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RESEARCH ARTICLE

Systemic Design for Complex Ecosystems: Advancing Circular Airport Waste Strategies

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Abstract

Airports, as high-density public ecosystems, face significant challenges in adopting circular waste management practices due to complex stakeholder dynamics and logistical constraints.

This study employs a local waste hub integrated with a Pay-As-You-Throw approach as a systemic design intervention to enhance waste separation in the residual waste stream at Oslo Airport. By applying systemic design principles, the intervention addressed interconnected behavioural, organisational, and infrastructural factors to advance circularity. A one-month pilot, involving seven commercial units, tested the intervention using mixed-method data collection.

Results demonstrated a measurable reduction in incorrect waste disposal within residual waste streams, alongside heightened employee awareness toward waste separation. The study underscores the potential of context-based interventions to advance circular practices in complex environments and delivers an empirical study that offers actionable, real-world insights for advancing sustainable waste management in similar high-density ecosystems, such as shopping malls and train stations.

Keywords Green Transitions · Systemic Design · Circular Economy · Waste Management · Airports · Action Research

1. Introduction

One of the globally fastest-growing commercial industries is the aviation sector, with an expected continuation of its upward trajectory due to rising passenger numbers (IATA, 2024). Next to operational activities, airports have expanded into transient high-density public environments for recreational activities, including hotels, shops, restaurants, transport hubs, conference units, etc. (Ferrulli, 2016). This growth has raised concerns regarding the environmental impact, of which waste management has become one of the many areas with increasing attention (Sebastian & Louis, 2021). Circular economy (CE) offers a key strategy in advancing sustainability (European Commission, 2018).

Despite the relevance of this topic, academic research on airport waste management remains limited (Sebastian & Louis, 2021), focusing on either descriptive analyses or theoretical frameworks rather than empirical interventions. While case studies, such as Baxter's (2022) analysis of Incheon Airport's policy enablers; Baxter et al.'s (2018) examination of Kansai Airport's waste separation, energy recovery, and CE integration; and Özbay & Gokceviz's (2022) exploration of Istanbul Airport's zero-waste initiatives, propose real-world initiatives, interventions rarely get empirically tested. Theoretical contributions give further suggestions for advancing circular waste management at airports. For example, Tjahjono et al. (2024)

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developed a 9R-based framework for airport retail waste; Sartzetaki et al. (2025) proposed a circular economy evaluation framework integrating business intelligence technology; and van der Tuin-Rademaker et al., (2024) suggested a waste stream analysis method for strategic planning and progress assessment. Similar challenges and gaps exist in other high-density public environments, such as hospitals and shopping centres. For example, research on hospital waste reveals a focus on medical waste, with limited exploration of circular economy interventions for general waste, like plastic (Fletcher et al., 2021). Similarly, studies on shopping centres emphasise that research predominantly targets municipal or commercial buildings (Baharum & Pitt, 2010; Pitt, 2005), leaving retail environments understudied with some limited empirical examples (e.g. (Pongpunpurt et al., 2025). More recent research identified barriers to CE adoption in shopping centres, including costs, consumer roles, supplier relationships, and policy risks (Pongpunpurt et al., 2024), which are parallel with those in airports. Despite waste management being a global issue, there is no one-size-fits-all solution. Regions and cities adopt context-specific strategies tailored to their local needs, regulatory frameworks, and infrastructural capacities (ElSaid & Aghezzaf, 2018; Fletcher et al., 2021). When comparing the implementation of circularity measures in similar environments, airports are singular in their unique international, highly-controlled, multi-stakeholder ecosystems and therefore require a different approach that can deal with this complexity.

As the literature predominantly focuses on theoretical frameworks advancing CE in airports, empirical studies implementing and evaluating interventions to advance waste management in real-world airport settings remain limited. To address this gap, this study applies systemic design (SD) to develop and evaluate a context-based intervention within the real-world environment of Oslo airport. To our knowledge, this study is among the first to empirically implement a circular waste management intervention in an airport.

SD was selected due to its promising ability to navigate complex multi-stakeholder environments by integrating systems thinking and design thinking (Jones & van Ael, 2022; Ryan, 2014). As an interdisciplinary approach, SD provides both the theoretical foundation and practical tools to develop interventions in complex systems (Bijl-Brouwer & Malcolm, 2020; Jones, 2014). Airports, as ecosystems, are characterised by complex interactions and restrictions among various actors, technologies, and processes (Aarikka-Stenroos et al., 2021). They are a unique waste setting because high public density and stress meet a transient, multicultural flow of infrequent visitors unfamiliar with local disposal systems and with minimal repeated exposure. A systemic lens allows to reveal root causes of waste challenges and operation and stakeholder interdependencies, enabling a targeted intervention design. Furthermore, SD's co-creative nature (Jones, 2018) facilitates the needed stakeholder engagement, which is critical for advancing CE in airports (van der Tuin-Rademaker et al., 2024). Aarikka-Stenroos et al. (2021) argue that advancing CE "*requires a socio-technical transition that touches on actors across many levels of analysis. Therefore, related ecosystem initiatives cannot be isolated, either.*" Following this argument, a systemic approach is required (Guzzo et al., 2022), and SD's ability to bridge system theory and design practice while facilitating stakeholder participation results in the appropriate approach for designing an intervention within the airport ecosystem.

The objective of this study is to assess the application of SD, in the development of an intervention advancing CE in a high-density public ecosystem. This was approached through the development and implementation of a local waste hub designed to enhance waste separation at Oslo Airport. The intervention was tested during a one-month pilot and assessed using a variety of quantitative and qualitative data. This study is guided by the following research question: *"How can SD be applied to develop an intervention that improves waste separation and material circularity in airport environments?"*

By addressing this question, this research fills the gap in the limited empirical research on interventions advancing circular waste management in airports. The findings offer practical insights for similar high-density public ecosystems and theoretical perspectives on SD advancing CE.

2. Background Oslo Airport

Oslo Airport, part of the Avinor group, aims to halve residual waste from daily operations by 2030 through zero waste projects, driven by internal objectives on advancing CE by managing "waste efficiently and in accordance with the waste hierarchy, prioritising prevention, reduction, reuse and recycling over recovery and disposal" (Avinor, 2023). To address this, the study redesigns the waste management system to increase residual waste separation in commercial units (shops, duty-free stores, restaurants, and cafes).

Residual waste is the targeted waste stream, as it is not only the largest waste stream generated by the airports' operational activities but also the most problematic waste stream, as it is incinerated.

The current waste management system at Oslo airport relies on three centralised waste stations located in the basement, with one serving as the primary station. However, this system faces significant challenges, including the misalignment between security control and retail opening hours. This limitation prevents waste disposal during the late closing hours of commercial units, forcing employees to either walk to the other distant waste stations or store waste overnight at their units. Over 100 commercial units manage their waste independently, often using ad-hoc methods. Logistical issues arise from distant and underutilised waste stations, as well as an overcrowded primary station. Staff and waste collectors often prioritise speed over accuracy, a problem made worse by low motivation, unclear guidelines, and conflicting interests, where airport sustainability goals are in conflict with tenants' emphasis on cost and convenience.

Over a two year-period, three residual waste interventions were explored. Two were piloted, including the waste hub concept, to evaluate effectiveness and scalability potential.

3. Methods

This study adopted an action research approach (Kemmis et al., 2014), using SD as the methodological framework for problem framing, system analysis, and intervention development. The researcher acted as a participant-observer, enabling co-design, implementation and refinement of the SD intervention in collaboration with airport stakeholders.

3.1. Research Set Up

The study focused on developing and piloting a local waste hub to improve waste separation, particularly in residual waste, at Oslo airport. The intervention was co-designed over two years with the airport circularity team, with the lead author as a participatory action researcher on-site for six months. The waste hub concept was piloted for one month with seven commercial units participating. The pilot was developed with key stakeholders, including two representatives from the airport's circularity team (of which the lead author became part of), managers and employees from the participating units, the facilities team for waste management, and external partners. The study combined quantitative and qualitative data. Qualitative data was collected through a comparative analysis of the weight of 100 waste bags pre-pilot and 100 bags during the pilot. Qualitative data was collected through semi-structured interviews (n=17) with employees and managers. Additionally, field observations, informal conversations, and field diaries documented daily interactions, challenges, and reflections. The collaborative and iterative SD process of this research was organised around the four action research cycles (Figure 1), adapted from the Interaction Design Foundation (2015), with origins in Kemmis et al. (2014) spiral of self-reflective cycles.

Figure 1. Illustration of the research process

3.1.1. Planning: Exploration Airport The planning phase focused on exploring the airport context to identify key waste challenges, define the scope and propose a potential intervention. An initial waste composition analysis was conducted as part of the EU project TULIPS (Rademaker et al., 2023), which included mapping materials flow and examining resource stream compositions based on weight, volume, and treatment methods, while also verifying the treatment processes. This analysis revealed that in 2023 alone, 5317 tons of waste were generated. More than one-third was categorised as residual waste from operational processes, of which nearly half could be reduced through better source separation by employees. Scoping sessions with stakeholders led to the development of local waste hubs, which incorporated a Pay-As-You-Throw (PAYT) (Dijkgraaf & Gradus, 2009) approach, where waste fees were modulated based on the volume of residual waste disposed (van der Helm., 2024).

3.1.2. Act: Pilot Development To test the waste hub concept, a pilot was developed to trial a fully operational infrastructure for localised waste separation for one month at the international D gate and involved seven participating units (three shops and four food and beverage units, which included one restaurant, one kiosk and two cafes). The development of this infrastructure was carried out iteratively through co-creation sessions with Avinor (including the circularity team, restaurants, shops, and cleaning facilities) and external stakeholders (provider of the weighting system). The hub was strategically located in an unused room, chosen for its proximity to the participating units (2-minute walking distance), the accessibility of the elevators for the facilities team for waste disposal and the inaccessibility for passengers. Bins and metal cages for the six most common waste streams were installed, namely paper and cardboard (two cages), plastic foil/wrappers (one cage), residual waste (two 660l wheelie bins), glass and metal (one 240l bin), deposit bottles (one cage and one 240l bin), and food waste (one 240l bin). A scale and touchscreen were mounted next to the waste streams, so that the employees could register their commercial unit and the weight of their waste. The interface of the scale was provided by an external stakeholder, specialised in waste measurement solutions. Additionally, a desk for the researcher was set up for field research and observations (Figure 2).

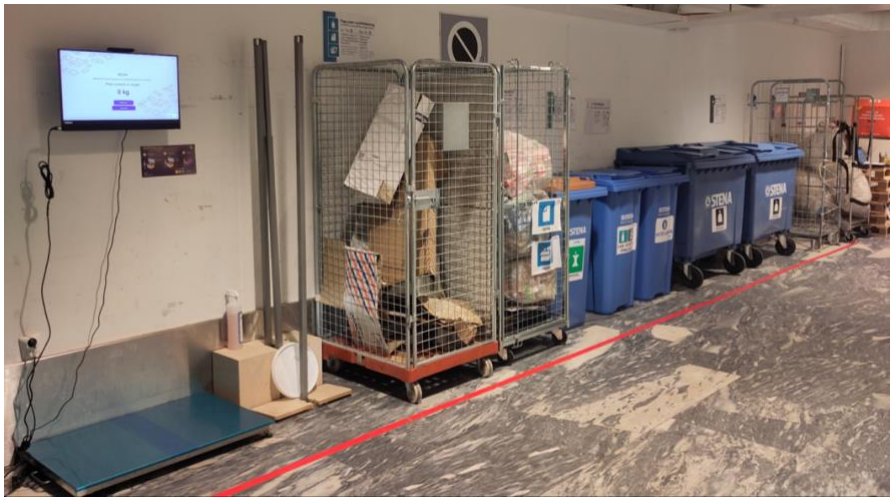

Figure 2. The waste hub pilot set up

The pilot flow (Figure 3) involved employees bringing the waste bags from their unit to the waste hub, where they weighed the waste bags before disposing them in the appropriate waste stream. The researcher conducted random spot checks (1-2 per day) alongside informal interviews. These spot checks involved visually inspecting the waste bags for incorrect items and providing a feedback card when missorted items were found (Figure 4).

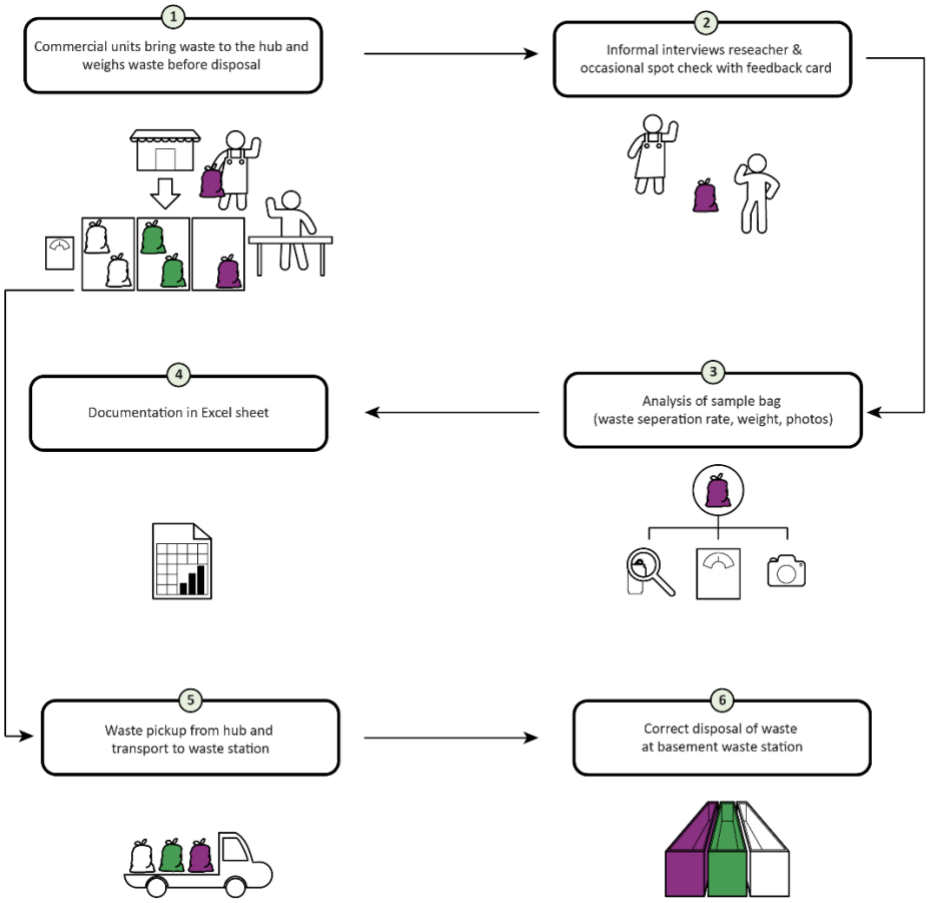

Figure 3. Flow of the pilot - **Steps 1-2** show the interaction of the employees with the waste hub and the researcher, which involves bringing waste to the hub, weighing before disposing and occasional informal interviews of feedback. **Steps 3-4** show the data collection steps of the researcher. **Steps 5-6** show the backend of the infrastructure in terms of the waste pick up from the hub by the cleaning team and disposing it at the big waste station.

Figure 4. Feedback card example

3.1.3. Observe: Pilot Execution Quantitative data collection included a baseline measurement of waste separation rates based on 100 waste bags one week before the pilot, followed by a measurement of an additional 100 waste bags during the pilot. Each bag was weighed, opened, and sorted into correctly and incorrectly disposed items (Figure 5). The weight of incorrectly disposed items was subtracted from the total weight to determine the waste separation rate per bag. The overall waste separation rate for a specific waste stream was calculated as the average of all bags collected for that stream. All data was systematically recorded in a spreadsheet. The pilot measurement followed the same manner of analysis, allowing for a comparison with the baseline measurement. Additional quantitative data was obtained through the weight measurement interface, which provided insights into peak hours, waste disposal frequency and predominant waste streams.

Figure 5. 5.a Waste bag transportation (baseline measurement), 5.b Residual waste bag (baseline measurement), 5.c Cardboard waste stream (pilot measurement), 5.d Residual waste bag analysed (pilot measurement)

One week after finalising the pilot, qualitative data were collected through interviews (n=17) with employees and managers from the participating units (for semi-structured interview guide see Appendix A). Employee interviews captured diverse perspectives (employees who used the waste hub, logistical workers and kitchen leads) on the waste hub and perceptions of changes in waste separation practices. Participation was voluntary, with interviews lasting 10–20 minutes in quiet areas near or within the participating units. Manager interviews aimed to assess, in addition to the perception of the waste hubs, the operational and financial viability. These interviews were scheduled via the circularity team representative, accommodating the managers' availability and preferences (in-person or online). A circularity team representative also joined to focus on financial aspects. During the time the researcher was on-site, additional data was gathered through two field diaries (Couvinhas et al., 2015), which document real-time observations of the airport environment and the pilot, in form of written notes and sketches. Further, the diaries captured daily interactions such as informal conversations with employees, as well as formal meetings, observed operational challenges, and feedback on the pilot. The researcher kept a diary handy to take notes and set aside time at the end of each workday to write down additional observations and reflections.

3.1.4. Reflect: Causal-Loop-Diagram (CLD) The reflection phase involved three stages: 1.) Review and initial topic generation; 2.) Coding and topic iteration; 3.) Mapping causal relationships of insights into CLD. First, interview transcripts, observational notes, and researcher reflections on the quantitative data were reviewed. Throughout the pilot study and the review process, notes were taken on general impressions and recurring topics, leading to a rough categorisation of the content into eight initial themes. Second, the eight initial themes were further iterated on while the collected data was systematically coded using Atlas.ti. During this process, the names of the themes were further refined, and one initial theme was removed, as fewer insights were found than anticipated. As a result, seven final themes were defined (Figure 6).

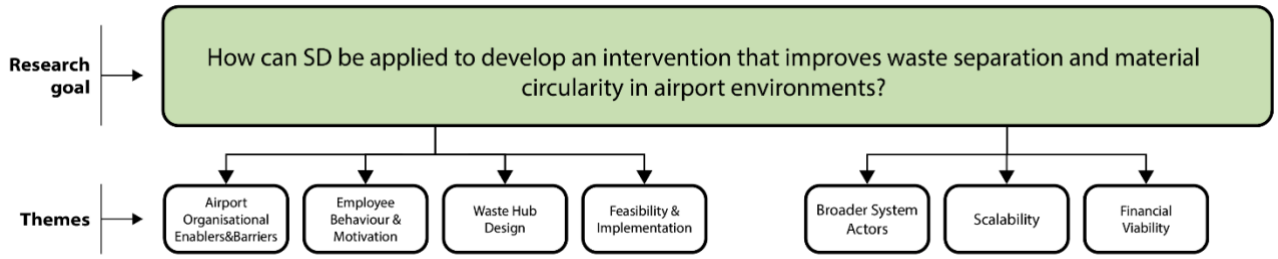

Figure 6. Analytical framework with seven themes

The first themes, "Airport Organisational Enablers & Barriers" and "Employee Behaviour & Motivation" emerged as they directly relate to the complexity of the airport. Additionally, these themes provide insights into operational activities as the primary waste source. The following two themes, "Waste Hub Design" and "Feasibility & Implementation", reflect on the waste hub design and future improvements. The final three themes, "Broader System Actors", "Scalability" and "Financial Viability" were identified as relevant to uncover insights on generalisability and transferable knowledge for similar high-density public environments.

Third, the summaries of the seven themes were organised into a CLD, which is considered an effective approach for SD (Murphy & Jones, 2020). While the seven themes' summaries present the findings in isolated paragraphs, the CLD visually illustrates the recurring patterns and causal relationships among the various insights and their dynamics (Bala et al., 2017). The CLD was created using the online tool Kumu. Initially, the causal relationships of each theme were drafted in individual "mini-maps," and later, these "mini-maps" were interconnected to form an overarching final CLD (Tschavgova et al., 2024). This process involved continuous iteration and reflection.

3.1.5. Second Research Cycle Building on the insights gained from the first cycle, a second cycle will be initiated in which the design of the intervention will be further refined and iterated on. This second cycle, however, is not reported in this paper as it is still ongoing.

4. Results

By combining data from the comparative study, interviews, and observations, this section offers a comprehensive overview of the impact of the intervention on waste separation rates, changes in commercial units and waste separation practice, as well as insights on the waste hub itself. These findings were organised in a CLD using the seven analytical themes.

4.1. Improved Waste Separation Rate

The comparative study examined 656.2 kg of waste (332.3 kg baseline measurement and 323.9 kg pilot measurement). The weight fluctuation between the measurements is attributed to the differing weight of waste items. For example, a bag of food waste can be very heavy if it contains a lot of coffee grounds, but relatively light if it consists mainly of orange peels. Therefore, not the weight but the waste separation rate of the two measurements is more insightful, which indicated a 3% reduction in the residual waste stream of incorrectly disposed items. In addition to the reductions in incorrect disposal in residual waste, contamination in other recycling streams also improved (Figure 7). It is important to note that certain waste streams, such as deposit bottles, already had a high separation rate because of deposit money. Similarly, the paper and cardboard waste stream already had high separation rates. All measurement data can be found in Appendix B.

Waste stream	**Baseline measurement:** % of wrong items in waste stream	**Pilot measurement:** % of wrong items in waste stream
Paper and Cardboard	9%	2%
Plastic foil/wrappers	6%	8%*
Glass and Metal	22%	0%
Deposit Bottles	0%	0%
Food Waste	2%	0%

Figure 7. Comparison of separation rate of the waste streams between the baseline measurement and pilot measurement (* A single bag of hard plastic in the plastic foil/wrapper stream accounted for the incorrect sorting—removing it reduced the error rate to 0%)

This increase in waste separation aligns with the observed changes in items disposed in the residual waste stream, such as certain recyclable items no longer being present in this stream. For instance, hard plastic packaging that was previously disposed of as residual waste is now being sorted separately as hard plastic. Similarly, milk cartons, once found in the residual waste, are now correctly placed in separate bags for the paper waste stream at the waste hub (Figure 8).

Figure 8. 8a: Hard plastic in residual waste (baseline measurement), 8b: Hard plastic as separate waste stream (pilot measurement), 8c: Milk cartons in residual waste (baseline measurement), 8d: Milk cartons in paper/carton waste (pilot measurement)

Furthermore, there were noticeable differences in the paper waste stream and soft plastics between restaurants and shops (including the duty-free shop). Overall, shops had a higher waste separation rate, as their waste was primarily packaging waste, consisting of paper, cardboard, and soft and hard plastic. These units produced minimal residual waste since they did not serve or produce food items. Any residual or food waste reported was typically from employees' lunches or passengers disposing of waste in the shops. However, the introduction of the waste hub led to an increase in waste separation accuracy of paper and plastic waste streams, where employees started to separate plastic elements from paper and cardboard packaging.

4.2. Changes at Commercial Units

Interviews revealed that several commercial units made local adjustments in their facilities to better align with the waste hub's streams. These changes were initiated partly by employees and partly by team leaders. For instance, a shop employee requested additional bins to improve source separation at their shop:

"... in order to use the waste hub effectively, it's a lot easier to separate it in advance (...). Now we have two trash cans instead of one where we put plastic and everything together. So now we have one for cardboard and one for plastic. So (...) ever since, you guys implemented that (the waste hub) we've (...) been trying to do more things in our store."

Another example of a change involves the separation of milk cartons. Both serving units that received feedback cards regarding milk cartons have successfully implemented new routines to dispose milk cartons, either directly into the paper waste stream or into a separate bag. Overall, direct feedback, conversational or written, was well received and considered positive and effective. Managers and employees expressed confidence that while changing waste separation routines through adjustments (such as adding bins or changing routines) would take time, these changes were feasible and beneficial.

4.3. Employee Awareness and Behavioural Changes

Sorting waste became a visible part of daily routines through direct interaction with waste disposal. Employees shared that this hands-on engagement with waste not only fostered a sense of accountability for waste separation practices but also encouraged sustainable behaviours and heightened overall awareness of waste separation. A manager has shared the following:

"...it has brought a different way of thinking to the whole team (...). Whereas previously in their head it would be "OK- I just take my trash bag. I'd take it downstairs and then a member of my management team or myself would then do the separation in the stockroom". This would get the entire team thinking about it as well, so that that has been a bonus. And also, them being able to go to the smaller waste stations as it is to be able to get it weighed and then they actually do the separation themselves. Again, can be a more accurate way of getting the residual waste separated."

Additionally, the introduction of bins within the commercial units led to higher rates of source separation. Since employees are responsible for sorting waste correctly, they are more likely to dispose of it in the appropriate waste stream.

4.4. Insights on the Waste Hub Design

One of the key themes of the analytical framework was "Waste Hub Design", where several important insights emerged. From a UX/UI perspective, the scale and its interface were intuitive and user-friendly, contributing to a seamless user experience. The overall UI was perceived as self-explanatory, minimising the time required for the weighing process and making it convenient for employees, as data recording was automatically handled by the machine. The waste disposal process itself was perceived as clear and straightforward, largely due to the visual guidance provided by the interface and clear signage. For example, the scale interface displayed step-by-step instructions, and colour-coded bins with labelled icons directed employees on where to dispose of the waste streams. A comprehensive overview of the benefits and improvements suggested by interviewed employees during the pilot can be found in Appendix C. Nevertheless, the pilot has uncovered a fundamental obstacle in the implementation of multiple waste hubs at the airport. Initial research had suggested potential locations, but closer inspection revealed that not all potential locations fulfil the size and visibility requirements. Significant financial investment would be required by the airport management to restructure enough locations for the hubs, leading to concerns about financial viability.

4.5. Causal-Loop-Diagram

A CLD visualises the complex relationships among the seven analytical themes (Figure 9). This diagram visually maps the key loops and interdependencies between the themes of the thematic analysis, offering a systemic perspective of how an intervention can advance circular waste strategies within the airport ecosystem. The CLD addresses the research question by organising insights into two main clusters: **Case-Specific Enablers and Barriers** and **General Transition Enablers**. The seven themes embedded in the CLD are briefly described below, while the detailed topic summaries can be found in Appendix C.

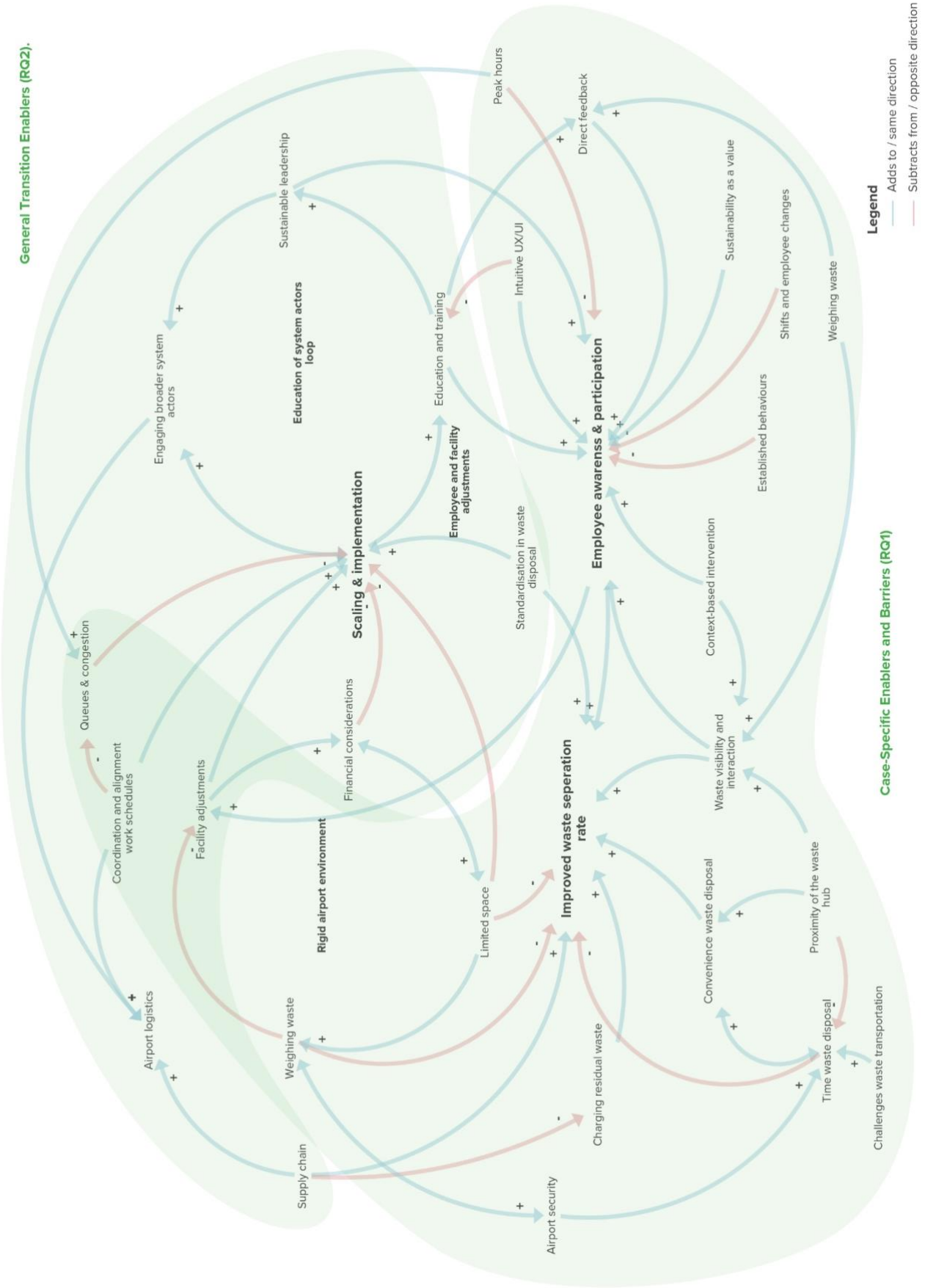

Figure 9. CLD (high-resolution version in Appendix D)

4.5.1. Case-Specific Enablers and Barriers

- *Airport Organisational Enablers & Barriers:* Limited space and high costs slow down the implementation of waste hubs, while bottom-up initiatives serve as enablers. Duty-free stores, which have unique logistics, generate almost no residual waste but the highest volume of paper waste, which may contribute to congestion in this waste stream. Standardisation, such as unified waste disposal, reduces confusion and improves implementation and scaling.
- *Employee Behaviour & Motivation*: The visibility of waste in the daily operations and the proximity of the hub promote employee awareness and participation. Direct feedback, like reminders and peer-feedback, enhances awareness. However, time pressure during peak hours and established behaviours act as balancing forces that can hinder participation. Employee-driven initiatives, such as adding more bins, generate bottom-up momentum, as well as training and education.
- *Waste Hub Design:* The 24/7 accessibility and shorter walking distances made the hub more convenient and increased waste separation rates. However, queues during peak hours and space constraints hinder the implementation of the waste hubs. A clear UI, such as an intuitive scale interface, enhances employee awareness and participation. Additionally, data collected from weighing helps with management adjustments and demonstrates a positive impact on waste separation by making waste streams more visible to the employees.
- *Feasibility & Implementation:* The intuitive design minimises training requirements, promoting quick adoption. However, queues during peak hours, shift changes, and unclear roles can create friction. Implementing peer-to-peer feedback and using clear icons enhances waste separation. Long-term success relies on integrating the hub into daily routines.

4.5.2. General Transition Enablers

- *Broader System Actors:* Leadership from the units and particularly from the airport management fosters higher employee engagement in waste separation, while supply chain impacts waste separation by providing more (or less) packaging and thus increasing/decreasing waste.
- *Scalability:* Implementing multiple waste stations could enhance adoption rates, but not coordinating schedules (such as during peak hours) may lead to congestion issues. Clear communication and standardised training are essential for success, while factors like space availability and coordination of waste streams can pose challenges. The financial viability of this system depends on demonstrated time and cost savings.
- *Financial Viability:* Charging for residual waste encourages better waste separation by linking costs to residual waste. Time savings (e.g., shorter distances) offset expenses. Concerns about upfront investments may hinder adoption. However, upcoming fees, such as incineration taxes, could motivate long-term commitment to the system.

5. Discussion

This study explored the application of SD to develop an intervention that improves waste separation and material circularity at Oslo Airport. Results showed a 3% reduction in incorrect disposal of residual waste, demonstrating its short-term effectiveness in improving waste separation. Qualitative findings identified proximity to the waste hub, direct feedback, and employee engagement as critical enablers, while operational constraints and limited awareness emerged as barriers. These insights highlight both the potential of interventions to foster sustainable change in complex ecosystems and the need for context-specific adaptations to address organisational challenges.

5.1. Practical Learnings of SD Application

5.1.1. Context-based interventions The introduction of the waste hub changed the way employees directly engage with waste. Previously, waste disposal was often an abstract or distant task, which was delegated to colleagues from the logistics or taken to a remote waste station. The waste hub required employees to personally carry and dispose their unit's waste bags, making waste sorting a tangible and hands-on part of employees' daily routines. This shift aligns with behavioural science, which suggests that behaviour is significantly influenced by what attention is drawn to (Kahneman & Thaler, 2006). As employees interacted directly with waste streams, their awareness and responsibility reportedly increased. Consequently, the waste hub acted as a context-based intervention. It modified the environment in which employees interact with waste without altering their underlying cognitions, as behaviour is significantly influenced by situational or contextual factors humans find themselves in (Dolan et al., 2012). As Chater & Loewenstein (2023) state, *"(...) often the most powerful way to help people make better decisions is not merely to modify their 'choice architecture' but to fundamentally change the 'rules of the game.'"* By transforming the environment around waste disposal, the waste hub created a setting where employees were able to make more sustainable decisions. This context-driven approach demonstrates how environmental redesign, in addition to cognitive or motivational campaigns, can effectively foster sustainable behaviours in public high-density environments.

5.1.2. Sustainable Leadership The CLD revealed that active managerial involvement correlated with higher employee engagement. In facilities where managers were actively involved, employees showed the tendency to be more engaged. In addition to the leadership in facility management, employees indicated that the involvement of airport management has made waste separation a more significant topic. This supports the argument of Chater & Loewenstein (2023) that for systemic change, individual actions should not be regarded as more relevant than those of the corporation. Therefore, sustainable leadership at the management level needs to shift away from attributing responsibility for unsustainability solely to individual behaviour and instead encourage a broader perspective. Or as Hale (2010) framed it, *"the impasse between government, business, and individuals must, somehow, be broken... If we are to do so, we must understand the kind of public intervention that will make a difference... There has been a growing tendency to portray climate change as an issue of personal responsibility... but this is not simply about our behaviour. While individual behaviour does matter, there are significant limits on our ability to determine our personal carbon footprint."*

5.1.3. Lessons for Similar Contexts The airport pilot demonstrated that the waste hub intervention impacted waste separation rates and employee awareness in the short term. This impact may provide transferable learnings to similar high-density public ecosystems such as hospitals, train stations, and shopping malls. These environments also share similar characteristics, such as having different businesses, departments, and tenants sharing common spaces and waste management systems. Further, various types of waste and the disposal of this waste is challenged by diverse logistical issues, such as space constraints and peak hours. Given the unique complexities and security challenges of airports (e.g., restricted access, security controls), they can serve as an ideal controlled setting for case studies and transferable learnings.

Therefore, despite the limited generalisability of one pilot, the following learnings could be relevant to other contexts: (1) a clear and consistent system for waste disposal across all service units reduces confusion and improves compliance. Similar findings have been noted at Boston Logan International Airport (Sebastian & Louis, 2021); (2) support from higher management is needed for making sustainability a collaborative effort rather than just an individual responsibility (Chater & Loewenstein, 2023; van Dam & Bakker, 2024); (3) co-creating a context-based intervention can create an environment where employees can make more sustainable decisions; (4), enforcement between bottom-up and top-down approaches, with support from government and supply chain partners, is fundamental for sustainability efforts (Geels, 2011).

5.2. Reflective Considerations on SD Advancing CE

5.2.1. Systemic Interventions Driving Change A major obstacle to advance CE is that sustainable solutions often lack immediate benefits to stakeholders, as they are seen as a collective good and typically perform lower in price and performance compared to established technologies within the current profit-and-growth-oriented paradigm (Geels, 2011). This can challenge the replacement of existing systems if substantial changes are not made to economic frameworks, such as taxes, subsidies, and regulatory adjustments (Geels, 2011). However, the co-creative approach of SD demonstrates that interventions like the waste hub can offer user benefits and sustainability, which is essential for organisational acceptance. The pilot illustrated the effectiveness of SD in navigating complex ecosystems like airports. As (Jones, 2014) points out, SD is effective for addressing "wicked problems" in sustainability, allowing for iterative processes involving multiple airport departments and external stakeholders. As the design process of the waste hub highlights the need for multidisciplinary teams in creating interventions, future research should also engage stakeholders beyond the airport ecosystem, combining top-down and bottom-up sustainable initiatives and wider involvement from supply chain stakeholders and regulations.

Additionally, the waste hub has led to spillover effects (Truelove et al., 2014), with employees initiating improvements in their work areas to increase source separation, such as adding waste separation bins and encouraging colleagues to separate waste. Additional examples include increased waste separation rates across other waste streams and employees sharing that fewer residual waste bags are being filled daily. It appears that a systemic intervention may cause ripple effects, such as adjusting waste separation structures beyond the waste hub. However, the CLD indicated that the waste hub alone is not sufficient to truly advance CE. Further interventions focusing on increasing circularity beyond recycling are needed. Systemic interventions should not be viewed as a single solution (Bijl-Brouwer & Malcolm, 2020; Jacoby & van Ael, 2021); a variety of strategically aligned interventions are required for broader systemic change (Geels, 2011). Therefore, next to exploring alternative concepts to the waste hub, interventions focusing on waste reduction, such as in packaging, are required.

5.2.2. Airports Driving Change Although generalisations are limited by the single short-term pilot, this research provides some initial insights for reflection on how a micro-level context, like an airport, can facilitate larger CE transitions. Literature emphasises the need for a systemic perspective on advancing CE across micro (individual/firm), meso (regional), and macro (national/governmental) levels (Kirchherr et al., 2017). The CLD highlighted the need to explore the supply chain's direct influence on waste volumes, such as through packaging reductions or increases. This aligns with Sebastian & Louis (2021), who note that airport recycling depends on logistical constraints, legislation, management, and contracts. Lacoste (2016) argues that such network-wide coordination is essential for sustainable supply chains. However, airports are limited in supplier alternatives, which restrict the ability to enforce sustainability criteria or negotiate flexible contracts and interviewed employees have expressed doubts about whether airports have enough influence to effectively reshape supply chains. Existing research confirms that firms face systemic barriers, such as economies of scale, sunk investments, institutional inertia, and political lobbying (Unruh, 2000) and path dependencies, such as a reliance on single-use packaging from suppliers, that constrain their ability to drive supplier-level changes. Yet, despite the dependency on meso and macro actors, it is acknowledged that CE requires individual actors, such as firms (Hofmann, 2019), to shift their value perception from a traditional economic, value-centric perspective to one that includes ecological and social values (Aarikka-Stenroos et al., 2021). This study demonstrates how an intervention can address ecological aspects (reducing residual waste through better source separation) and social value (improving waste disposal routes for employees) while minimising financial burdens on commercial units. However, further case studies in similar high-density environments, like shopping malls or train stations, are needed for broader insights on effective systemic interventions.

5.3. Limitations and Study Quality

This study encountered several limitations, including the researcher’s inability to speak Norwegian and a short-term presence at the airport, which hampered relationship-building with stakeholders. The study's scope was

restricted, focusing on one pilot without addressing waste reduction in operational activities or controlling waste after it left the airport. Arguably, the limited pilot time and small scope may raise bigger concerns regarding study quality and restricted insights on broader systemic implications. However, the triangulation of findings due to the use of multiple quantitative and qualitative data sources provided a more holistic understanding of the intervention's impact, as well enhanced construct validity (Yin, 2009). Results were strengthened by cross-checking quantitative trends, like separation rates, with qualitative feedback from employees and managers for consistency.

Other concerns about study quality may include the influence of the researcher's presence on sorting behaviour (e.g., Hawthorne effect). For the baseline measurement, while the researcher's presence might have influenced employee behaviour due to awareness of the study, the results remained consistent with previous airport waste audits. This consistency suggests that employee behaviour was unaffected, likely due to familiarity with prior waste measurements, high staff turnover, shift rotations limiting awareness spread, and the prioritisation of operational tasks in the fast-paced environment. Thus, the baseline measurement serves as a valid representation of typical waste separation behaviours before the pilot. During the pilot, waste bags were analysed across all shifts, including early mornings, evenings, and weekends. Given the commercial units' long operating hours (6:00 AM–10:00 PM), the researcher could not be present at all times. However, no significant differences were found between periods with and without the researcher present. This consistency is explained by the team-based nature of waste separation, as bags were filled collaboratively within units and disposed of by available staff.

6. Conclusion

This study demonstrates that context-based, user-centred interventions can significantly advance CE practices in high-density public ecosystems. The results indicate a positive change in waste separation through an intervention, such as the waste hub. This suggests that it is worthwhile to explore further SD for CE, including co-creation, pilot projects, and CLD interpretations. Although this is a short-term pilot, the learning insights may be transferable to similar high-density public ecosystems. Future research could be extended to similar ecosystems, such as shopping malls and train stations, while also considering a broader range of system actors, including supply chain stakeholders, to address larger systemic barriers.

Authors' Contributions **Author A:** led the research as the main investigator, conducted the field research, performed the data analysis, and authored the manuscript. **Author B, C, D:** served as supervisors, providing guidance on structuring the paper, proofreading, and contributing to the conceptual development of the study. **Author E:** affiliated with the company where the field research took place, facilitated the setup and execution of the field research and contributed to proofreading the manuscript.

Data Availability All appendices mentioned in this publication are publicly available in a repository to ensure transparency and reproducibility. The materials can be accessed via the following link: https://doi.org/10.4121/9382f351-ac07-49e3-888c-f5d35e46eb84

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Declarations

Competing Interests The authors declare no competing interests.

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Appendix

The following appendices can be found under this link: (https://doi.org/ 10.4121/9382f351-ac07-49e3-888c-f5d35e46eb84)

- Appendix A: Semi structured interview guides
- Appendix B: Data comparative study (excel sheet)
- Appendix C: Topic summaries
- Appendix D: High resolution CLD + link to interactive CLD