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Research Article

Design Thinking Approach in Handling Organic Waste in Residental Areas of Semarang City

[1]Ardiaz Ajie Aryandika, [2]Dhena Kamalia Fu'adi, [3]Afanda Ahmad Dzaki
[1,3]Department of Management, Faculty of Economics and Business, Diponegoro University, Semarang, Indonesia.
[2]Department of Informatics, Faculty of Science and Mathematics, Diponegoro University, Semarang, Indonesia.

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Abstract: *Organic waste constitutes over 60% of daily waste generated in Semarang City, posing significant environmental and health challenges due to improper management. Despite policy interventions and waste reduction initiatives, efforts to control organic waste remain insufficient, particularly in residential areas. This journal article aims to explore a human-centered approach, utilizing the design thinking framework to enhance organic waste management strategies. Employing a qualitative case study method, the research integrates three stages of design thinking—Empathize, Define, and Ideate—to understand community behaviors, redefine key problems, and generate practical solutions. Data were collected through interviews and secondary sources, including the National Waste Management Information System (SIPSN), to focus on the trends and composition of organic waste from 2019 to 2024. Findings reveal a lack of public awareness and inadequate government communication as major barriers to effective waste handling. The study proposes innovative solutions, including the empowerment of waste banks, utilization of Black Soldier Fly (BSF) maggot technology, and the production of eco-enzymes at the village level. These strategies promote decentralized waste processing, enhance community participation, and generate economic value from waste materials. The results underscore the importance of collaborative efforts and adaptive policies that align with community needs to achieve sustainable waste management in urban areas. The application of design thinking in this context demonstrates its effectiveness in producing socially acceptable and implementable solutions for waste management.*

Keywords: *Design Thinking, Organic Waste, Semarang City, Sustainability, Waste Management.*

I. INTRODUCTION

Waste management remains a significant challenge in Indonesia, with a total annual waste generation reaching approximately 16.32 million tons. Of this amount, only 76.96% is managed, leaving 23.04% unhandled [1]. The primary sources of this waste include households (44.3%), traditional markets (23.6%), and industrial zones (10.1%) [1]. This situation highlights the need for systemic improvements in waste management across both urban and rural regions of the country.

In the city of Semarang, Central Java, the issue is particularly pressing. The city produces approximately 1,270–1,388 tons of waste per day [2], with estimates from 2020 indicating around 1,200 tons per day for a population of 1.68 million [3]. Alarmingly, over 60% of this waste is organic [3], [4], [5], originating mainly from households, traditional markets, schools, and public facilities [6]. The Jatibarang landfill, Semarang's sole final disposal site, is nearing capacity and is projected to be overloaded within the next ten years if current waste accumulation continues unchecked [3]. Although the city's waste management system has achieved 71.34% effectiveness as of 2024, ranking Semarang 122nd out of 962 cities and regencies nationwide, this progress remains insufficient [7]. Policies such as Perda Kota Semarang No. 27/2019 have improved plastic waste control [3], and initiatives like waste banks and paid plastic bags are in place. However, studies indicate these efforts are not yet adequate to significantly reduce the volume of waste transported to the landfill [1].

Proper waste management, particularly for organic waste, plays a pivotal role in maintaining environmental and public health. One major benefit is the prevention of natural disasters, such as urban flooding, which often results from unmanaged waste obstructing drainage systems [8]. Additionally, recycling organic waste significantly contributes to reducing pollution in air, water, and land. It curtails odor problems and greenhouse gas emissions while simultaneously promoting sustainability, zero-waste initiatives, and the bio-based circular economy [9]. The transformation of organic waste into bio-fertilizers not only reduces landfill burdens but also enhances soil quality and supports agricultural productivity, presenting a dual environmental and economic benefit [9].

Conversely, improper handling of organic waste leads to a multitude of environmental hazards. In developing countries, organic waste is often disposed of in open dumps or poorly managed landfills, where it decomposes anaerobically, releasing methane—a potent greenhouse gas that accelerates global warming [9]. Moreover, poor composting practices can lead to the

release of volatile organic compounds, the proliferation of harmful microorganisms, and the contamination of soil and water sources due to chemical residues and leachates. Given the high water content (around 70%) of organic waste and its potential for cross-contamination with heavy metals, improper separation can significantly exacerbate health and environmental risks. Additionally, centralized waste management systems may impose high operational and logistical costs, prompting a shift toward more decentralized, community-supported waste strategies [10].

Given the increasing volume of organic waste and the challenges in its proper management, it is crucial to adopt an approach that not only addresses technical aspects but also considers the behaviors, needs, and limitations of those involved in the waste generation and handling process. Conventional approaches often overlook these human-centered factors, leading to ineffective implementation and low community participation.

Design thinking presents a viable alternative by emphasizing empathy and a deep understanding of users as the foundation of problem-solving. Through its five iterative stages—Empathize, Define, Ideate, Prototype, and Test—this approach enables stakeholders to co-develop solutions that are context-specific, creative, and practical. For organic waste management, design thinking can be used to uncover the root causes of poor waste handling practices, generate innovative educational tools, design user-friendly sorting systems, and test scalable initiatives that align with the habits and capacities of local communities. By aligning solutions with real user needs, design thinking helps ensure that waste management strategies are not only technically sound but also socially accepted and sustainably implemented [11].

II. LITERATURE REVIEW

A) Design Thinking Concept

The Stanford Design Thinking model outlines five key stages: Empathize, Define, Ideate, Prototype, and Test. The Empathize stage involves approaching the problem by deeply understanding users' needs from a human-centered perspective. This can be achieved through various methods, such as conducting interviews, observing student behaviors, and encouraging imaginative perspective-taking activities [12]. The Define stage focuses on analyzing and synthesizing the collected data to articulate the core problem and gain clarity on the needs to be addressed. This includes identifying who requires the solution, understanding their needs, and what insights have been gained [12], [13]. In the Ideate phase, potential solutions are generated based on the previously defined problems. A range of creative techniques, such as mind mapping, diagramming, and visual storytelling, can be employed to explore alternative solutions. At this stage, materials needed to construct prototypes are also prepared [12], [13]. The Prototype phase entails the tangible development of ideas into forms such as models, detailed diagrams, or illustrations that represent potential solutions [12], [13]. Finally, the Test phase involves demonstrating the prototype to users—in this case, students—and collecting their feedback. This feedback may lead to iterative refinements or redevelopment of the prototype until the desired outcome is achieved [12], [13]).

Design thinking offers a structured, human-centered approach to solving environmental issues, including organic waste management. In the case of PT Atim and Wanti Saiyo Jaya, a catering business in West Java, the five stages of design thinking—Empathize, Define, Ideate, Prototype, and Test—were applied to address food waste problems. The Empathize phase involved gathering insights through interviews and observations, revealing food waste as the dominant and poorly managed waste type. In the Define phase, the core problem was clarified: the lack of waste handling policies and staff awareness. The Ideate stage generated key solutions such as employee training, waste cycle planning, and partnerships with local animal feed producers. Although limited by time, the Prototype and Test phases highlighted the practicality of these ideas. Overall, design thinking proved to be a valuable tool in creating actionable and sustainable waste management strategies [11].

B) Organic Waste Management

Various approaches have been employed to manage organic waste, combining regulatory frameworks, community engagement, and technological innovation. First, regulation plays a significant role in structuring waste management systems. For instance, Semarang City enforces waste regulation through Perda Kota Semarang No. 6 of 2012 concerning Waste Management and Perwalkot No. 27 of 2019 on the Control of Plastic Waste Use [3]. In addition to legal frameworks, education, and awareness programs, including counseling, discussion sessions, and direct guidance, have been conducted to enhance public knowledge and behavior regarding proper waste handling. Practical waste management processes include sorting, storage, collection, transportation, and treatment of waste materials [6].

Furthermore, technological innovations have shown great potential in enhancing organic waste processing. The hydrothermal method, for example, is a promising technology capable of converting organic waste into environmentally friendly and economically valuable products such as compost, which can support entrepreneurship activities [14]. Another innovation is the Dry Leaves Cremation Processor (DLCP), an eco-friendly incinerator specifically designed to process organic waste. The system incorporates a smoke containment and filtration mechanism that utilizes sand filters to reduce emissions, and the resulting ash is repurposed as a component in organic bio-compost fertilizers [14].

In response to the increasing generation of waste and the need for sustainable waste management practices, Semarang City has implemented structured waste management policies. A key initiative includes the formulation of a Standard Operating Procedure (SOP) for waste handling, which serves as a practical guideline for waste management actors and enforcers. This Standard Operating Procedure (SOP) aligns with the legal mandates stated in Perda Kota Semarang No. 6 of 2012 and Perwalkot No. 27 of 2019, emphasizing both general waste control and specific measures to reduce the use of plastic materials [3]. These efforts demonstrate the city's commitment to integrating policy with practical implementation to address the challenges of urban organic waste management.

III. RESULTS AND DISCUSSION

A) Research Design

This research methodology employs a case study approach, enriched by integrating a design thinking framework during the data collection stage. The application of design thinking specifically prioritizes the exploration and utilization of innovative ideas through concentration on three fundamental phases: the empathy stage, which aims to build a deep understanding of the user's perspective and experience; the problem formulation stage, which focuses on redefining the challenge more sharply and relevantly based on empathy findings; and the ideation stage, which encourages the creation of diverse creative solutions. Essentially, design thinking seeks to foster an ecosystem that supports creativity and collaboration. This enables the research team to gain more comprehensive and nuanced insights into the root of the problem, the characteristics and unique needs of the audience (or customers/end-users), and the critical aspects that support the realization of sustainable development goals. Thus, combining case studies and design thinking collects data and stimulates human-centered and sustainable solutions.

B) Emphasize

The empathy stage in the Design Thinking framework is a crucial first step, where the primary focus is on understanding needs and problems. At this stage, researchers try to see the problem from the community's perspective, explore the challenges faced, and understand the social, emotional, and environmental contexts that influence the community's experience [15]. Interviews were conducted to obtain information about user desires and needs [16]. Research related to the amount of waste generated in Semarang City and Regency by utilizing data from the National Waste Management Information System (SIPSN) for 2019-2024. Based on the information obtained from this system, there is a trend of increasing amounts of waste generated yearly.

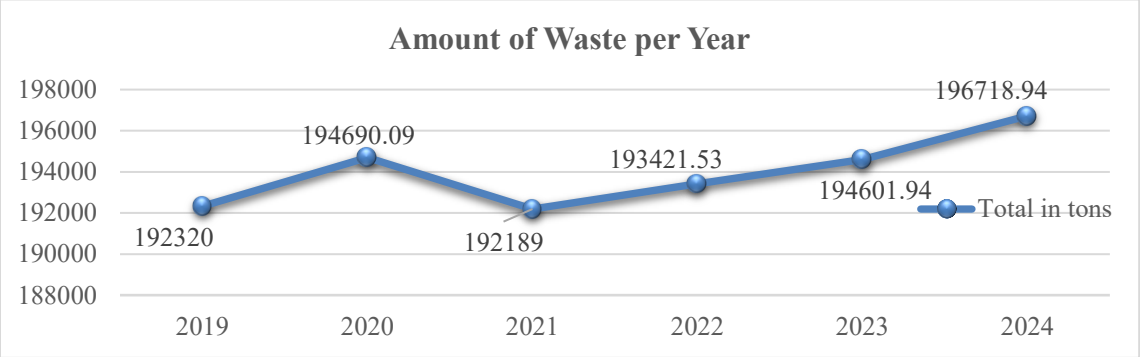

Figure 1 Amount of waste per year

Figure 1 shows that waste management is an increasingly urgent issue to be addressed, considering the volume of waste that continues to grow over time. The amount of waste generated annually continues to increase each year. The data collected provides an overview of the waste composition in the area, which is expected to be used as a basis for designing more effective and efficient waste management policies.

Table 1 Category of waste per year

Types of Waste	2019	2020	2021	2022	2023	2024
Leftovers	57,50	58,00	3,00	61,56	61,56	61,56
Wood-Twigs	4,00	5,00	9,00	1,58	11,58	11,58
Paperboard	7,10	8,90	23,00	4,25	4,25	4,25
Plastics	18,20	19,00	30,00	18,53	18,53	18,53
Metal	1,90	2,50	4,00	0,25	0,27	0,27
Cloth	2,20	3,20	4,00	0,21	0,18	0,18
Glass	1,20	2,30	5,00	0,37	0,38	0,38
Others	0,50	0,50	20,00	3,25	3,25	0

In Table 1, Food waste records the most significant amount each year based on the types of waste recorded in SIPSN. This amount is much greater than other types of waste; this shows the phenomenon in society in producing household waste, especially from food waste. Food waste, which is a type of organic waste, has various impacts on society. Organic waste has the potential to trigger greenhouse gas emissions from home composting caused by household organic waste. [17] In addition, various types of organic waste can affect the soil's physical, chemical, and biological properties, plant growth, and yield. [18] Improper management of organic waste can harm human health, for example, through the spread of disease vectors. [19]

Local governments in Indonesia, including those in Semarang City (Both the City and the Regency), have made various efforts to handle organic waste, the most significant component of household waste. These efforts usually include [20]

- Reducing Organic Waste from its source
- Household and communal-scale composting
- Utilization of Black Soldier Fly Larvae (BSF) / Maggots
- Development of Waste Banks
- Optimizing the Function of TPST (Integrated Waste Management Site) and TPA (Final Processing Site)

C) Define

The define stage is the second stage in the design thinking framework, which aims to formulate the problem clearly and structured based on the information collected in the first stage, namely empathize. At this stage, the primary focus is to analyze and clarify the data obtained and make decisions based on a deeper understanding of the users' needs and challenges. This process is convergent, meaning that diverse information will be filtered and focused on the core of the problem that needs to be solved. [20]

One of the techniques used at this stage is to ask critical questions to stakeholders or parties directly involved in the problem. This question aims to dig deeper into the needs, expectations, and limitations in the context of the issue. Thus, the defined stage allows researchers to gain clearer and more specific insights into the problems that need to be solved and to ensure that the understanding obtained at the empathize stage is relevant to the reality on the ground. Here, researchers can connect qualitative insights from the community with a more focused understanding of the problems that need to be solved, which will form the basis for the next steps. From the results of the community investigation, researchers found several important points related to awareness of organic waste management. One of them is that many people still do not understand how to manage organic waste, mainly because of the lack of information the government provides. This lack of education is a fundamental problem because people should have a proper understanding of the policies and procedures related to organic waste management. Sufficient knowledge is needed so that people can apply the proper steps for managing organic waste in their daily lives.

Table 2 Average Daily Waste

Year	Average Daily Waste Production (tons)
2019	526,90
2020	533,40
2021	526,55
2022	529,92
2023	533,16
2024	538,96

In addition, although organic waste management has great potential for widespread implementation, it requires strong support from local governments. Without the support of infrastructure, policies, and programs, effective organic waste management at the community level will be challenging to achieve. Local government support through clear regulations, outreach to the community, and provision of adequate facilities are key factors in the success of large-scale food waste management programs.

D) Ideate

The ideate stage is the third step in the design thinking process, which focuses on finding solutions to previously identified problems. At this stage, researchers aim to develop various creative ideas that address the challenges faced by the community. At the ideate stage, researchers think openly and generate as many ideas as possible without being limited by existing solutions or resource limitations. This aims to explore various possibilities that can be used as innovative solutions. In addition, the brainstorming session also examines the perspectives of multiple parties involved, ensuring that the resulting solutions are more comprehensive and relevant to the community's needs. After collecting various ideas, the next stage is to filter and select the most potential ideas to be tested further in developing more concrete solutions.

Table 3 Potential Ideas

No.	Solution	Target	Description
1.	Strengthening of TPS3R and Compost House	Sub-district level community	Independent sorting and processing of organic waste
2.	Empowerment of BSF Maggot Technology	Groups of livestock breeders, local farmers, and households	Processing organic waste into animal feed or liquid compost
3.	Capacity Building of Waste Banks and Community-Based Education	Waste bank managers and the community	Increasing the effectiveness of sorting and processing organic waste and increasing awareness and participation in waste management.

1. Utilization of compost and eco-enzyme at the village level

Eco-enzyme is a fermented liquid from organic materials such as fruit and vegetable waste mixed with sugar and water. This fermentation process is facilitated by natural microorganisms, such as bacteria, which convert organic compounds in these materials into simpler and more useful substances. One of the main benefits of Eco-enzyme is its ability to function as an effective natural cleaner. In addition to being used for cleaning, Eco-enzyme has other significant environmental benefits, namely its ability to reduce pollution. Many organic wastes that are not appropriately managed can pollute the environment, for example, by polluting soil and water. However, by processing organic waste into Eco-enzyme, the waste can be utilized as a helpful product, reducing the amount of waste that must be disposed of and preventing further pollution.

2. Empowerment of BSF Maggot Technology

Using Black Soldier Fly (BSF) maggots to process organic waste into animal feed or liquid compost is an innovative solution that can be applied in Semarang City/Regency. This process reduces the volume of organic waste and produces products with economic value that can be utilized, such as animal feed and liquid fertilizer. Utilization of BSF maggots to process organic waste provides many benefits, both for the environment and the economy:

- Reducing Waste Volume. Organic waste processed with BSF maggots experiences a significant reduction in volume, thereby helping to reduce the burden on landfills and minimize environmental pollution.
- Nutritious Animal Feed. BSF larvae are rich in protein, fat, and other essential nutrients beneficial for animal feed. This feed can reduce dependence on more expensive commercial animal feed.
- Liquid Compost for Agriculture. The process of processing waste by BSF maggots produces liquid compost rich in nutrients. This liquid fertilizer can increase soil fertility and support plant growth in a more environmentally friendly way.
- Reduction of Greenhouse Gas Emissions. Unmanaged organic waste produces methane gas, a greenhouse gas that contributes to climate change. Processing organic waste using black soldier fly (BSF) maggots can reduce methane gas emissions.

3. Capacity Building of Waste Banks

Increasing the capacity of waste banks in Semarang City is an important step in improving the waste management system at the local level. Waste banks function as a place for collecting, sorting, and processing waste, especially inorganic waste such as plastic, paper, glass, and metal, so that it can be recycled or reused. This capacity building aims to reduce the volume of waste disposed of in final disposal sites (TPA), provide economic and environmental benefits, and increase waste management efficiency in Semarang City. To increase the capacity of waste banks, it is necessary to strengthen the infrastructure, which includes:

- Improving Waste Bank Infrastructure by providing Separate Waste Bins, Waste Processing Facilities, and Waste Storage Places: Providing a place to store waste properly so that the processing process runs smoothly.
- Education and Training for the Community through Waste Sorting Socialization and Waste Bank Management Training.
- Cooperation with Collectors and Recycling Industries

IV. CONCLUSION

This research on organic waste management in Semarang City/Regency revealed that efforts to handle one of the most significant waste components have shown progress, although they still face substantial challenges. It was found that the volume of organic waste generated from domestic, commercial, and public facility activities in Semarang City/Regency continues to increase along with population growth and urban dynamics.

Various initiatives include optimizing the function of the Integrated Waste Management Site (TPST) based on community needs through the 3R program (Reduce, Reuse, Recycle), developing composting technology on both a communal and individual scale, and utilizing Black Soldier Fly (BSF) larvae. However, these programs will not be effective if the level of active community participation in sorting waste from its source is low, there are limited adequate supporting facilities and infrastructure, aspects of funding sustainability are not addressed, and the integration between related stakeholders from the local government level to the

minor units in society is not optimal. The analysis shows that the success of organic waste management in Semarang City/Regency is highly dependent on the synergy of various parties. The main challenge lies not only in the technical and infrastructure aspects but also in the socio-cultural aspects, namely, building awareness and sustainable responsibility at all levels of society.

Therefore, a comprehensive strategy is needed that is more structured, measurable, and adaptive to the unique characteristics of Semarang City/Regency to realize sustainable organic waste management and positively impact the environment and residents' quality of life.

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