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Integrating Design Thinking into Household Organic Waste Management: A Participatory Approach Toward a Circular Economy in Cirebon City, Indonesia

Zakiyah Amini[1,2], Lilik Sutiarso[1*], Ngadisih[1], Chandra Setyawan[1], Latifah Abd Manaf[3], Joko Nugroho Wahyu Karyadi[1], and Dwi Purnomo[4]

[1]Department of Agricultural and Biosystems Engineering, Faculty of Agricultural Technology, Gadjah Mada University, Yogyakarta, Indonesia
[2]Studies Program of Agrotechnology, Faculty of Agricultural, Swadaya Gunung Jati University, Cirebon, Indonesia
[3]Department of Environment, Faculty of Environmental and Forestry, Universiti Putra Malaysia, Seri Kembangan 43400, Malaysia
[4]Agribusiness Studies Program, Faculty of Agricultural, Swadaya Gunung Jati University, Cirebon, Indonesia

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*** Corresponding author:**
E-mail: ngadisih@ugm.ac.id; lilik-soetiarso@ugm.ac.id

ABSTRACT

Household organic waste management in many Indonesian cities remains dominated by linear collect-transport-dispose systems, limiting the implementation of circular economy principles. In Cirebon City, low community participation and limited source separation remain key challenges. This study aims to integrate the Design Thinking framework into the assessment of household organic waste management behavior to support the transition toward a circular economy. A mixed-methods approach was applied, combining a quantitative survey of 300 households and participatory qualitative observations involving 30 respondents from three active community-based waste banks. Five behavioral indicators awareness and understanding, attitudes toward the program, actual waste management practices, willingness to participate, and perceptions of circular economy benefits were measured using a Likert scale questionnaire. Data were analyzed using descriptive statistics and Spearman's rank correlation analysis. The results show a significant positive relationship between awareness, willingness to participate, and perceived benefits of the circular economy (ρ=0.395; p<0.01). Field implementation of the Design Thinking stages (Empathize Test) resulted in a 23% increase in community participation, improved perception of economic benefits, and the formation of habitual organic waste sorting behavior. Prototype trials using three types of dry materials (sawdust, charred rice husk, and raw rice husk) indicated that sawdust was the most effective, maintaining composting temperature stability (38-42°C) and producing mature, odor-free compost. This study contributes a participatory behavioral assessment framework that integrates Design Thinking into household organic waste management. The findings provide practical implications for local governments and community-based programs in strengthening circular economy implementation at the household level.

HIGHLIGHTS

- Household organic waste dominates the waste composition in Cirebon
- Design Thinking is applied as a behavioral assessment and participatory framework
- The layered composting system effectively reduces odor, leachate, and maggots
- Community participation increased by 23% after prototype iteration
- Participatory innovation supports the transition toward a circular economy

1. INTRODUCTION

Organic waste is a dominant component of household waste in Indonesia, accounting for more than 40% of the total national waste generation (SIPSN, 2024). The lack of optimal handling of organic waste at the source, namely households, has the potential to produce methane (CH_4) emissions through anaerobic decomposition in waste piles.

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Studies in several locations in Indonesia confirm that landfills are a major source of methane emissions, which is a potent greenhouse gas contributing to climate change and other risks such as landfill fires due to methane gas accumulation (Citrasari et al., 2025; Kristanto and Koven, 2019; Permatasari et al., 2025).

The Circular Economy (CE) approach offers sustainable solutions through resource recovery and waste reduction at source. However, most studies in Indonesia still focus on technical and infrastructure aspects, while the social dimensions and community behavior as the main drivers of the circular system remain under explored (Gunamantha et al., 2023). In particular, existing studies on organic waste management in Indonesia predominantly emphasize technical and infrastructure-based solutions, with limited attention to household-level behavioral assessment and participatory design approaches that integrate circular economy principles. This study addresses this gap by integrating Design Thinking as both a behavioral assessment tool and a participatory intervention framework at the household level. Although various organic waste treatment technologies have been developed, their effectiveness is often limited due to cost factors, space requirements, and a lack of user skills (Kharola et al., 2022; Manea et al., 2024; Wicaksana et al., 2025).

Furthermore, although public awareness of environmental issues is relatively high, waste sorting practices at the household level remain low. This gap between knowledge and behavior indicates the need for a human-centered approach to bridge the gap between awareness and concrete action. Design Thinking (DT) is relevant because it is oriented towards empathy, collaboration, and solution iteration through the stages of empathize, define, ideate, prototype, and test (Buhl et al., 2019).

Therefore, this study emphasizes the importance of shifting from a linear waste management system to a circular economy model that places the community as part of the resource management cycle. The integration of the DT method is used to identify behavioral barriers and design participatory solutions that are contextualized to the social and institutional characteristics of Cirebon City. This study positions DT not only as a solution design method but also as a behavioral assessment tool to understand the needs, barriers, and motivations of the community in managing household organic waste.

By integrating a survey of 300 respondents and a collaborative participatory process with 30 households in three Waste Bank Communities in Cirebon City, this approach provides empirical understanding of the interaction between awareness, attitudes, practices, participation, and perceptions of economic benefits in the context of a circular economy. This participatory approach bridges the social and technical aspects of environmental management through simple and contextual solution designs, such as a layer composting system based on local materials (sawdust, charred rice husk, and raw rice husks). This system is easy to apply, does not require special skills, and is low-cost. Empirical studies show that decentralized composting led by civil society can provide environmental and social benefits in large cities (Amato et al., 2024).

Based on this background, this study aims to assess the level of understanding, attitudes, practices, and readiness of households to participate in organic waste management; identify behavioral barriers and opportunities for circular economy implementation in the local context; and develop design-driven policy and intervention recommendations through a participatory Design Thinking approach. Importantly, the novelty of this study lies in the integration of Design Thinking as both a behavioral assessment tool and a participatory intervention framework in household organic waste management. Unlike previous studies that primarily focus on technical or infrastructure based solutions, this research emphasizes household level behavioral dynamics, co-design processes, and prototype testing to support circular economy implementation.

The study contributes a participatory assessment framework that links awareness, attitudes, practices, and willingness to participate with design-driven interventions. These findings provide practical implications for local governments and community-based waste management programs by demonstrating how simple, low-cost, and user-centered composting solutions can enhance community participation and support the transition toward a circular economy at the household level.

2. METHODOLOGY

2.1 Study location

This study was conducted in Cirebon City, West Java Province, Indonesia. Cirebon City was selected as the study area due to its persistent challenges in

municipal solid waste management. The city still relies on an open dumping system at the final disposal site, and several waste-related incidents, including landfill fires, have occurred in recent years. These conditions indicate limited waste reduction at source and low household level participation in waste sorting, making Cirebon City a relevant case for examining household organic waste management behavior and participatory interventions towards a circular economy.

Administratively, Cirebon City is divided into five subdistricts: Harjamukti, Lemahwungkuk, Pekalipan, Kejaksan, and Kesambi, which represent diverse socio-economic and environmental characteristics. These differences formed the basis for selecting proportional survey locations and three active community-based Waste Banks as sites for participatory Design Thinking activities (Figure 1).

Topographically, Cirebon City is dominated by low-lying coastal plains with relatively gentle slopes. This condition affects drainage patterns and organic waste management, as household waste disposal systems are largely dependent on urban facilities and conventional transportation systems. In addition, the city's location, which borders the Java Sea to the north and a water catchment area to the south, means that environmental and domestic waste management have important implications for the quality of the coastal ecosystem and public health.

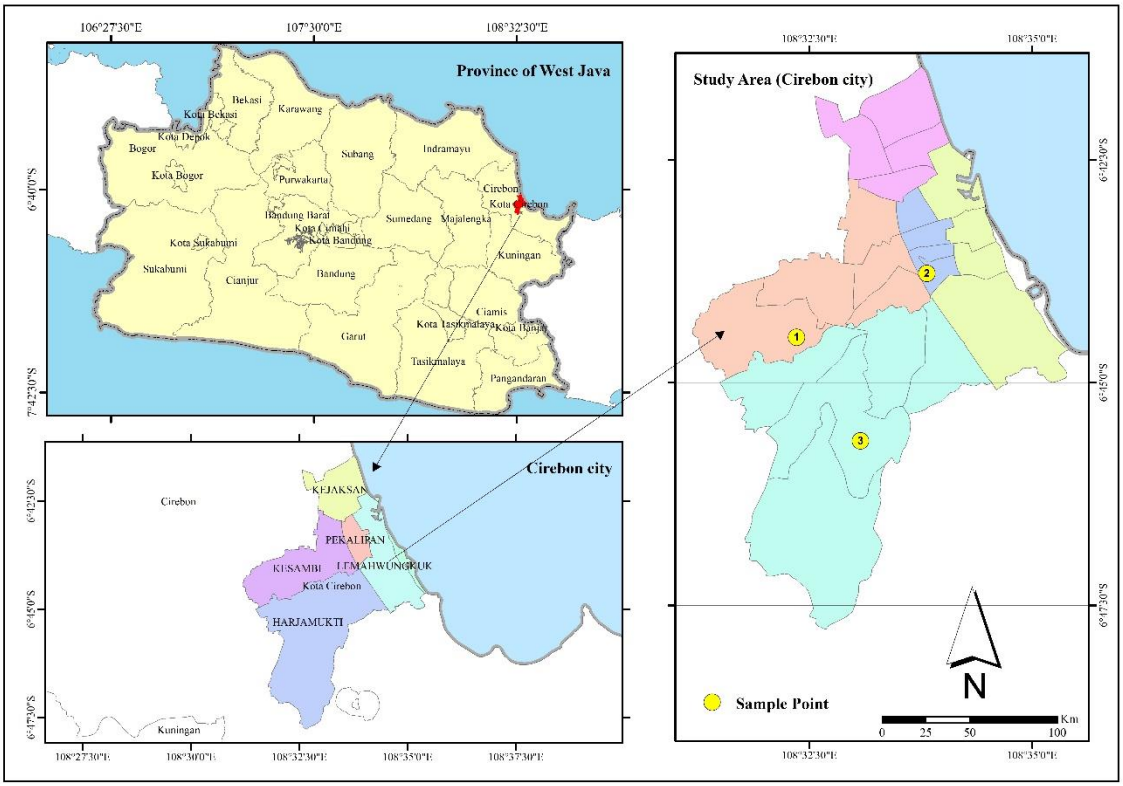

Figure 1. Study area map of Cirebon City, West Java Province, Indonesia, showing five administrative districts and three community-based waste bank sampling points.

Figure 2 shows the waste management system in Cirebon City, which is still dominated by the linear collect-transport-dispose pattern. The community still does not independently sort organic and inorganic waste, so material value has not been returned to the economic cycle, and community involvement is still limited to the collection stage. This condition is in line with research Ikhlayel (2018) which shows that most cities in developing countries face similar problems: end-oriented waste management systems and a lack of integration of circular economy approaches.

2.2 Data collection

This study employed a mixed-methods research design using a convergent parallel approach. Quantitative and qualitative data were collected concurrently and integrated during the analysis stage to provide a comprehensive understanding of

household organic waste management behavior. The quantitative component consisted of a structured household survey involving 300 respondents to capture statistically representative behavioral patterns, while the qualitative component focused on participatory observation, co-design discussions, and prototype testing conducted through the Design Thinking framework. The number of participants in the Design Thinking stage was determined based on methodological guidelines suggesting that approximately 30 participants are sufficient for exploratory and participatory research, where depth of engagement and interaction quality are prioritized over statistical representativeness (Hair et al. 2010). This study was conducted in two main stages, as summarized in Table 1.

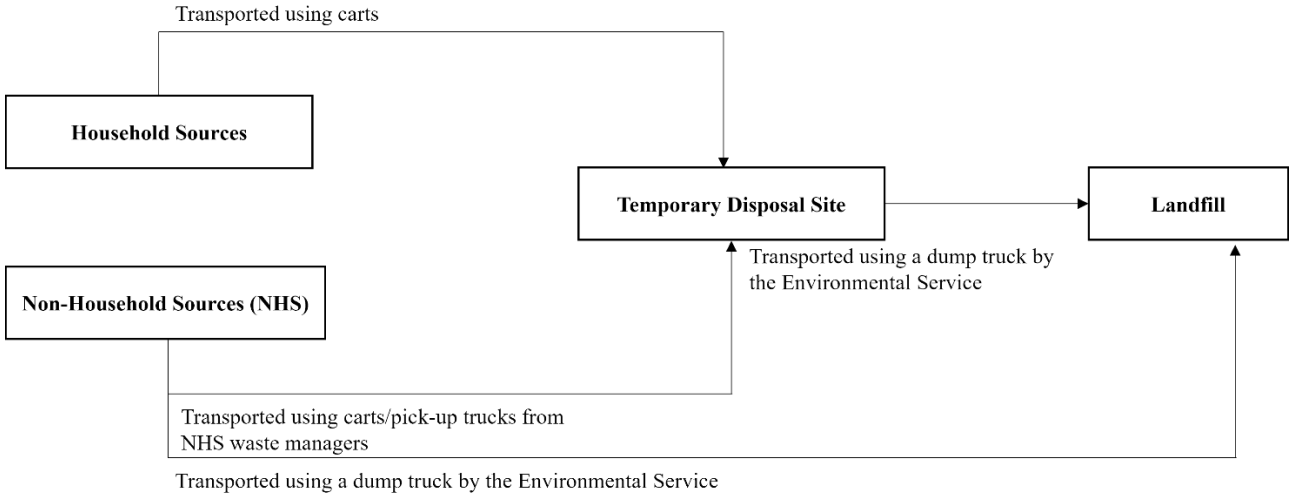

Figure 2. Illustration of the linear waste stream from source to landfill in Cirebon City (adapted fromWaste4cange Alam Indonesia, 2022)

Table 1. Research stages

Research stages	Method	Number of participants	Instruments	Main output
Stage I: Behavioral Assessment	Quantitative survey	300 respondents	Likert scale questionnaire	Behavioral data and participation profiles
Stage II: Design Thinking	Participatory design (co-design)	30 households (3 Waste Banks)	Observation, interviews, and prototypes	User-based waste management solutions

2.2.1 Stage I

At this stage, a behavioral environmental assessment was conducted. This approach is in line with the concept of socio-behavioral assessment, which assesses the relationship between awareness, attitudes, and actual actions in the context of household waste management (Bulhões et al., 2023; Treyes et al., 2023; Wilson, et al., 2025). A quantitative survey was conducted with 300 household respondents to evaluate behavioral dimensions related to organic waste management. The number of respondents in this study was determined using the Slovin formula to determine the sample size from a known population. This formula was used to obtain a representative sample size with a certain margin of error. The formula is as follows:

$$n = \frac{N}{1 + N(e)^2}$$

With the following explanation: n=required sample size; N=population size; e=margin of error, set at 6% (0.06) in this study.

Based on data from the Central Statistics Agency (BPS) of Cirebon City in 2023, the population of Cirebon City is 341,980 people. Thus, the sample size calculation is as follows:

$$n = \frac{341.980}{1+341.980(0.06)^2} = 277.55 \approx 278$$

$$ni = \frac{N_i}{N} \times n$$

With the following explanation: ni=number of respondents in the i-th subdistrict; N_i=population in

the i-th subdistrict; N=total population of Cirebon City; n=total research sample (300 people).

The sample distribution as shown in Table 2 indicates that respondents were distributed proportionally distributed across the five subdistricts in Cirebon City according to the population of each area. This proportional distribution was intended to ensure that each subdistrict was adequately represented, allowing the data to reflect the social, and geographical diversity of the community. After the number and distribution of respondents were determined, the next step was to develop a research instrument used to measure community behavior towards organic waste management. This instrument was developed in the form of a structured questionnaire using a five-point Likert scale (1=strongly disagree to 5=strongly agree).

The questionnaire indicators were structured into two functional groups based on their analytical purpose. Indicators 1-3 were designed to capture baseline household waste disposal practices and existing organic waste management conditions, including disposal habits, waste separation behavior, and the level of organic waste generation. These indicators were analyzed descriptively to provide an overview of the current waste management situation in Cirebon City.

Indicators 4-8 represent the core behavioral constructs of this study, including awareness and understanding, participation (actual action), challenges in waste management, organic waste composting practices, and support for circular economy practices. These indicators were subsequently subjected to validity and reliability testing, as well as Spearman's rank correlation analysis, to examine the relationships between behavioral dimensions in household organic waste management. Each statement in the questionnaire was developed based on the results of a literature review and the empirical context of waste management in the Cirebon City, which were then grouped into five main behavioral indicators, namely understanding and awareness, attitudes towards waste management programs, actual practices of organic waste management, willingness to participate, and perceptions of the benefits of the circular economy, as presented in Table 3.

Table 2. Number of samples by district in Cirebon City

No.	District	Population	Number of Samples
1	Harjamukti	128,778	113
2.	Lemahwungkuk	58,418	51
3.	Pekalipan	29,716	26
4.	Kesambi	78,398	69
5.	Kejaksan	46,670	41
Total		341,980	300

Source: BPS (2024)

Table 3. Measurement indicators

Indicator number	Research indicator	Measurement purpose
4	Understanding and Awareness	Assessing the level of knowledge, awareness, and concern of respondents regarding environmental issues and the negative impacts of poorly managed organic waste.
5	Attitude toward Waste Management Programs	Measuring respondents' acceptance, support, and trust in waste management policies, programs, and activities implemented by the government or local communities.
6	Actual Practices of Organic Waste Management	Evaluating respondents' actual actions in sorting, storing, processing (e.g., composting), and disposing of organic waste on a daily basis.
7	Willingness to Participate	Assessing respondents' readiness, motivation, and willingness to actively participate in organic waste management activities at the household and community levels.
8	Perceived Benefits of Circular Economy	Measuring respondents' views on the potential economic benefits (such as cost savings or the sale value of compost), social benefits (community togetherness), and environmental benefits of implementing circular economy principles.

Before being used in the main study, the questionnaire instrument was tested for validity and reliability to ensure the consistent measurement of behavioral constructs. The validity test was conducted using Spearman's Rank correlation (Spearman's rho) with a total of 30 pilot respondents who had characteristics similar to the main study population. This test was selected because the data were ordinal (Likert scale) and not normally distributed. The results showed that all statement items had calculated correlation coefficients greater than the critical value ($r=0.361$; $\alpha=0.05$), indicating that all items were valid

and suitable for use in the main study. Instrument reliability was assessed using Cronbach's alpha coefficient. The results showed a Cronbach's alpha value of 0.701 for the five questionnaire items, indicating acceptable internal consistency. All items demonstrated corrected item total correlation values above 0.30, and the Cronbach's alpha value did not increase when any item was deleted, confirming that all indicators were retained for further analysis. (Sullivan and Artino Jr, 2013).

2.2.2 Stage II

This stage was conducted using the Design Thinking (DT) method to explore community needs and design practical solutions for household organic waste management that are appropriate to the social context of Cirebon City. A total of 30 participants were involved in the Design Thinking (DT) stage. Participants were purposively selected from three active Waste Bank communities in Cirebon City, with 10 participants from each location. The selection aimed to ensure the diversity of perspectives, including ordinary residents, Waste Bank members, and Waste Bank managers, who represent different roles and levels of engagement in household organic waste management.

The number of participants was determined based on two considerations. First, previous methodological guidelines suggest that a minimum sample size of approximately 30 respondents is adequate for exploratory and relatively simple analytical models (Hair et al., 2010). Second, in participatory and Design Thinking based research, the emphasis is placed on depth of engagement, interaction quality, and information saturation rather than statistical representativeness. The involvement of 30 participants across three community settings was sufficient to capture diverse behavioral patterns, identify key barriers, and support iterative co-design and prototype testing processes. This approach serves as an innovative framework based on community participation (human-centered approach), which aims to produce a waste management system design that can be directly applied at the household and community levels. The Design Thinking stages applied in this study were adapted from established Design Thinking frameworks consisting of five main phases: Empathize, Define, Ideate, Prototype, and Test (Brenner and Uebernickel, 2016). The following diagram illustrates these stages.The following diagram shows these stages.

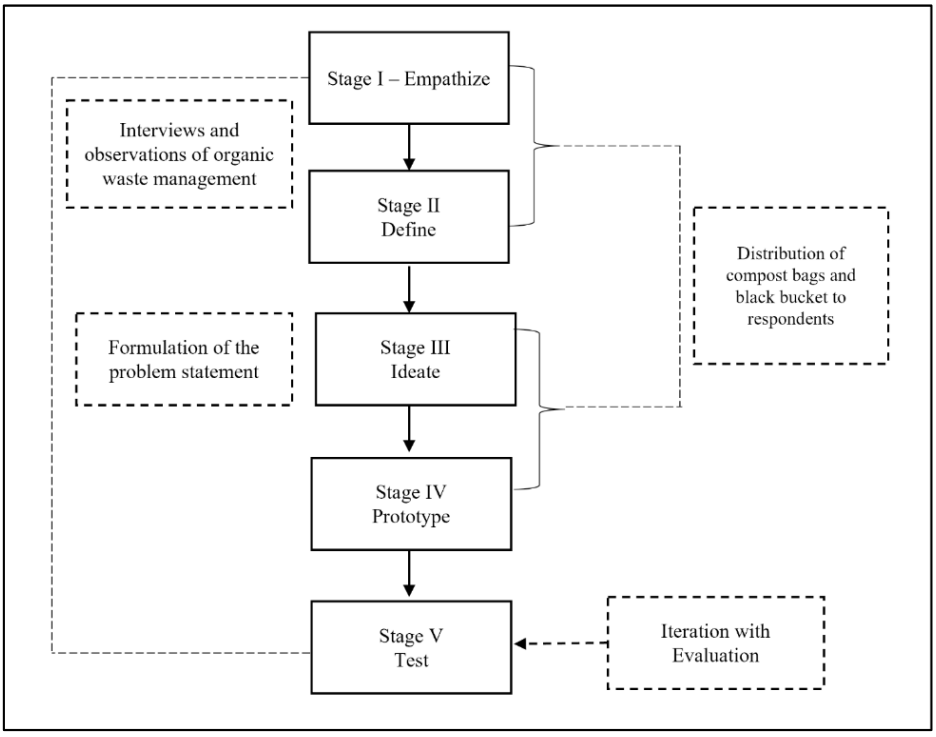

Figure 3. The five stages of the Design Thinking process applied in this study (Empathize, Define, Ideate, Prototype, and Test), showing the iterative participatory process with household respondents.

All stages were carried out participatively by involving 30 respondents from three active Waste Banks in Cirebon City, namely Harjamukti Waste Bank, Lemahwungkuk Waste Bank, and Kesambi Waste Bank, with 10 respondents from each location (Figure 3). The participatory approach in this study not only emphasized community involvement in designing solutions but also ensured that the research was conducted in accordance with academic ethical standards, taking into account the rights, comfort, and confidentiality of participants, with approval from the Gadjah Mada University Research Ethics Committee (Approval Number: KE/UGM/160/EC/2025).

The Empathize stage was conducted through direct observation (shadowing) and in-depth interviews to understand the respondents' interactions with organic waste in their households. The researchers traced the flow of organic waste from the moment it was produced in the kitchen to its disposal at the final disposal site, in order to identify the needs, obstacles (pain points), and habits of the community. The interview results showed that most respondents stored organic waste in plastic bags in the kitchen area, and once full, the waste was disposed of along with other waste without any prior processing. This practice caused various problems, such as unpleasant odors, leachate leaking from plastic bags, and the presence of flies and maggots that disturbed household comfort.

This was followed by the Define stage, which aimed to formulate the main problem statement. The community needs a closed, hygienic, odorless, and easy-to-use organic waste management system that does not add to the workload of households and allows organic waste to be reused as compost. Thus, the problem statement focused on the need for a practical, hygienic, and productive household organic waste management solution. Based on the problem formulation results, the participants and researchers developed a solution sketch. The most promising idea was a two-container system, namely:

1. A black bucket with a lid used as a temporary container in the kitchen,
2. A compost bag used as the main container for the composting process.

Next is the prototype stage, during which researchers provide two containers to each respondent and gave instructions on how to use them. The aim was to test the practicality, cleanliness, and comfort of use in the context of daily household activities. At the prototype stage, the solution design was further developed through the application of a layer system within the compost bag. This system was designed to support mize the decomposition process while minimizing odors, leachate, and maggot growth. This approach aligns with the findings of Jihad and Arif (2024), who developed aerobic composters based on a layered recycled material system that can stabilizes moisture and reduce ammonia emissions during the composting process.

Research by Tumanggor et al. (2024) also shows that a simple compost bag method with standardized guidelines effectively improves community skills and participation in independent organic waste management. In this study, the bottom layer of the composter was first filled with dry materials such as sawdust, raw rice husks, or charred rice husk with a thickness of approximately 10 cm. This initial layer serves as a leachate absorption pad, aeration support, and a source of carbon-rich material, thereby helping to balance the C/N ratio of the compost mixture. Kitchen organic waste was then added on top of the base layer, and was covered again with a thin layer of dry material. This layering pattern was repeated gradually according to the volume of organic waste produced, so that each input of wet waste was always "trapped" between layers of dry material. Afla et al. (2023) explain that the success of household composting is influenced by the balance between carbon-rich materials (such as husks and sawdust) and nitrogen-rich materials (food scraps), which helps maintain microbial activity and compost temperature stability.

Compost bags have covers. In this study, the covers were not kept tightly closed, but left slightly open, with approximately 20% airflow to maintain oxygen supply and sustain the aerobic decomposition process. This ventilation arrangement was intended to keep the internal temperature of the composter within a warm range, thereby supporting the activity of decomposing microorganisms and suppressing maggot growth. Aeration through ventilation can maintain aerobic conditions in the composter, thereby increasing the optimal internal temperature for aerobic microbes and reducing the chance of unwanted vectors such as insect larvae, from developing (Amrul et al., 2022). Thus, the layer system method in compost bags not only improves the quality of the composting process but also forms part of a biological control strategy against maggots and other vector pests in household organic waste management.

The next stage is the testing stage, where field trials are conducted through iterative cycles.

Participants (respondents) are asked to provide feedback on the system's effectiveness, odor control capabilities, ease of use, and compost quality. This input is used to refine the system design and evaluate its potential for wider application through the Waste Bank, allowing this iterative process to enable researchers and the community to make continuous adjustments to the system design, resulting in a waste management model that is not only functional but also contextually appropriate to local needs. This approach is in line with the findings of Ermayendri et al. (2025) on the concept of participatory collaboration as a crucial component in developing adaptive solutions where participant feedback becomes part of a continuous improvement strategy in urban waste management.

3. RESULTS

3.1 Socio demographic characteristics and existing conditions of organic waste management

3.1.1 Socio demographic profile of respondents

Understanding socio-demographic characteristics is crucial for explaining organic waste management behavior at the household level.

Based on a survey of 300 respondents in Cirebon City, Table 4 shows that the majority of respondents were women (60.3%), were of productive age (36-55 years, 45.7%), with the dominant occupations being office workers/teachers (37.7%) and housewives (21.3%). Most had an income below IDR 2.5 million (54.3%) and consisted of small to medium-sized families (1-6 household members, 97%).

Table 4. Socio-demographic characteristics of respondents

Demographic background		Frequency	Percentage (%)
Gender	Male	119	39.67
	Female	181	60.33
Age	15-25	60	20.00
	26-35	50	16.67
	36-45	68	22.67
	46-55	69	23.00
	56-65	45	15
	66-75	8	2.67
Occupation	Housewife	64	21.33
	Other	46	15.33
	Merchant	39	13.00
	Farmers	3	1.00
	Office worker/teacher	113	37.67
	Students	35	11.67
Income	>1.5 million	103	34.33
	1.5 million - 2.5 million	60	20.00
	2.5 million - 3.5 million	45	15
	3.5 million - 4.5 million	40	13.33
	> 4.5 million	52	17.33
Number of family members	1-3 people	136	45.33
	4-6 people	155	51.67
	7-9 people	8	2.67
	> 10 people	1	0.33

3.1.2 Gender dimension and role of women in waste management

A total of 60.3% of respondents were women, while 39.7% were men. Female respondents were predominantly involved in household-level organic waste activities, particularly sorting, collecting, and processing organic waste into compost, whereas male participation was more limited and primarily indirect.

3.1.3 Influence of age and household lifecycle

Based on the survey results in Cirebon City (Table 4), the majority of respondents were in the productive age group (36-55 years). In this study, respondents within this age range showed higher levels of awareness and willingness to participate in household organic waste management compared to younger respondents. This finding is consistent with previous studies (Tarigan et al., 2020), which report a positive association between age, environmental

awareness, and participation in waste management activities.

In contrast, younger respondents (15-25 years, 20% of the sample) tended to report lower engagement in waste management practices, which may be related to lifestyle patterns and weaker attachment to household management responsibilities. These findings highlight the importance of intergenerational education strategies, particularly through schools and universities, to foster circular economy behavior from an early age.

3.1.4 Occupational and income factors

Occupation and income levels have direct implications for waste management behavior. Office workers and teachers (37.7%) have high environmental knowledge, but time constraints may reduce their level of active involvement. Meanwhile, housewives (21.3%) play a major role in waste sorting at home. Low income (<Rp2.5 million, 54.3%) face challenges in participation due to limited financial resources and waste management facilities (Rois et al., 2020). However, within a circular economy context, low-income groups may have high participation potential if supported by appropriate incentive mechanisms and infrastructure (Gunamantha et al., 2023). This is supported by empirical research demonstrating that economic motivation particularly financial saving motives plays an important role in encouraging household behaviors related to waste reduction and resource utilization (Begho and Zhao, 2023).

3.1.5 Household size and waste generation

The majority of households (51.7%) have 4-6 family members, which implies a higher volume of organic waste generation. As household size increases, the amount of waste generated also rises, making greater collaboration among household members essential for implementing a circular economy-based waste management system. A study in Jakarta shows that household size is a significant variable influencing sorting behavior and organic waste processing (Pravitasari, 2025).

3.1.6 Current conditions of organic waste management in cirebon

Organic waste management in Cirebon City remains inadequate and requires significant improvement. Most of the organic waste produced by the community is still disposed of directly in landfills without proper separation or treatment processes at the household level.

Based on a survey of 300 respondents in Cirebon City, organic waste management patterns are still traditional as shown in Figure 4. Figure 4 presents baseline household waste management practices in Cirebon City based on Indicators 1-3, which capture disposal habits, waste separation behavior, and the intensity of organic waste generation prior to behavioral intervention analysis. Most of the community (82%) still relies on a collect and dispose system. Only 21% of respondents always sort organic waste, while 49% never sort it. This pattern shows that organic waste management in Cirebon is still linear and has not yet implemented the principles of reduce, reuse, recycle (3R) to become circular. This condition is similar to the findings of (Ikhlayel, 2018), which states that many developing cities still focus on end-of-pipe systems (collection and disposal to landfills) rather than source processing. Recent research also shows low levels of community participation due to limited sorting facilities and low social motivation (Wijayanti et al., 2023). The lack of facilities such as composters, waste bank infrastructure, and incentive systems has made the community reluctant to participate actively. The results confirm that community participation will increase if there is support in the form of facilities, economic incentives, and clear policies (Viva et al., 2020).

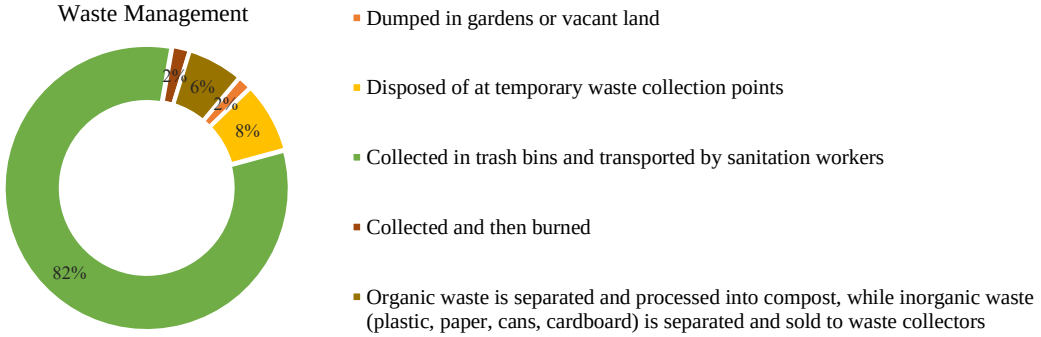

Figure 4. Household waste management practices in Cirebon City, Indonesia based on a survey of 300 respondents.

The results of a survey of 300 respondents in Cirebon City related to organic waste sorting practices are presented in Table 5. Nearly half of respondents (49%) reported that they never sort organic waste, while 30% indicated that they sort waste occasionally. Only 21% of respondents consistently separate organic waste at the household level.

Table 5. Organic waste sorting data

Response category	Percentage (%)	Interpretation	Implications for organic waste management conditions
Yes (always sorts)	21	Only a small portion of the community consistently separates organic waste.	Active participation is still low, indicating limitations in sorting at source.
Sometimes sorting	30	Some people sort waste but not regularly; it is more situational.	Awareness exists, but the behavior has not yet become a habit; a sustained approach is needed.
Do not sort	49	Nearly half of respondents never sort organic waste.	This indicates the weakness of the existing conditions, so that management still depends on the collect-transport-dispose system to landfills.

As shown in Table 5, although some respondents are aware of the importance of separating organic waste, the practice has not yet become a habit. This data shows that although some people are aware of the importance of separating organic waste, the practice has not yet become a habit. As a result, organic waste management is hampered, and the implementation of the program in the field has not been running as it should. Figure 5 shows that most respondents exhibit high levels of awareness regarding organic waste management, with the "very strong" and "strong" categories dominating the distribution. In contrast, fewer respondents fall into the "weak" and "very weak" categories, indicating generally favorable knowledge and understanding among the surveyed population.

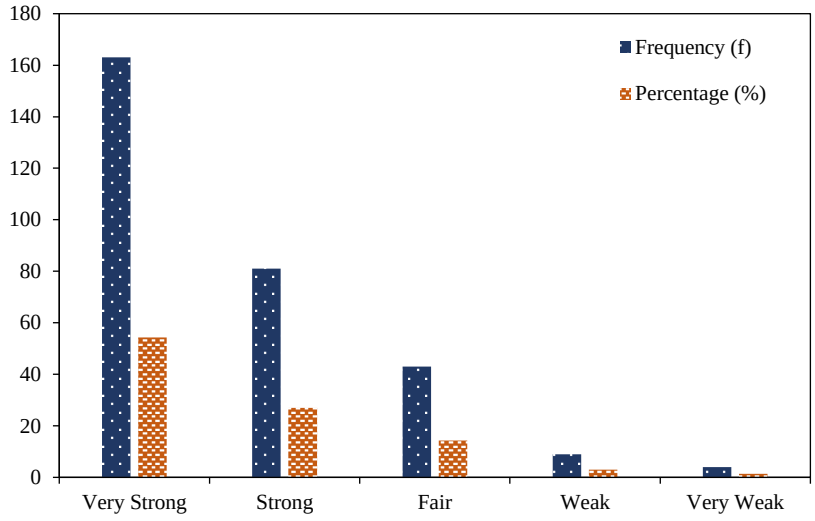

Figure 5. Average levels of respondents' awareness and understanding of household organic waste management

The graph in Figure 5 shows that the level of public awareness and understanding of organic waste management is high. Most respondents (around 58%) fall into the very strong awareness category, followed by 26% in the strong category, 11% in the moderate category, and only a small portion (around 5%) in the weak and very weak categories. These results indicate that most people understand the importance of organic waste management for the environment, especially in the context of reducing household waste volume and supporting the potential implementation for a circular economy.

3.1.7 Challenges in implementing circular economy-based waste management

The biggest challenges in implementing a circular economy-based organic waste management system in Cirebon City include three main aspects:

a) Limited infrastructure

The absence of processing facilities such as household composters, separate organic waste collection points, and incentive facilities remains a major obstacle.

b) Socio-cultural aspects

The community's mindset, which still views waste as a burden rather than a valuable resource, slows down the adoption of a circular economy system.

c) Policy and governance

The absence of specific regulations that encourage waste valorization and provide economic incentives hinders implementation in the field.

d) This situation is in line with research findings in various Indonesian cities that point to weak governance, poor inter-agency coordination, and a lack of technological innovation as the main causes of low effectiveness in waste management (Listiningrum, 2023).

3.2 Results of Spearman's Correlation analysis

Spearman's rank correlation analysis was used to measure the relationship between indicators of community behavior in organic waste management in Cirebon City. This test was chosen because the data obtained were on a Likert scale. As shown in Table 6, several indicator pairs exhibit positive and statistically significant correlations at the 99% confidence level ($p<0.01$). The strongest relationship was observed between awareness and understanding (Indicator 4) and willingness to participate (Indicator 7) ($\rho=0.500$), indicating that higher public awareness is associated with greater community participation in household organic waste management.

Table 6. Spearman's rank correlation analysis

	Indicator 4: Awareness (knowledge and understanding)	Indicator 5: Participation (actual action)	Indicator 6: Challenges in waste management	Indicator 7: Organic waste composting	Indicator 8: Support for circular economy practices
Indicator 4: Awareness (knowledge and understanding)	—	0.335	0.258	0.500	0.395
Indicator 5: Participation (actual action)		—	0.209	0.287	0.215
Indicator 6: Challenges in waste management			—	0.255	0.332
Indicator 7: Organic waste composting				—	0.451**
Indicator 8: Support for circular economy practices					—

**Correlation is significant at the 0.01 level (two-tailed)

Spearman's rank correlation analysis was conducted using Indicators 4-8 to examine relationships among the main behavioral constructs. As shown in Table 6, several indicator pairs exhibit positive and statistically significant correlations at the 99% confidence level ($p<0.01$). The strongest relationship was observed between awareness and understanding (Indicator 4) and willingness to participate (Indicator 7) ($\rho=0.500$; $p<0.01$), indicating a strong association between public awareness and community participation in household organic waste management. This suggests that direct experience in waste management plays an important role in shaping awareness of the circular economy (Gunamantha et al., 2023). This relationship is further illustrated in Figure 6, which shows a positive trend between awareness and understanding scores and willingness to participate.

As shown in Figure 6, awareness and understanding are positively associated with willingness to participate in household organic waste management. The scatter plot indicates an upward trend, which is supported by a significant Spearman correlation ($\rho=0.395$; $p<0.01$). Overall, these results indicate that all components of behavior; awareness, attitude, practice, participation, and economic perception have mutually supportive relationships and form an integrated behavioral system. This aligns with the findings of Utomo et al. 2021 which state that the success of household waste management is significantly influenced by a combination of cognitive factors (knowledge and awareness), affective factors

(attitudes and motivation), and instrumental factors (participation and perceived benefits). Thus, the results of this correlation test reinforce that circular economy-based organic waste management at the household level requires a multidimensional approach that integrates environmental education, social support, and community economic empowerment.

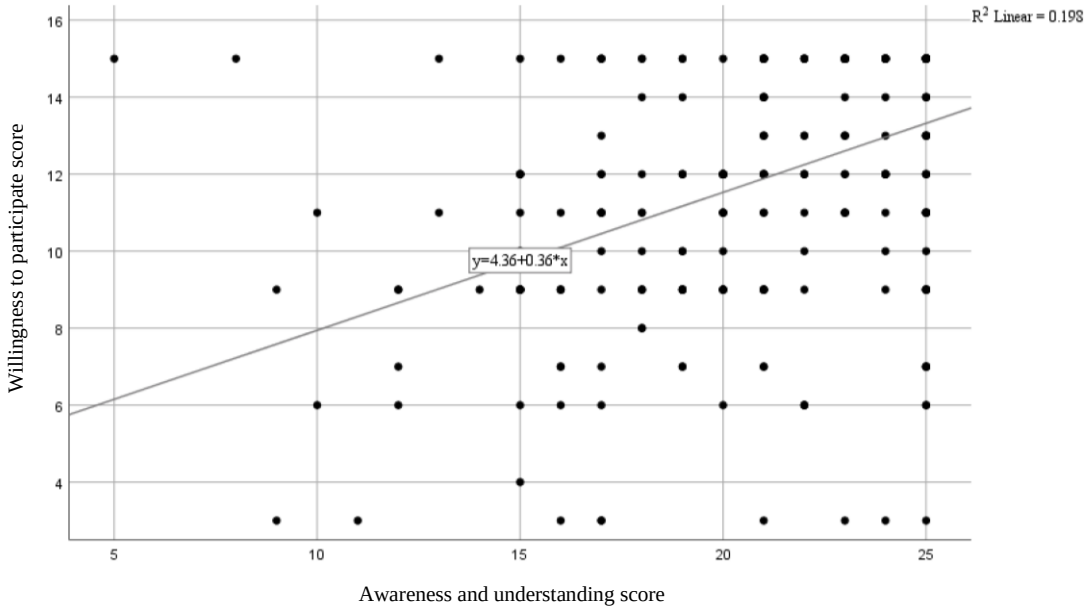

Figure 6. Relationship between awareness and willingness to participate in household organic waste management (Spearman's correlation).

3.3 Integration with the design thinking approach

The quantitative results formed the basis for the DT stages applied to 30 respondents across three Waste Bank locations. Based on the survey results, the two aspects with the highest scores (awareness and participation) were used as social capital, while the two aspects with low scores (attitudes and economic perceptions) became the focus of design interventions. The five behavioral indicators were mapped onto the five main stages of DT presented in Table 7.

After a series of DT sessions, the next step was to analyze the challenges in using the prototype as a basis for further iteration through participatory collaborative process sessions. This process is important because the initial prototype is evaluated not only from a technical functionality perspective, but also from the end-user's perspective, to ensuring that the developed solution is aligned with the needs and local context of the community (Leal Filho et al., 2024). In the literature on design-based innovation methodologies, an iterative approach that actively involves participants in participatory workshops enables researchers and stakeholders to re-evaluate initial assumptions, identify operational obstacles, and generate design improvements based n users' real experiences (Denecke et al., 2025).

The ongoing participatory and collaborative process have been recognized as an important practice in DT to support the development of relevant and sustainable solutions, as participants not only provide feedback but also actively contribute to refining prototypes based on their own socio-environmental context. Through this approach, prototype iterations become more meaningful because each design revision is informed by empirical insights gained from participant involvement in activities that reflect their daily routines. This method aligns with DT principles that emphasize solution development through direct user involvement, the exploration of real needs, and continious iterative feedback to strengthen the relevance of solutions to the problems faced by the community (Hoolohan and Browne, 2020).

Furthermore, this collaborative workshop process not only produces technically improved designs but also strengthens the community's shared understanding, attitudes and behavior towards organic waste management. This is important in the context of the transition to a circular economy, as changes in community behavior are a determining factor in the successful adoption of new practices (Barile and Kelestyn, 2023). Thus, participatory feedback-based iterations ensure that prototypes are not only tested as

research objects but also co- developed together with the community, so that the final solution is more more adaptive, responsive, and potentially more likely to be accepted by the community in the long term.

Based on observations at three research sites, the main challenges in household organic waste management, as shown in Table 8, relate to container capacity, moisture control, and rodent infestation that can puncture composters. This analysis emphasizes the importance of empathy-based composter design, focusing on functional needs (aeration, moisture, and hygiene) and user experience (ease of use, cleanliness, and economic benefits).

Table 7. Design thinking process steps

Design thinking stages	Activity focus	Relevant behavioral indicators	Key outcomes
Empathize	Exploring empathy for respondents' experiences in producing organic waste from generation to disposal through in-depth interviews and observations at three Waste Bank locations.	Understanding and Awareness (Ind.4)	Most respondents store organic waste in plastic bags in the kitchen, then dispose of it together with inorganic waste without sorting or processing.
Define	Formulating problem statements based on pain points and insights to define the community's primary needs.	Attitude toward the Program (Ind.5)	Residents need a household organic waste management system that is: - is closed and hygienic, - does not cause odors, - is easy to operate, - does not increase the workload for households, - enables the reuse of organic waste as compost.
Ideate	Conducting co-creation workshops to generate various alternative solutions.	Willingness to Participate (Ind.7)	Agreed on a solution design in the form of a dual-container system consisting of: 1. A black bucket as a temporary storage container in the kitchen, and 2. A compost bag as the main container for the composting process.
Prototype	Designing and distributing waste management tools for testing.	Practical Application (Ind.6)	Respondents used compost bags at home for 2 months
Test	Evaluating the effectiveness of prototypes on residents' behavior and perceptions.	Perception of Economic Benefits (Ind.8)	Participation increased, perceptions of economic benefits rose by 23%, and waste sorting became a routine practice as people became accustomed to it.

Table 8. Challenges in organic waste sorting during the prototype stage

Aspect	Seruni Waste Bank (Jagasatru)	Carangka Runtah Waste Bank (Harjamukti)	Sukses waste bank (Karyamulya)	Thematic analysis and design insights
Initial management practices	Waste is initally collected in plastic bags before being transferred to bins.	Some residents directly put waste into buckets and add dry materials.	Many residents place organic waste directly into the composter without using a temporary bucket.	A flexible container design that matches the volume of household waste is needed to encourage source separation.
Main problem faced	Unpleasant odors caused by the accumulation of organic waste	Odors are relatively reduced by the addition of sawdust; however, leachate is still present.	High moisture levels and tightly closed containers lead to odor and maggot proliferation.	Adequate aeration and moisture control are critical factors for successful household composting.
Local adaptation efforts	Placing buckets in open areas to reduce odor.	Sawdust is used as a natural absorbent material to control moisture and odor.	Residents attempt to reduce impacts by drying waste before disposal or utilizing maggots as animal feed.	Existing local adaptation practices should be integrated into solution design to enhance effectiveness.
Key pain points	Limited bucket capacity and poor hygiene conditions.	Leakage continues to occur despite the use of dry materials.	Composters fill up quickly, with many maggots.	Households require closed organic waste management containers to improve hygiene and comfort.

Table 8. Challenges in organic waste sorting during the prototype stage (cont.)

Aspect	Seruni Waste Bank (Jagasatru)	Carangka Runtah Waste Bank (Harjamukti)	Sukses waste bank (Karyamulya)	Thematic analysis and design insights
User priority needs	Need for a large-capacity, odor-resistant container that is easy to clean.	Need for a container with controlled air ventilation and a simple drainage system.	Need for a compost bin that allows waste compaction and controlled aeration.	Applying a user-centered design principle, the system must control odor, leachate, and maggots without increasing household workload.

Field test results, as presented in Table 9, show that the type of dry material (carbon source) has a significant effect on the effectiveness of the household composting process. Of the three materials tested, sawdust, charred rice husk, and raw rice husks, sawdust showed the best performance in maintaining the stability of the biological process and the quality of the final compost. The sawdust composter maintained an optimal temperature of 38-42°C during the thermophilic stage, stable moisture conditions, and produced dark brown compost with a neutral earthy odor in six weeks. This indicates that sawdust has an ideal C/N ratio and porosity, thereby supporting aerobic microbial activity and accelerating decomposition (Kaur et al., 2019) .

On the other hand, charred rice husk, although effective in reducing odor and leachate, has a disadvantage in terms of water absorption. The composting process runs more slowly because moisture quickly falls below the ideal threshold, requiring the addition of water or fresh organic material to maintain microbial activity (Bhatia et al., 2013). Meanwhile, raw rice husks provide good aeration but are unable to absorb excess moisture. These conditions cause leachate formation, odor, and high maggot populations, especially in the third to fourth week of observation. Although some residents use maggots as animal feed, these conditions indicate an imbalance in the aerobic decomposition process that can inhibit compost maturity.

Table 9. Field findings: User needs and behavioral barriers in compost bag utilization

Location/Waste Bank	Habits and challenges in bucket use (Pre-compost)	Challenges and needs in compost bag use (Composting Stage)	Design insights and initial recommendations
Seruni (Jagasatru)	The majority of respondents store organic waste in plastic bags before transferring it to buckets. Main complaints: odor, leachate, and concerns about rats.	Some composters experience leaks due to rat bites and strong-smelling leachate. Respondents complain about wet conditions and maggot infestations.	Composters need good ventilation, stronger materials to resist rodents, and a leachate control system. Simple technical training is needed to maintain the dry-to-wet ratio.
Carangka Runtah (Harjamukti)	Most respondents added sawdust to the bucket to reduce odor and moisture. Some still delayed waste transfer.	Most users are satisfied and do not experience strong odors. A minor challenge is slow waste addition due to small volumes.	The use of dry materials is effective; it can be used as a best practice model. A medium-capacity composter is needed to accommodate the volume of household waste.
Success (Karyamulya)	Many respondents do not use buckets due to their small capacity; they prefer large plastic containers. Some use them for inorganic waste.	Main issues: odor, maggots emerging during the rainy season, and the composter filling up quickly. Some residents use the maggots as animal feed.	The composter design needs a cross-ventilation system and humidity control, as well as an automatic leachate removal mechanism. There is a need for socialization of the frequency of filling and periodic maintenance.

In general, these results confirm that the physical characteristics of dry materials determine the efficiency of household composting systems, especially in terms of aeration, moisture, and odor control. From a Design Thinking perspective, these findings form the basis of the Define and Ideate stages, namely design of household composters with cross-ventilation systems, automatic moisture control, and capacities tailored to the needs of urban households. This approach is in line with the principles of human-centered design in environmental management, where technical solutions must consider user behavior, comfort, and ease of

maintenance (Kim et al., 2021). The integration of field results with a participatory design approach shows that the community's direct experience in using composters can increase engagement, environmental awareness, and the perceived economic benefits of circular economy practices.

4. DISCUSSION

4.1 Behavioral interpretation of household waste management practices

As shown in Table 4, household organic waste management in Cirebon City is strongly influenced by gender roles and daily domestic responsibilities. The predominance of women respondents reflects their central role in sorting, collecting, and processing organic waste at the household level. This finding is consistent with evidence from developing countries showing that women can play a central role in community-based waste management and that their empowerment and active participation can contribute to broader improvements in waste management systems (Estrada et al., 2023). However, the lower participation of men suggests the need for more inclusive, gender-sensitive community engagement strategies. In this context, Waste Bank programs can strengthen women's roles as agents of change while encouraging greater male participation through targeted community-based interventions.

4.2 Awareness participation gap and theory of planned behavior

Despite relatively high levels of awareness regarding the importance of organic waste management, actual household participation remains limited. This awareness-participation gap indicates that knowledge alone is insufficient to drive behavioral change. According to the Theory of Planned Behavior (TPB), behavior is influenced not only by attitudes, but also by subjective norms and perceived behavioral control.

In this study, although respondents generally showed positive attitudes toward organic waste management, participation was constrained by weak social norms and limited perceived control. The lack of sorting facilities, composting infrastructure, and clear incentives reduced households' confidence in their ability to manage organic waste effectively. The application of Design Thinking (DT) helped address these barriers by enhancing perceived behavioral control through user-centered composting solutions and participatory co-design processes. By involving households directly in problem identification, solution design, and prototype testing, the intervention strengthened both individual agency and collective norms, demonstrating the potential of Design Thinking to bridge the gap between awareness and sustained participation in household-level circular economy practices.

4.3 Design thinking as a participatory intervention tool

In this study, Design Thinking functioned not only as a problem-solving framework but as a participatory intervention tool that facilitated behavioral change in household organic waste management. By emphasizing empathy, collaboration, and iterative learning, the Design Thinking process enabled households to identify barriers, co-create solutions, and test practical interventions within their daily routines. This participatory approach strengthened perceived behavioral control by allowing households to develop composting solutions aligned with their capacities, space constraints, and time availability, thereby reducing psychological and practical barriers to participation. Collective activities during the Design Thinking stages also fostered shared norms and peer learning, reinforcing pro-environmental behavior at the community level.

4.4 Implications for circular economy implementation

The findings of this study highlight important implications for the implementation of the circular economy at the household and community levels. While circular economy policies often emphasize technological and infrastructure-based solutions, this study demonstrates that behavioral and social dimensions are equally critical. The persistence of linear waste management practices, despite relatively high awareness, indicates that circular economy implementation cannot rely solely on information provision or technical interventions. By integrating Design Thinking as a participatory intervention, this study shows how circular economy principles can be operationalized through user-centered solutions that align with local capacities, routines, and social contexts.

At the community level, the involvement of Waste Banks as participatory platforms and catalysts for circular economy practices. Beyond waste collection, Waste Banks can function as spaces for learning, co-design, and experimentation, enabling

households to actively engage in resource recovery. This decentralized and inclusive approach is particularly relevant for medium-sized cities in developing countries withlimited institutional capacity and infrastructure.

4.5 Policy and practical implications

The findings of this study suggest several policy and practical implications for strengthening household based organic waste management within a circular economy framework. At the policy level, local governments should move beyond infrastructure-centered approaches and integrate participatory and behavior-oriented strategies into waste management programs. Embedding Design Thinking within community-based initiatives, such as Waste Bank programs, can enhance public engagement by aligning interventions with household capacities, routines, and social contexts.

From a practical perspective, Waste Banks can be repositioned as platforms for learning and co-creation rather than solely as waste collection facilities. Facilitating co-design activities, hands-on composting demonstrations, and prototype testing can help households build skills and confidence, thereby increasing sustained participation. The use of simple, low-cost, and locally available materials can further reduce technical and financial barriers. In addition, gender-sensitive and inclusive engagement strategies are essential to strengthen social norms and collective responsibility. Overall, the proposed approach offers a scalable and context-sensitive model that can be adapted by other medium-sized cities transitioning from linear waste management systems toward a circular economy.

5. CONCLUSION

This study demonstrates that integrating Design Thinking into household organic waste management effectively supports behavioral change and facilitates the implementation of circular economy principles at the local level. The participatory and user centered approach successfully transformed environmental awareness into concrete action, increased community participation, and improved perceptions of the economic benefits of organic waste management. Field testing confirmed that simple, locally available materials, particularly sawdust enhanced household composting performance. This study contributes by positioning Design Thinking as both a behavioral assessment and participatory intervention tool in household-level circular economy implementation. However, the research is limited to a single urban context and a relatively short intervention period. Future studies should expand the analysis to multiple cities and adopt longitudinal designs to assess long term behavioral change and explore the integration of smart composting systems.

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AUTHOR CONTRIBUTIONS

Experimental run, data Collection, Writing-original draft: Zakiyah Amini; supervision, Conceptualization, methodology, investigation, data curation: Lilik Sutiarso; Supervision, formal analysis, visualization: Ngadisih; Supervision, validation, data curation: Chandra Setyawan; Consultation on environmental aspects: Latifah Abd Manaf; Supervision, project administration: Joko Nugroho Wahyu Karyadi; Supervision Writing, review and editing: Dwi Purnomo.

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

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