the most valued functions, followed by point rewards 28.92%, hygiene and cleaning 20.97%, and lid opening method 20.74%.In terms of the measurement method for the waste sorting reward mechanism, 38.57% of respondents support calculation by weight, making it the most favored option, followed by 31.45% who prefer calculation by classification type. Regarding the paid semi-transparent RFID garbage bags, 66.39% of respondents chose to accept or strongly accept them. Overall, residents have high expectations for the intelligent upgrading of waste sorting facilities, while there is still considerable room for improvement in management and guidance. Consumer Questionnaire Survey Summary as shown in the Table 6.

3.5. Persona and user journey map

Based on a quantitative questionnaire survey of Public Residential community users in Shanghai, a large amount of user data has been collected. as shown in the Fig. 8 Two typical user personas have been identified by analyzing user characteristics: Mr. Wang, a working professional, and Mr. Zhang, a retired senior. The typical users' waste sorting and disposal processes are visualized through the service design tool "User Journey Map."

Based on the preliminary consumer questionnaire survey summary and typical user journey maps, data analysis has yielded insights into two aspects: the waste classification and recycling system and the waste classification facilities. Firstly, regarding the issues of the waste classification and recycling system, residents generally reported that waste classification management is not strict enough, with unclear management responsibilities and insufficient supervision frequency being the main problems. Additionally, the frequency of classification guidance is relatively low, with only a small portion of respondents indicating that they frequently or always receive guidance from staff. In terms of residents' awareness of waste classification, most respondents believe that weak classification awareness is one of the main factors affecting the effectiveness of waste classification.

Regarding the design of waste classification facilities, many respondents feel that the design of waste classification bins is unreasonable, mainly due to inconvenient openings and unclear classification labels. Moreover, untimely waste collection is a common problem reported by residents, leading to bin overflow and environmental deterioration, especially during peak usage periods. These issues directly impact residents' satisfaction with waste classification facilities and their willingness to use them.

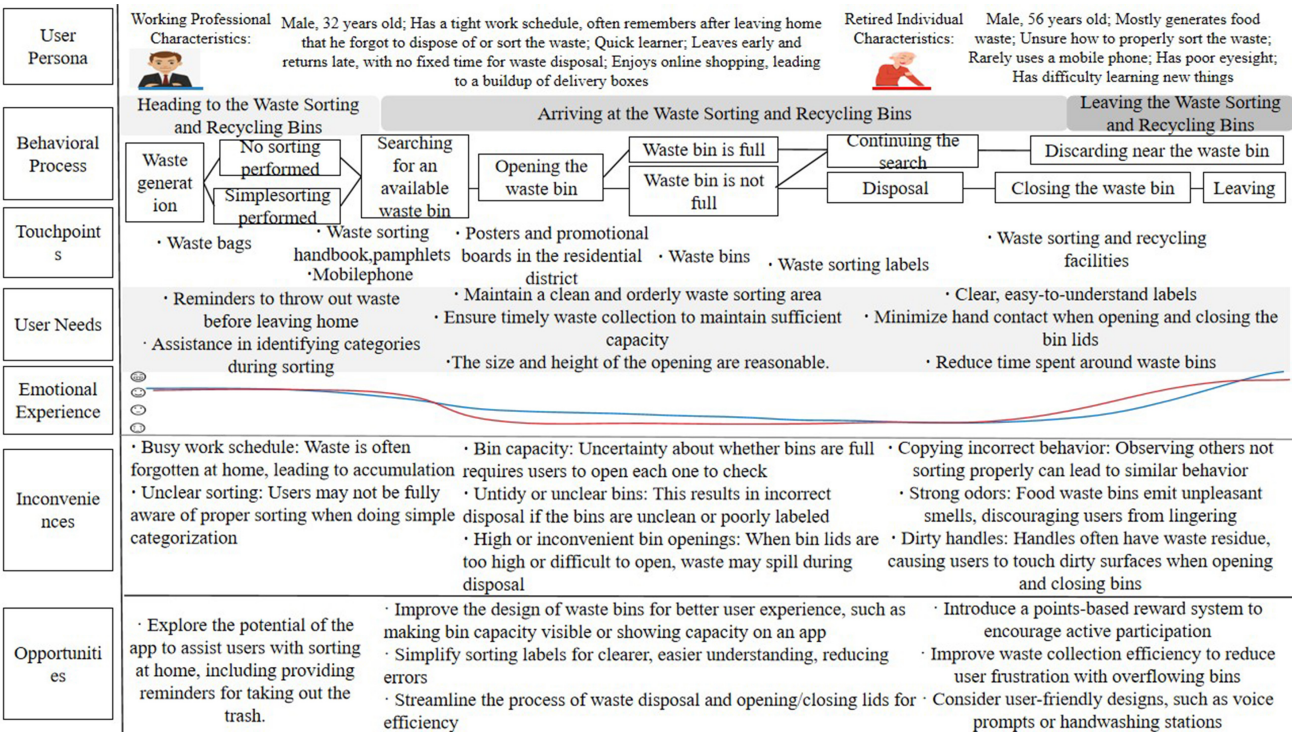


Fig. 8. The personas and user journey maps of Mr. Wang (working professional) and Mr. Zhang (retired resident)

Regarding intelligent facilities, respondents generally hold a positive attitude and are willing to try a coexistence model of intelligent and traditional waste bins. The core functions of intelligent waste bins should include classification guidance, disposal reminders, incentive points, while also considering hygiene management and convenience of opening. Considering the varied usage habits of different residents, intelligent waste bins should coexist with traditional methods while strengthening waste collection management to maintain a clean and efficient waste classification environment.

4. Proposal for the Design of a Waste Sorting and Recycling Service System in Public Residential Districts in Shanghai

4.1. Optimization design strategies for the waste sorting and recycling service system in public residential districts in Shanghai

Based on the analysis of Shanghai's public residential waste bins, consumer surveys, user personas, journey maps, and case studies from South Korea and Japan, this paper proposes optimization strategies for the waste classification service system, as illustrated in Table 7 and Fig. 9.

(1) User-Centered Design and Simplified Operation. the optimization of the design should focus on the convenience and humanization of facility operation, ensuring that residents can easily operate during waste disposal. Smart waste sorting and recycling bins can employ lid-opening mechanisms via QR code scanning (e.g., QR codes from mobile apps). For residents without smartphones or elderly users, RFID cards linked to personal data can be provided. Additionally, a manual lid-opening option should be retained. Manual opening will not be included in the incentive points system, balancing convenience and incentive effectiveness to meet the needs of different user groups. (2) Intelligent Real-Time Management The waste sorting service system should fully utilize intelligent technologies (such as overflow sensors and dynamic monitoring systems) to achieve real-time overflow warnings, classification guidance, and optimized collection scheduling. Through big data analysis and optimization of waste collection routes, it is possible to reduce overflow incidents (Li & Bao, 2018 [5]), enhancing collection efficiency and management quality. (3) Hygiene Optimization and Cleaning Convenience To address the issue of hygiene inconvenience after waste sorting operations, the optimization plan suggests installing handwashing sinks near the waste bins. This setup would allow residents to clean their hands immediately after disposing of waste. Such a design can significantly enhance the user experience and prevent dissatisfaction caused by hygiene issues. (4) Diversified Guidance and Clear Instructions To improve residents' understanding and compliance with waste sorting rules, the system should provide diversified guidance methods, such as a dedicated mobile application that displays sorting rules, facility status, and operational instructions in real-time. The bins themselves should feature clear, stand

Table 7. Derivation of hardware design elements

Derivation of Hardware Design Elements	
Design Elements	Details
Function	• Add terminal devices for interaction with the user's mobile app, enabling real-time visualization of remaining bin capacity and equipping a handwashing area. • Introduce a rewards system where users can redeem points for waste bags.
Shape	Adopt a modern, minimalist design with modular units that allow for multiple categories to be set based on need, offering a high-tech and contemporary feel.
Color	The bin body primarily features a silver-gray metallic finish. The monochromatic tone highlights the four different colors of the waste sorting labels, improving the accuracy of waste disposal.
Material	Stainless steel: The recycling bins require a certain level of strength, hardness, and durability. Since they are outdoor public facilities, the material must be resistant to oxidation and corrosion. Therefore, stainless steel is used as the main material for the bin's framework.

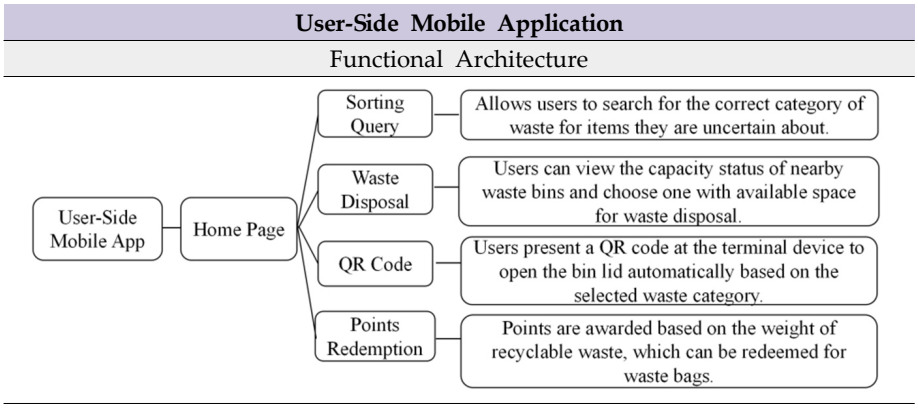


Fig. 9. Derivation of software design elements

ardized sorting labels and visual cues. By combining mobile notifications with graphic and textual labels on the bins, the system can reduce the workload of staff and ensure that residents receive accurate sorting guidance. (5) Incentive Mechanism, regarding waste sorting incentives, it is recommended to establish a quantitative and transparent point-based reward system. For instance, since kitchen waste and recyclable waste are types of waste that can be reused through secondary recycling, points can be calculated based on the weight of kitchen waste and recyclable waste disposed of [6], ensuring both operability and fairness. The earned points can be redeemed for daily necessities or used to enjoy property fee reductions, which can further stimulate residents' enthusiasm for participating in waste sorting. This inducive incentive model helps to cultivate good sorting habits [2], thereby promoting the sustainable development of the community waste sorting system.

4.2. Design proposal for waste sorting and recycling bins in public residential districts in Shanghai

To improve the efficiency of waste sorting and enhance the user experience in Shanghai's apartment communities, as shown in the Fig. 10, Fig. 11, this study has designed a modular waste sorting and recycling bin that integrates humanization intelligence and convenience. The bin features a modern, minimalist design as shown in the Fig. 12, with the main body made of silver-gray stainless steel, offering high strength, hardness, and weather resistance, suitable for outdoor environments. The modular unit design allows the number of bins to be flexibly adjusted according to the specific needs of different communities, with increased capacity for waste categories that generate higher volumes. The bin's exterior uniformly adopts a silver-gray tone, prominently displaying four standard sorting labels (Recyclable, Wet Waste, Hazardous Waste, Dry Waste), enhancing visual recognition and improving sorting accuracy. Functionally, the left side of the bin integrates an intelligent terminal device, equipped with features such as QR code scanning, RFID sensing, sorting guidance, and capacity monitoring. During the initial setup, users must complete pre-authentication: smartphone users can register through an app and bind their personal information, while elderly users who prefer traditional methods can obtain an RFID card from the property management office. Before disposing of waste, users can consult the intelligent terminal device or mobile app to receive guidance on uncertain waste typesas shown in the Fig. 13 During the disposal process, users must present a QR code (generated via the

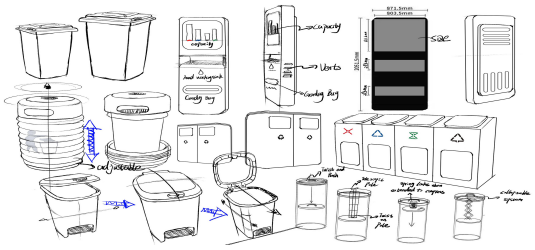
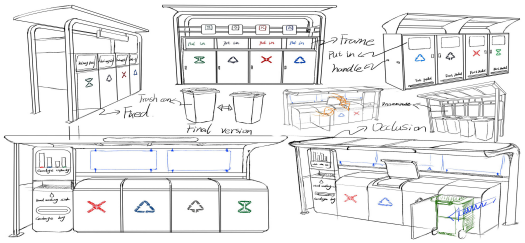
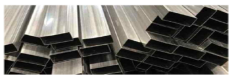
<table>
<tr><th colspan="4">Sketch</th></tr>
<tr><td colspan="2">  </td><td colspan="2">  </td></tr>
<tr><td colspan="2">Fig. 10. Design sketch 1</td><td colspan="2">Fig. 11. Design sketch 2</td></tr>
<tr><th colspan="4">Final Design</th></tr>
<tr><td colspan="2">  </td><td colspan="2">  </td></tr>
<tr><td>Material</td><td>Stainless Steel
  </td><td colspan="2">• Steel is used as the primary material for the bin's framework.
• The color of the bin can be altered by applying paint or coating to the original material.</td></tr>
<tr><td colspan="4">Shape</td></tr>
<tr><td colspan="4">The overall dimensions, including the canopy, are (3420×867×2200mm). Building on the original standalone bins, the design has been integrated into a unified modular system, incorporating terminal devices, a rain shelter, and promotional slogans.</td></tr>
<tr><td rowspan="2">Color</td><td>Main Structure</td><td colspan="2">Internal Bin Structure</td></tr>
<tr><td>C67 M57 Y51 K3</td><td colspan="2">C97 M81 Y14 K0
C85 M38 Y100 K0
C41 M97 Y100 K7
C84 M76 Y75 K55</td></tr>
</table>

Fig. 12. Smart waste classification and recycling bin with User-End mobile application

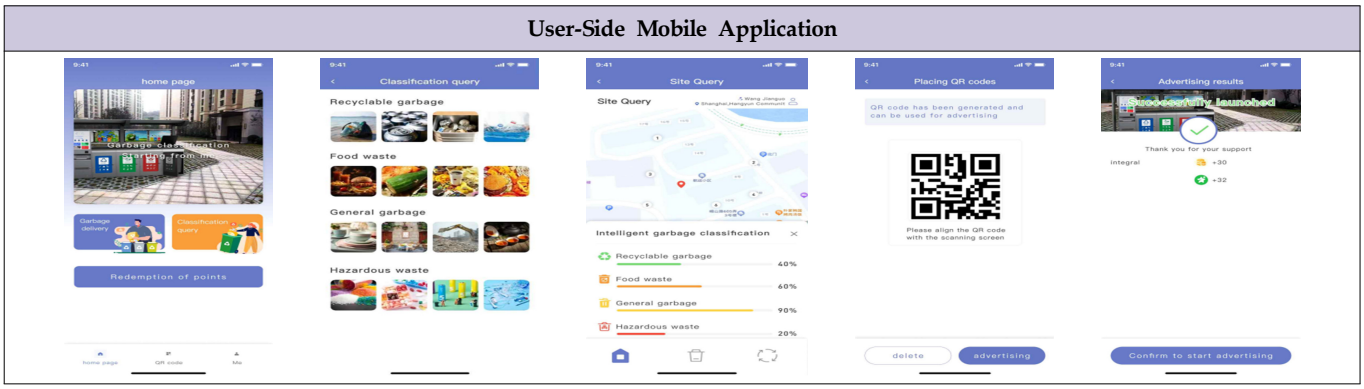


Fig. 13. With User-End mobile application

app) or an RFID card in front of the intelligent terminal for identity verification. After reading the user's personal information, the corresponding waste category is selected. By simply presenting the label on the waste bag beneath the intelligent terminal, the YOLOv5 algorithm-based image recognition engine will automatically identify the waste type through the top-mounted camera and open the designated lid accordingly [8], ensuring accurate waste disposal. The intelligent terminal automatically calculates the weight of kitchen waste and recyclables through weight sensors located at the bottom of the respective bins and awards points accordingly. These points can be redeemed for daily necessities or property fee deductions. However, manual lid opening does not earn points, encouraging residents to improve sorting accuracy. Additionally, the bin is equipped with an overflow sensor and dynamic monitoring system to monitor capacity in real-time. When the bin is nearly full, an alert sound is triggered, prompting the cleaning

staff to replace the inner bin. To maintain post-disposal hygiene, the area beneath the intelligent terminal is equipped with an automatic sensor faucet, ensuring cleanliness after waste disposal.

5. Conclusion

Based on the current situation of waste sorting in Public Residential communities in Shanghai, this study draws on exemplary intelligent cases from South Korea and Japan, data analysis from questionnaire surveys, and key touchpoints identified in user journey maps to propose a modular waste sorting and recycling bin design. The proposed design integrates humanization, intelligence, and convenience, incorporating features such as QR code scanning, RFID sensing, intelligent point rewards, and sanitation maintenance. The aim is to provide a new direction for the construction of intelligent waste sorting and recycling bins in future Public Residential communities.However, this study has limitations. Since it is based on a case study from a specific region and uses a simple random sampling survey method, the results may have limited applicability when extended to other regions with significant differences in social, cultural, or policy environments. Variations may exist in citizen participation methods or administrative operating mechanisms. Additionally, implementing an intelligent waste sorting system involves high initial investment and technical maintenance costs. For local governments with limited budgets, a lack of technological infrastructure and human resources could pose practical challenges in actual operations. To address these limitations, future research should conduct empirical user testing and pilot projects in multiple cities to validate the system's effectiveness. Combining user feedback to optimize the system can help balance intelligence and traditional operation methods, thereby promoting the popularization and enhancement of waste sorting service design.

Author Contribution

Conceptualization, Lu. D.; and Han. S.; methodology, Lu. D. and Han. S.; validation, Lu. D.; and Han. S.; formal analysis, Lu. D.; and Han. S.; user research, Lu. D.; data curation, Lu. D.; writ-ing—original draft preparation, Han. S.; writing—review and editing, Han. S.; visualization, Lu. D.;

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Conflicts of Interest

No author has any other conflict of interest to declare.

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