ISSN: 2944-6163 Vol. 2, No. 3 (2026)

JCP JOURNAL OF CREATIVE PERSPECTIVES

Understanding Barriers to Public Recycling Behaviour in Hamburg: A Mixed-Methods Study of Human-Technology Interaction and User-Centered Design

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Abstract

This study investigates why individuals disengage from appropriate recycling behaviour at public collection points and examines the interaction-design and behavioural factors underlying this gap. The study employed a Sequential Mixed Methods approach between March and June 2026. Research began with sensory observations of existing recycling environments, followed by semi-structured interviews with residents and stakeholders (Stadtreinigung Hamburg and Starship Technologies), a community focus group, behavioural data collection, and an online survey. A total of 83 survey responses were collected, of which 55 were included in the final analysis. The combination of qualitative and quantitative methods enabled cross-validation of findings and provided a broader understanding of users' needs, expectations, and experiences. Findings triangulated across methods indicate that incorrect disposal is driven less by the willingness to recycle than by difficulties in decision-making at the point of disposal. Most participants generally expressed interest in recycling and a willingness to contribute, but their ability to act on this intention was affected by cognitive load, poor environmental visibility, low trust in system outcomes, and a mismatch between institutional system logic and users' everyday mental models. The study also identifies openness toward robot-assisted waste collection, tempered by concerns regarding data privacy, reliability, and cost.

These findings inform a set of evidence-based design requirements for human-centered recycling interventions in dense urban environments and provide the empirical foundation for the design developed from these findings, which is beyond the scope of the present study.

Keywords:

Behavioural UX, public recycling behaviour, user-centered design, nudge theory, technology acceptance model, smart cities, human robot interaction, mixed-methods research.

1. Introduction

1.1 Background and Problem Statement

Cities across Europe are investing heavily in digital public services, including recycling systems. Although recycling facilities already exist in Germany in general as well as in Hamburg as a major city, many residents continue to struggle with confusion about sorting waste, locating appropriate recycling points, and making disposal decisions in public spaces. Research in user experience (UX) design suggests that users often disengage from public systems not because the underlying technology is missing, but because those systems are not designed around real behavioural models. According to Don Norman (2013), when products or services do not match how people think and behave, users tend to avoid using them even if the system itself is functional. The challenge in Hamburg's recycling system therefore appears to be behavioural as much as technical. Residents are frequently willing to recycle, but the disposal process is perceived as complex, unclear, or inconvenient at the precise moment of interaction. This suggests a persistent gap between the design of existing recycling touchpoints and the real needs, habits, and motivations of the people who use them.

Municipal data indicates that approximately 70% of the contents in Hamburg's residual waste bins consist of recyclable materials, such as organic waste and paper, which are incorrectly discarded (Stadtreinigung Hamburg, 2016). Furthermore, the WEEE collection rate in 2023 was 37.5% across the EU, while Germany recorded a lower rate of 29% (Eurostat, 2025). Separately, field-based research on waste-separation behaviour suggests that a substantial proportion of residents, in the region of 42%, remain unsure of correct sorting rules (Pawelczyk, Mielinger and Weinrich, 2026).

Together, these figures suggest that the public recycling system is not perceived by residents as a single, linear process but as a series of fragmented touchpoints encountered under time pressure and environmental distraction. Users primarily engage with the system at the point of disposal, where they must identify the correct receptacle, interpret limited visual information, and make a rapid decision, typically without forming any broader mental model of the downstream recycling process. This positions the point of disposal as the critical design target: any intervention must

support immediate, low-effort decision-making, since users neither engage with nor understand what happens to their waste once it leaves their hands.

1.2 The Hamburg Context

Hamburg presents a productive setting in which to examine this problem. With a population of approximately 1.9 million (WorldStats, 2026) and a GDP contribution exceeding €160 billion (Hamburg Invest, 2024), the city ranked second in the 2025 Smart City Index (Hamburg Business, 2025) and has committed to a 70% reduction in carbon emissions by 2030 (Port of Hamburg, 2019). Hamburg's Agenda 2030 sustainability strategy explicitly frames environmental responsibility as a standard part of everyday urban life rather than a voluntary add-on and identifies the expansion of recycling infrastructure and public awareness as central to this ambition (Freie und Hansestadt Hamburg, n.d.). The city therefore occupies a strategic position at the intersection of digital innovation and sustainability policy: its dual commitment to becoming a Smart City and a Circular City by 2030 makes it an appropriate environment in which to study, and prototype, smart-driven recycling interventions. At the operational level, residents are expected to navigate a household separation system comprising general waste (Restmüll), organic waste (Biotonne), paper (Altpapier), and plastics and metals (Wertstoffe), alongside glass-bottle banks, deposit-return points for bottles (Pfand), textile drop-off containers, and twelve free municipal drop-off centres (Recyclinghöfe) for bulky and special waste. Collection is carried out by Stadtreinigung Hamburg (SRH), the city's statutory waste-management and street-cleaning provider, using separate vehicles for each waste stream. This is, by international standards, a granular and demanding system, a point that becomes significant later in this study.

1.3 Research Aim and Objectives

The aim of this study is to explore the potential contribution of interaction design to reducing sorting errors, increasing user engagement, and supporting a more efficient recycling experience in Hamburg's public spaces. In pursuit of this aim, the research sought to: (i) analyse the current user experience of Hamburg's existing recycling system; (ii) identify the principal pain points and barriers that lead residents either to engage with or to avoid recycling; and (iii) generate a set of contextually grounded, behaviourally informed design requirements capable of informing a subsequent design intervention.

1.4 Research Question

The research question evolved substantially over the course of fieldwork. Before any empirical engagement, the research question was initially framed around the development of a "smart design" solution for improving recycling in Hamburg: "How could smart interaction design enhance public recycling experiences in Hamburg?" Following sensory ethnography and both user and stakeholder interviews, the findings indicated that the challenges extended beyond bin and interface design to include physical effort, system inefficiencies, trust, and operational limitations.

The question was accordingly refined to: "How can multi-layered service design interventions reduce decision-making uncertainty and sorting errors in waste recycling in Hamburg?" This refined question was further decomposed into three linked sub-questions addressing, respectively, (i) the problem (the usability and behavioural challenges users experience when interacting with the current system); (ii) the design response (how interaction design can reduce uncertainty at the moment of decision-making); and (iii) the anticipated impact (the extent to which an interaction-based design can plausibly reduce that uncertainty).

1.5 Hypothesis

This study assumes that implementing a smart interaction layer to the recycling system in Hamburg would reduce sorting errors, increase user motivation and contribute to a more efficient recycling experience.

1.6 Scope, Boundaries and Structure of the Research

This study focuses on understanding users' expectations, interpretations, and interactions in relation to smart recycling interventions, as well as identifying measurable characteristics of interaction, such as frequency and duration of use, where applicable. Quantitative interaction data are used to complement and triangulate the qualitative findings. The study examines users' experiences and interactions with existing recycling touchpoints, with particular attention to the behavioural and usability challenges that arise at the point of disposal.

The study does not evaluate the technical performance or engineering feasibility of a recycling solution, the capacity or operational efficiency of existing municipal infrastructure, the environmental correctness or material-recovery performance of recycling outcomes, or the effectiveness of municipal policy. It also does not assess long-term behavioural change, as the research focuses primarily on immediate interaction, decision-making, and user experience.

The research presented in this paper forms part of a broader research-through-design project that also included the development of a design prototype. However, the prototype development and resulting design solution are not presented, evaluated, or discussed as part of the present study. Instead, this research focuses on the empirical research that informed the design process, establishing an evidence base and identifying behavioural, usability, and interaction-design requirements. The prototype therefore represents a subsequent design response to the findings reported here rather than an object of evaluation within this study.

The remainder of this study is structured as follows. Section 2 reviews relevant literature on user experience in public service systems, sustainable behaviour, smart cities, and technology adoption. Section 3 presents the integrated theoretical framework. Section 4 describes the mixed-methods research design. Sections 5 and 6 report the findings from the discovery and validation phases of

the research, respectively. Section 7 discusses the findings in relation to the research questions, Section 8 addresses the study's limitations, and Section 9 concludes the study.

2. Literature Review

2.1 User Experience and Public Service Systems

Research in User Experience Design shows that the success of public service systems depends not just on technical functionality, but also on usability, clarity, and user interaction (Norman, 2013). Where systems are not designed around users' needs and behaviours, users often tend to avoid them even if the service itself is available. User-Centred Design (UCD) offers a theoretical foundation for this observation, emphasising that systems should be designed around users' needs, behaviours, and mental models rather than organisational or technical priorities (Gulliksen et al., 2003).

This is particularly relevant in the context of public recycling systems, which require residents to understand complex sorting rules, locate the correct disposal points, and apply this knowledge correctly within the constraints of daily routines. Previous studies also point out that public service systems frequently fail because they are designed from an institutional perspective rather than a user perspective (Bason, 2010), producing a disconnect between how systems are conceived and how people actually use them. Even well-organised recycling programmes can consequently experience low participation due to usability shortfalls and limited engagement (Tanner et al., 2024). These findings collectively underline the relevance of user-centred design principles to the creation of sustainable, smart urban services (Norman, 2013; Gulliksen et al., 2003).

2.2 User Behaviour and Sustainable Practices

Research on sustainable behaviour indicates that individuals frequently fail to act in environmentally responsible ways despite being aware of sustainability issues, and that this gap is not always attributable to a lack of awareness but rather to complexity, inconvenience, or insufficient motivation (Papies et al., 2021). Nudge Theory offers one account of how this gap might be closed, explaining how small design interventions can influence behaviour without restricting choices or making users feel forced to change their actions (De Paolis, Tiberio and Caffaro, 2025).

Simple interventions such as reminders, visual feedback, and clear instructions can significantly increase user participation in sustainable practices. This is directly relevant to recycling contexts, where users may feel uncertain about sorting rules or perceive the process as time-consuming. Behavioural barriers such as confusion, effort, and lack of feedback can discourage users from engaging with the system. Therefore, integrating behavioural design strategies into UX solutions can play a key role in improving recycling participation and user engagement.

2.3 Smart Cities and Digital Transformation

The development of Smart Cities has expanded the role of digital technologies in public services, including waste management and sustainability systems. However, the success of such systems depends not only on the technology deployed but on how users interact with it in everyday life (Hollands, 2008; Nam and Pardo, 2011). From a UX perspective, public digital systems must be simple, accessible, and easy to integrate into daily routines (Norman, 2013); this shifts analytical attention from the technology itself toward the usability conditions that make sustainable behaviour more, or less, likely. Furthermore, the Technology Acceptance Model (TAM) explains that users are more likely to adopt systems that are easy to use and perceived as useful (Davis, 1989).

2.4 User-Centred Design and Technology Adoption

The adoption of digital systems is a critical factor in their overall success. The Technology Acceptance Model (TAM) proposes that users' willingness to adopt a system is shaped by its perceived usefulness and perceived ease of use (Davis, 1989). In the context of smart recycling systems, residents are more likely to adopt a new solution where they believe it will simplify the recycling process and fit within existing routines. Conversely, a system perceived as complicated or unnecessary is likely to be rejected regardless of its technical sophistication. Research on digital adoption further supports this, showing that usability and perceived value are key determinants of user engagement with public digital services (Norman, 2013). Combining usability, behavioural insight, and digital design considerations therefore appears central to increasing adoption of, and engagement with, sustainable smart urban solutions (Vial, 2019).

3. Theoretical Framework

This study integrates three theoretical perspectives, User-Centred Design (UCD), Nudge Theory, and the Technology Acceptance Model (TAM), not as independent lenses but as a layered design logic in which each addresses a distinct stage of the problem. UCD provides the foundation for understanding how systems can be designed to meet users' needs and behaviours. It tells who to design for and ensures that any proposed interaction is grounded in observed user behaviour rather than assumption. Nudge Theory addresses how the physical and digital touchpoints of a system might be designed to shift behaviour without forcing it, explaining how design elements such as simplicity, motivation, and nudging can influence recycling behaviour. TAM, in turn, explains how users adopt and interact with smart or digital systems., explaining why people would choose to accept, or reject, a new interaction.

Read together, these three frameworks provide a comprehensive basis for analysing how UX design can influence user behaviour, system usability, and technology adoption within smart recycling systems in urban environments.

4. Methodology

The research employed a sequential exploratory mixed-methods design, conducted in eight linked phases between March and June 2026 (Table 1). Qualitative methods were used first to build a rich, contextual understanding of the problem, before quantitative methods were introduced to test whether the resulting insights held at scale. Combining methods in this phased sequence enabled cross-validation between qualitative and quantitative data, strengthening reliability and providing a more complete account of how residents interact with Hamburg's recycling system than any single method could offer in isolation.

Table 1: Overview of the Research Design and Phases. Source: Authors' own compilation.

Phase	Method	Type	Purpose
1	Sensory Ethnography	Qualitative	Observe how users interact with the environment and identify friction points and sensory cues.
2	User Interviews (n = 5)	Qualitative	Explore residents' experiences, perceptions, and motivations through semi-structured conversation.
3	Stakeholder Interviews (n = 3)	Qualitative	Gather insights from key stakeholders on systemic constraints and opportunities.
4	Problem Refinement	Analytical	Refine the research question considering discovery-phase findings.
5	Community Insights (Focus Group Discussion)	Qualitative	Test emerging insights with a broader group of people through open discussion.
6	Online Survey (n = 83)	Quantitative	Validate qualitative findings at scale and measure broader trends.
7	Behavioural Data Collection	Quantitative	Directly and unobtrusively observe real user actions at a recycling point.
8	Cross Validation	Analytical	Compare findings across all methods to assess convergence and reduce single-method bias.

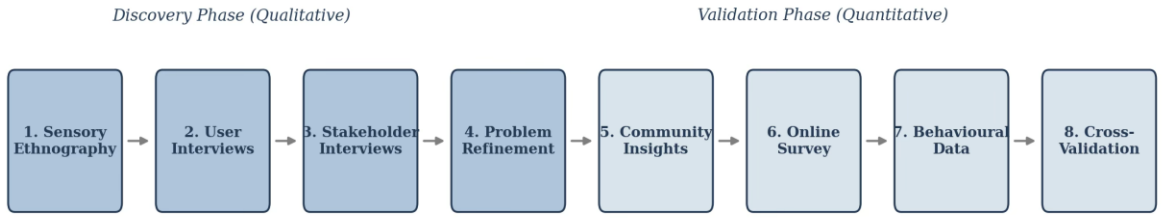


Figure 1: Overview of the sequential exploratory mixed-methods research design. Source: Author's own data, visualized with the assistance of AI (Claude, Anthropic, 2026)

Sensory ethnography was selected as a qualitative method because it focuses on user behaviour patterns, sensory impressions, and interactions within the environment. It captures how users engage with recycling systems in context, including movement, gestures, and environmental responses, providing rich insights into real-world usage. This method does not produce numerical data but highlights patterns and behaviours that inform design decisions. Behavioural data collection was selected as a quantitative method that collects numerical data on user interactions with the system. Examples include the number of times a user interacts with the system, time to read the provided guidance, repeated actions in use the system, time spent completing recycling tasks, accuracy in sorting waste. This method produces measurable, numeric evidence that can validate design decisions and evaluate the effectiveness of smart recycling interventions. Semi-structured interviews with residents and stakeholders provided depth and explanatory context, a community focus group tested whether individual accounts reflected shared community experience, and an online survey extended reach to a larger and more diverse sample than could be achieved through interviews alone.

All interview and survey participants participated on an informed and voluntary basis. Participant confidentiality was maintained throughout the research process. Personally, identifying information, interview transcripts, raw datasets, and related ethics documentation are not included in the public-facing project materials. Findings presented in this paper are based on anonymised and thematically coded data, with no personally identifying participant information reported.

5. Findings I: Discovery Phase

5.1 Sensory Ethnography

A sensory walk was conducted on 31 March 2026 between 13:55 and 14:30 in a high-traffic area of Hamburg combining a public park, a transport station, and food outlets. The method followed principles of sensory ethnography, recording sound, movement, atmosphere, and environmental cues without engaging directly with users to understand the environmental and behavioural conditions surrounding recycling practice in public space.

The observed environment exhibited a high level of sensory intensity, characterised by continuous traffic noise, overlapping conversations, and competing activity from commuters, children, and pedestrians. No signage, instructions, or awareness materials were present at the recycling point, and several bins were partially obscured by trees or shadows, reducing their visibility. Although paper bins were grouped separately from glass and electronics bins, no clear visual hierarchy distinguished the categories, and no dedicated plastics-recycling bin was available at all, indicating an incomplete on-site system. Movement observation over the session revealed minimal engagement with the recycling bins: general waste bins near the kiosk were used considerably more frequently than the dedicated recycling points, and only a single individual was observed using the paper-recycling container during the full observation period.

These observations point to three related gap categories, service design and spatial gaps, visibility gaps, and convenience gaps, that together constrain effective interaction with the recycling system. Poor lighting, visual clutter, and competing stimuli reduce the salience of recycling points; users rarely pause to search for instructions and instead respond to whichever option is most visually dominant. This generates a clear design requirement: recycling interfaces must establish strong visual hierarchy and prominence in order to compete successfully within visually saturated public space.

5.2 User Interviews

Five semi-structured interviews, each lasting up to twenty minutes, were conducted over a two-week period in April 2026 with residents recruited through personal and university networks. Participants were screened to ensure they had lived in Hamburg for at least one year, had some experience recycling household waste, used the standard public sorting system, and owned a smartphone or tablet. The resulting sample varied in age (from the twenties to over seventy), employment status, household composition, and self-reported technical confidence, allowing a range of perspectives to be captured. The interview guide addressed four themes: current user experience, awareness of the existing system, current pain points and challenges, and user needs and expectations.

Analysis of the interviews produced five recurring findings. First, all five participants described relying on informal workarounds, leaving items beside a bin, storing items until a shop visit, searching online, asking others, or simply defaulting to general waste, rather than describing a clean or confident recycling experience; these workarounds function as necessary coping strategies for a system perceived as insufficiently supportive. Second, two participants expressed explicit doubts about system transparency, fearing that waste is mixed again after collection regardless of how carefully it is sorted, a concern with direct implications for motivation. Third, four of the five participants felt the system demanded excessive individual effort, with one arguing that correct recycling should not depend on individual behaviour at all. Fourth, every participant lacked a clear, confident route for disposing of electronic waste, regardless of age, background, or length of residence, suggesting that the formal e-waste pathway is inaccessible in practice even where it exists on paper. Fifth, four participants described fear of fines or social judgement, and of being visibly seen to get it wrong, as a driver of avoidance rather than of careful compliance, indicating that the social cost of a visible mistake can exceed the perceived benefit of attempting to recycle correctly at all.

Interview data also indicated that users with lower technical confidence, including several older participants, experienced heightened uncertainty and avoidance when facing complex systems, with small text, ambiguous labelling, and reliance on prior knowledge acting as concrete accessibility barriers. This generates a further design requirement: any resulting interaction must be legible, self-explanatory, and operable without prior technical knowledge, in order to remain inclusive across age and ability levels.

5.3 Stakeholder Interviews

Three further semi-structured interviews, each of up to twenty minutes, were conducted in May 2026 with two representatives of Stadtreinigung Hamburg (SRH), the city's statutory waste-management operator, and one representative of Starship Technologies, an operator of autonomous delivery robots active in Hamburg. These interviews were designed to surface systemic considerations that user interviews alone could not access, addressing operational inefficiencies, repetitive or physically demanding tasks, human robot interaction, and user trust in automated systems.

Stakeholder accounts revealed a significant disconnect between how the recycling system is designed to function and how residents perceive its outcomes: users frequently doubt whether their sorting effort translates into genuine recycling, a perception that undermines trust and discourages correct behaviour regardless of system design. Consultations with SRH further revealed that Hamburg's sorting standards are substantially more granular than simplified international benchmarks; while this supports quality control, it also places a considerable cognitive burden on users who must interpret fine distinctions between material categories, especially where labelling is unclear or overly technical. This finding necessitated a shift in emphasis, away from generic categorisation and toward precision-oriented, context-specific guidance capable of helping users navigate local complexity rather than relying on simplified but insufficient labels.

The interview with Starship Technologies surfaced a further, consequential constraint: the company's autonomous robots operate without a built-in microphone, a design choice driven by data-protection (Datenschutz) requirements. This rules out voice-based interaction entirely and requires that any human robot communication in this context rely on non-verbal channels such as light, colour, and movement. Across both organisations, public trust and acceptance of autonomous systems appeared to depend less on technical sophistication than on predictability, clarity, and behavioural consistency; users are more likely to trust systems that behave in understandable and non-judgemental ways and to avoid ones that introduce uncertainty or social exposure. Within this framing, the robot is positioned in the wider concept not as an autonomous actor but as an interaction mediator, guiding, reassuring, and confirming user actions at the point of decision, without displacing user responsibility.

Stadtreinigung and Starship Technologies converged on several points, including the value of human robot collaboration for reducing physical strain on waste workers and the importance of reliability and clear communication, but diverged in their risk tolerance: Starship characterised its robots as already functional and proven, whereas SRH remained more cautious about reliability in day-to-day municipal operations, prioritising safety and practical usability over rapid deployment. SRH representatives also identified physically demanding and repetitive tasks, and inefficiencies stemming from incorrect disposal of items such as e-waste, furniture, and clothing (particularly during large public events), as pressing operational pain points, alongside concerns about robots' ability to navigate narrow streets, obstacles, and unpredictable pedestrian environments.

5.4 Problem Reframing

Taken together, the discovery-phase findings substantially reframed the research problem. Fieldwork indicated that residents do not lack awareness so much as confidence, trust, and clarity: users repeatedly reported not knowing the rule, not being sure a given action was correct, or finding the system confusing, three related expressions of a single underlying issue, uncertainty in decision-making, rather than three distinct problems. Comparing system expectations against observed human logic reinforced this reading: the system assumes users sort correctly and consistently, have sufficient information, and are willing to spend time separating waste; residents, by contrast, described making frequent mistakes, prioritising convenience over correctness under time pressure, and experiencing the system as passive and lacking in-the-moment guidance. This reframing motivated the shift in the research question described in Section 1.3, from a general focus on smart design toward a more precise focus on reducing decision-making uncertainty through multi-layered service interventions.

6. Findings II: Validation Phase

The validation phase tested whether the qualitative insights generated during discovery held at a larger scale, drawing on community discussion, an online survey, and direct behavioural observation.

6.1 Community Insights

A single in-person focus group of approximately 30 - 35 minutes was held on 10 May 2026 with five residents of varying ages, occupations, and backgrounds, recruited through direct neighbourhood outreach. Discussion converged on five points. Participants reported difficulty quickly distinguishing between waste categories at the point of disposal and suggested that clear, simple guidance is needed to support immediate decision-making. They considered audio feedback poorly suited to noisy public environments, expressing a preference for visual or silent feedback over voice-based interaction, a preference that directly reinforced the microphone-free constraint identified in the Starship Technologies interview. Participants also felt that overly complex visuals, an excess of icons, colours, or illustrations, reduce rather than improve clarity, and that systems intended for a large, dynamic city need to be prominent and legible at a distance, particularly for visitors and residents with disabilities who are unfamiliar with local rules. Finally, participants wanted reassurance that a disposal action had been completed correctly, for example through a visible fill-level indicator, noting that uncertainty on this point often leads people to avoid a bin altogether or to leave waste nearby rather than risk using it incorrectly.

6.2 Online Survey

An online survey was distributed over a two-week period in May 2026 via QR code, LinkedIn, and SurveyCircle, generating 83 total responses, of which 55 were retained for analysis after being

screened for relevance to Hamburg residents. Respondents skewed young and urban: 86% were aged between 18 and 35, split almost evenly between students, and employed professionals, and two-thirds lived in Hamburg, with just over half based in the city centre. Given this profile, the survey results reported in this section describe patterns among younger, urban, digitally engaged residents, and should not be read as representative of Hamburg's population as a whole, a point revisited in Section 8. Table 2 and Figure 2 summarises the headline results on awareness and sorting accuracy for this sample.

Table 2: Summary of Survey Results. Source: Authors' own compilation.

Survey Item	**Result**
Aware of any recycling apps, portals, or online services in Hamburg	5% Yes
Agree that recycling at festivals, street parties, or public events is easy	44% No
Correctly identified where a specific test item should be disposed of	75% chose the wrong bin
Open to robots assisting in waste collection	62% Yes 36% Maybe 1% No
Would trust a combined human + robot system	65% Yes 31% Maybe 4% No

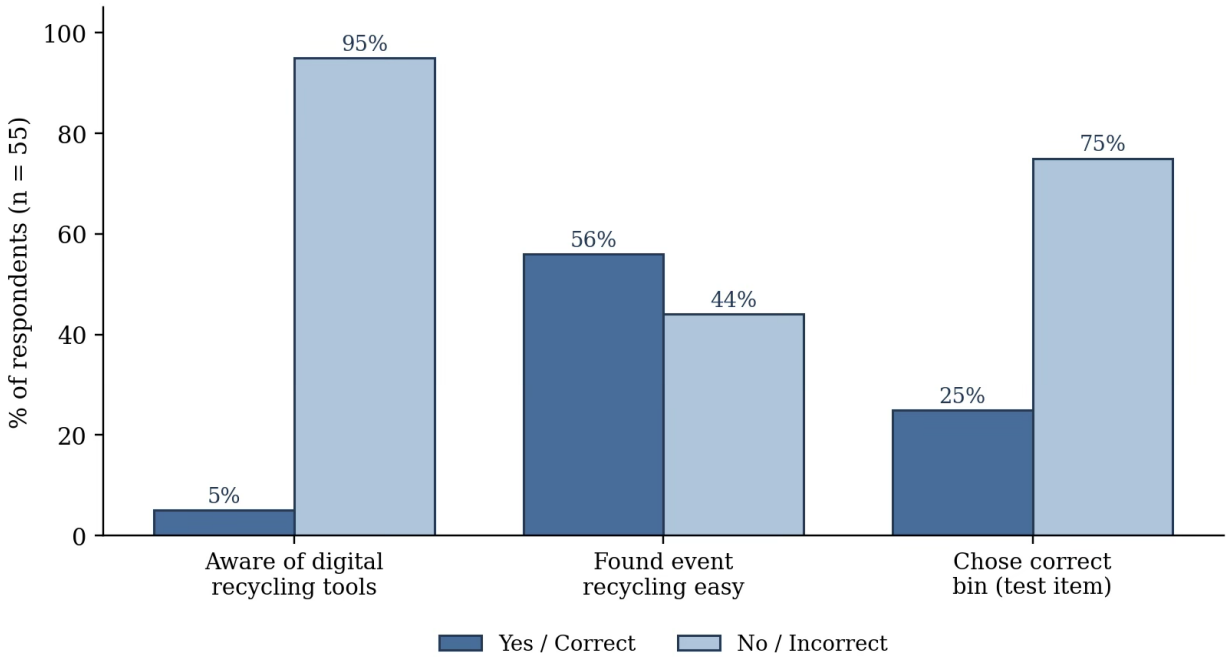


Figure 2: Survey results on awareness & sorting accuracy (n = 55). Source: Author's own data, visualized with the assistance of AI (Claude, Anthropic, 2026)

Beyond these headline figures, 65% of respondents reported recycling multiple times per week, and awareness of correct disposal locations was comparatively high (65%), even though awareness of digital recycling tools was extremely low (5%), pointing to a gap between physical and digital system awareness rather than a general lack of engagement. The most frequently cited barriers to recycling were a lack of space at home to sort waste, uncertainty about sorting rules, a generally confusing system, lack of time, and a perceived lack of time or the sense that recycling required too much effort.

Regarding robotic assistance, respondents showed considerable openness (Figure 3), although this openness was consistently accompanied by specific reservations (Figure 4). The main concerns related to data privacy, reliability, and cost, while job displacement, complexity, and safety cited less frequently. Notably, every respondent who expressed openness to robotic assistance also raised at least one concern. This suggests that trust and transparency may be more relevant design priorities than overcoming fundamental opposition to robotic assistance.

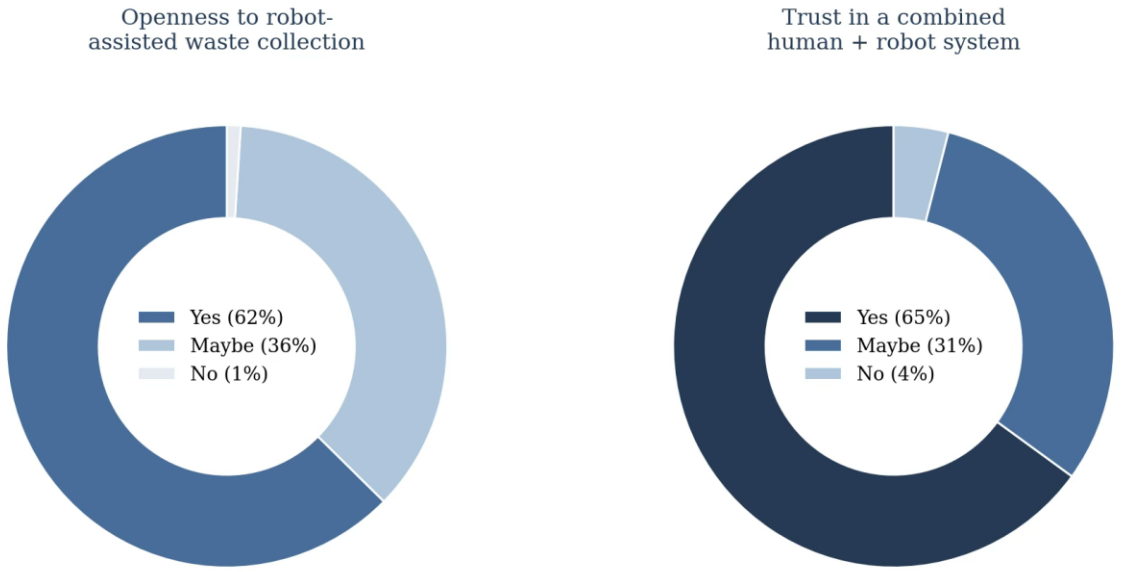


Figure 3: Respondent openness to robot-assisted waste collection system (n = 55). Source: Author's own data, visualized with the assistance of AI (Claude, Anthropic, 2026)

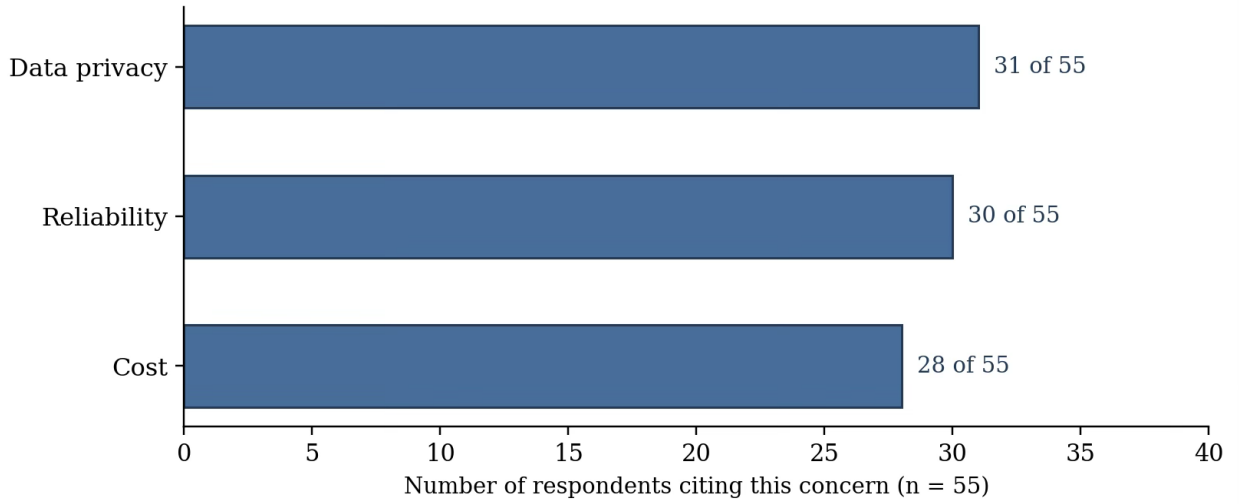


Figure 4: Most frequently concerns regarding robotic assistance in waste management (n = 55). Source: Author's own data, visualized with the assistance of AI (Claude, Anthropic, 2026)

When asked what most would improve their recycling experience, respondents most frequently requested clearer guidance and instructions, less physical effort, better access to bins, a faster process, and assistance from either a human or a robot.

Link to the Online Survey:

https://forms.cloud.microsoft/e/fL8UyCqPTg

Link to the Results Overview:

https://forms.office.com/Pages/DesignPageV2.aspxprevorigin=shell&origin=NeoPortalPage&subpage=design&id=NqIo_xyIKUubd3FAW2asoqsvQI6pXzhMg1nzOQ8te_9UM0RUTU1ZV0xWRDBGRlBZSDVRRFVJUEk2Ti4u&analysis=false&topview=Presentation

6.3 Behavioural Data Collection

Behavioural observation was included as the study's second quantitative method, alongside the survey, in order to address a limitation inherent to all of the preceding methods: ethnography, interviews, the focus group, and the survey each rely, to varying degrees, on what people say about their own behaviour, which is known to be vulnerable to social-desirability bias in the context of environmentally responsible behaviour. Rather than asking participants to describe their recycling habits, this method recorded what people actually did at the point of disposal, providing an unobtrusive, behavioural check against the self-reported findings from the preceding phases. Its aim was accordingly not to produce a statistically representative estimate of recycling behaviour across Hamburg, but to corroborate, or challenge, the patterns already identified through the qualitative and survey data, as part of the study's broader cross-validation logic (Section 6.4).

A single 120-minute observation session was conducted at a public recycling point on Vierbergen Street, Hamburg, on 14 May 2026, chosen to coincide with a public holiday in order to maximise the number of disposal interactions that could be observed within a single session. The same recycling station was observed throughout, and every disposal interaction occurring at or near that station was recorded in real time against five behavioural indicators: sorting accuracy (whether waste was placed in the correct stream per local Hamburg guidelines); time spent at the bin (approximate duration of the disposal interaction); recycling point usage (whether a user chose the recycling station or a nearby general-waste bin); avoidance behaviour (instances of bypassing the recycling station entirely); and ergonomics and accessibility (observable physical effort or hesitation). This observational protocol, rather than a survey or interview instrument, was used because it captures actual, in-the-moment decisions rather than retrospective or hypothetical accounts of behaviour.

Over the observation period, approximately 60 discrete waste-disposal interactions were recorded at the Vierbergen Street site, with each interaction classified into one of five behavioural categories by direct, real-time tally. Of these, 3 individuals (≈5%) actively used the designated recycling stations, 51 individuals (≈85%) used nearby general-purpose or kiosk bins instead, and 54 individuals (≈90%) bypassed the recycling station entirely displaying avoidance behaviour and opting for the more convenient bin rather than the correct one. All three recycling users (100%) sorted their waste correctly, and no incorrect sorting was observed among this group. Three further interactions, involving bulky items such as cardboard, required extended handling time due to the physical effort of fitting these items into standard bin openings. Table 3 reports the full raw counts underlying these percentages. Figure 5 presents these counts graphically.

Table 3: Raw counts underlying the behavioural observation findings (N ≈ 60 disposal interactions). Source: Authors' own compilation.

Behaviour observed	**Count**	**Share of total**
Used designated recycling points	3	≈ 5% of ~60
Used general-purpose / kiosk bins	51	≈ 85% of ~60
Bypassed recycling points entirely	54	≈ 90% of ~60
Correctly sorted (of recycling users)	3 of 3	100%
Incorrectly sorted	0	0%
Extended interactions with bulky items	3	—

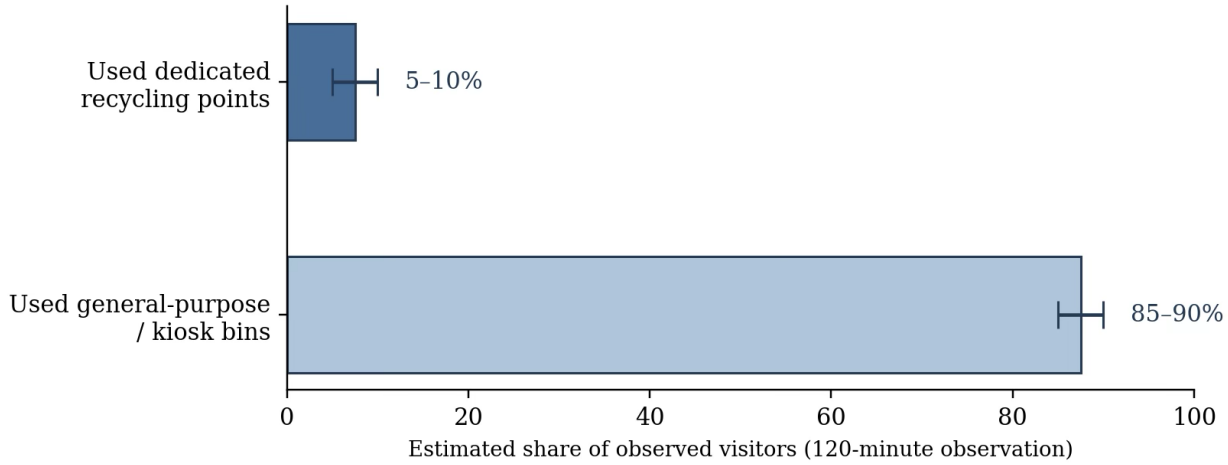


Figure 5: Estimated share of observed visitors using dedicated recycling points versus general-purpose bins. Source: Author's own data, visualized with the assistance of AI (Claude, Anthropic, 2026)

Where individuals did use the dedicated recycling points, sorting accuracy among this small group was 3 of 3 (100%), with no incorrect sorting observed, suggesting that correct use is concentrated among residents who already possess system knowledge rather than being distributed across the general population. Three further interactions, involving bulky items such as cardboard, required noticeably longer handling time, up to several minutes, due to the physical effort required to fold or compress these items to fit small bin openings, pointing to a further, physical dimension of interaction difficulty alongside the cognitive one identified elsewhere in this study.

Several important caveats apply to this dataset and are noted here explicitly. With approximately 60 disposal interactions, and only 3 individuals using the recycling station, this is a small, single-session, single-location observation rather than a statistical sample, and the resulting percentages should not be read as prevalence estimates generalisable to Hamburg's population as a whole, to other locations, or to other times of year. The session's deliberate scheduling on a public holiday, chosen specifically to maximise observable foot traffic, further means that the context may not reflect a typical weekday. The value of this dataset lies not in its statistical power but in its function within the study's mixed-methods design: it offers direct, non-self-reported, behavioural corroboration of a pattern already identified independently through ethnography, interviews, the focus group, and the survey, namely that disengagement from recycling in public space is common and that a small minority of already-informed users account for most correct use. It is this convergence across independent methods, examined formally in Section 6.4, rather than the behavioural dataset in isolation, that supports the findings reported in this paper.

6.4 Cross-Validation

Findings from ethnography, interviews, the community focus group, the survey, and behavioural observation were compared directly against one another to assess the extent to which they converged. Figure 6 summarises this comparison. The majority of findings were confirmed across

at least three independent methods, with two findings, relating to onboarding challenges for new residents and the visibility of environmental impact, achieving only partial confirmation, and therefore warranting more cautious interpretation.

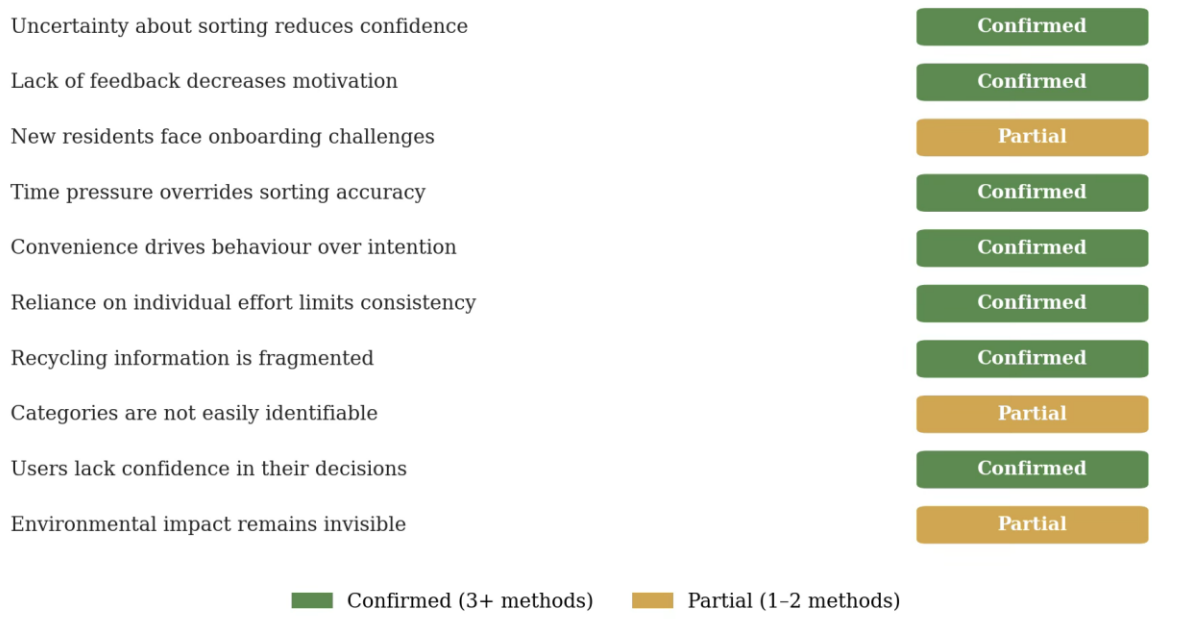


Figure 6: Cross-validation of key findings across research methods. Source: Author's own data, visualized with the assistance of AI (Claude, Anthropic, 2026)

7. Discussion

Read together, the discovery and validation phases indicate that residents' disengagement from correct recycling behaviour in Hamburg's public spaces is not primarily a problem of awareness. Awareness of the existence of a recycling system is generally high, but what is missing is confidence that a given action is correct, feedback confirming that it has been performed correctly, and trust that the resulting effort translates into genuine downstream recycling. This pattern held consistently across sensory observation, individual interviews, community discussion, survey data, and direct behavioural observation, and is well captured by the study's central construct of decision-making uncertainty, manifesting as a lack of knowledge, a lack of trust, and a lack of clarity, rather than as three unrelated problems.

Returning to the three research sub-questions set out in Section 1.3: with respect to the problem question, this study finds that the principal usability and behavioural challenges are cognitive overload at the point of disposal, poor visibility and prominence of recycling infrastructure, insufficient real-time feedback, and low trust in system outcomes, compounded by a genuinely more granular sorting taxonomy than many residents, and certainly many newcomers, are

accustomed to. With respect to the design question, findings suggest that interaction design can plausibly reduce this uncertainty by providing immediate, low-effort guidance at the moment of decision, non-verbal (and specifically non-audio) confirmation of correct action, and visible reassurance that a given disposal action has been registered and completed, rather than by attempting to change attitudes or increase general awareness through information campaigns alone. With respect to the impact question, the consistent 98% openness to some form of robotic or automated assistance recorded in the surveyed sample, predominantly younger and urban respondents (Section 6.2), set against specific and addressable concerns about privacy, reliability, and cost, suggests meaningful scope for an interaction-based intervention to reduce uncertainty, provided that any such intervention is explicitly designed around transparency and predictability rather than around technical novelty, whether this openness extends to older or less digitally engaged residents remains an open question for future research.

These findings extend the reviewed literature in three respects. First, they provide context-specific, triangulated evidence for the general claim that public service systems fail when designed from an institutional rather than a user perspective (Bason, 2010): in Hamburg, this institutional logic is visible in the gap between the system's implicit assumption of a fully informed, motivated user and residents' actual, time-pressured, uncertain experience at the point of disposal. Second, they extend Nudge Theory (De Paolis, Tiberio and Caffaro, 2025) into a genuinely public, outdoor, high-distraction setting, showing that even modest interventions such as visual hierarchy, colour coding, and fill-level feedback are likely to be more effective than audio-based nudges, which are actively unsuited to this environment. Third, the stakeholder findings extend the Technology Acceptance Model (Davis, 1989) by identifying trust and predictability, rather than perceived usefulness alone, as the decisive factor in residents' and institutional actors' willingness to accept robotic assistance in a public setting, a nuance that is particularly salient for autonomous systems operating in shared urban space.

Taken as a whole, this research establishes an empirically grounded and theoretically integrated set of design requirements, spanning visual guidance, real-time feedback, effort reduction, error prevention, journey-wide support, incentive structures, e-waste handling, and physical or cognitive load reduction, that respond directly to the barriers identified here.

8. Limitations

This study is subject to several limitations. The qualitative sample, five user interviews and three stakeholder interviews, is small and may not capture the full diversity of Hamburg's resident population; similarly, the retained survey sample of 55 responses, while adequate for identifying broad patterns, skews toward a younger, urban, and digitally engaged demographic and should not be read as representative of the city as a whole, particularly of older residents or those with lower digital literacy. The behavioural observation dataset is smaller still: a single 120-minute session yielding approximately 60 disposal interactions, of which only 3 involved the recycling station

itself, is not a statistical sample and cannot support generalisable prevalence claims; it is reported here as corroborating, rather than freestanding, evidence (see Section 6.3). The research and evaluation period was relatively short, which precluded any longitudinal observation of behaviour change over time. Obtaining formal engagement and interview access with stakeholders proved difficult within the available timeframe, and broader participant recruitment was similarly constrained, which may have limited the diversity of perspectives captured. Findings should accordingly be read as indicative of behavioural patterns and design priorities within this specific urban context, rather than as generalisable claims about recycling behaviour beyond Hamburg.

9. Conclusion

This study set out to understand why residents of Hamburg disengage from correct recycling behaviour in public spaces, despite the existence of an established recycling infrastructure. Using a sequential exploratory mixed-methods design integrating User-Centred Design, Nudge Theory, and the Technology Acceptance Model, the research found that disengagement is best explained by decision-making uncertainty, manifesting as gaps in confidence, trust, and clarity, rather than by any straightforward lack of awareness or willingness to recycle. These findings, triangulated across five independent methods, generate a coherent set of evidence-based design requirements and establish a strong openness among residents toward technologically assisted solutions, provided such solutions are transparent, predictable, and genuinely low-effort to use.

AI Use Declaration

Generative AI (Claude, Anthropic) was used to assist in producing data visualisations (Figures 1–6) from the author's original research data, and in formatting the manuscript for submission. All underlying data, findings, and written analysis are the author's own. AI-generated outputs were reviewed and verified by the author for accuracy before inclusion.

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