



# Smart waste bin design with automatic waste sorting system, ergonomic, functional, aesthetic, and IoT-based integrated point system

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## ABSTRACT

**Background:** Creating trash bins that are comfortable to use and attractive, integrated, and capable of automatic waste separation is the answer to the waste problem that has become a major issue in Indonesia and even the world. The purpose of this study is to analyze and design smart and ergonomic trash bins. **Methods:** This study in Tanjung Redeb, Berau Regency, surveyed 184 trash bin users. Data were collected through observation, interviews, questionnaires, and literature review, validated with SPSS, and processed using the QFD method to design an integrated, user-friendly trash bin. **Findings:** The results obtained based on the interpretation of user requirement data show that users of trash bins want materials that are easy to clean with an improvement ratio of 1.25, have usage instructions with an improvement ratio of 1.0, are comfortable to use and practical with an improvement ratio of 1.0, have audio information with an improvement ratio of 1.0, use renewable and environmentally friendly energy with an improvement ratio of 1.25, flexible and lightweight with an improvement ratio of 1.0, discarded waste can be converted into points with an improvement ratio of 1.25, waste can be separated automatically with an improvement ratio of 1.0, integrated with waste management personnel (who know the volume of waste in real time with an improvement ratio of 1.0), and attractive trash bins ratio of 1.34. after collecting and reprocessing the data, the results show that smart trash bins are ergonomically designed, integrated with personnel and sorting systems to meet user satisfaction. **Conclusion:** Therefore, an ergonomic design for smart waste bins is needed based on the needs of waste bin users in Berau Regency. Unlike previous researchers who generally focused only on technological aspects and automatic selection. **Novelty/Originality of this article:** The originality of this research is also demonstrated through the development of a design that not only emphasizes technical functions but also aesthetic aspects, environmental sustainability, and increased community participation in sustainable waste management.

**KEYWORDS:** customer satisfaction; product design; packaging and quality function deployment (QFD).

## 1. Introduction

Every day, humans produce millions of tons of waste, both household and industrial waste, which come in various forms and types (Pertiwi et al., 2025). According to research conducted by Kheyri et al. (2025), the global municipal solid waste (MSW) production rate is around 1.3 billion tons per year. This figure is estimated to reach 2.2 billion tons per year by 2025 (Saif et al., 2025). This will create unhygienic conditions for the surrounding environment and cause the spread of several deadly diseases and human illnesses (Pertiwi

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et al., 2025). This problem is influenced by population growth and urbanization (Verma & Reddy, 2025). One of the root causes of the lack of public awareness about proper waste disposal is the design of trash bins, which still use a simple method of manually opening and closing the bin (Manan et al., 2025), the choice of materials that are easily soiled and difficult to clean, and conventional trash bins that are not attractive for proper waste disposal (Celik et al., 2025). This design makes hands highly susceptible to bacteria from waste (Kirana, 2025). Thus, it is not user-friendly, both in terms of ergonomics and appearance (Hassan, 2025). The waste collection method is still manual (Kautsar et al., 2025), with sanitation workers checking each trash can individually without an integrated system (Ali et al., 2025). This also makes waste processing inefficient and time-consuming (Salmon et al., 2025).

This study was conducted to implement trash bins that are suitable for the characteristics of the community in Berau Regency, East Kalimantan. Berau Regency covers an area of 36,962.37 km<sup>2</sup>, which is divided into 13 subdistricts with very diverse geographical variations (Fasabbih et al., 2025). The largest subdistrict is Kelay (6,556.54 km<sup>2</sup>), followed by Maratua (5,616.26 km<sup>2</sup>) and Segah (5,241.29 km<sup>2</sup>), which indicate extensive inland and island areas, so that the evaluation of storage point determination needs to consider the factors of accessibility and distance between villages (Ardani & Hamid, 2025). Other subdistricts, such as Pulau Derawan, Batu Putih, Biduk-Biduk, and Sambaliung, have fairly large areas but are not comparable to the top three subdistricts. Meanwhile, Tanjung Redeb only has an area of 24.42 km<sup>2</sup>, but it functions as the center of government (Alif et al., 2025). This diversity in area size provides a starting point for selecting the most appropriate locations for smart waste storage, as well as a guide before combining it with population data, which will then be used to determine the proportional distribution of respondents in each subdistrict. Figure 1 shows the area size and population of each subdistrict in Berau Regency in 2024/2025.

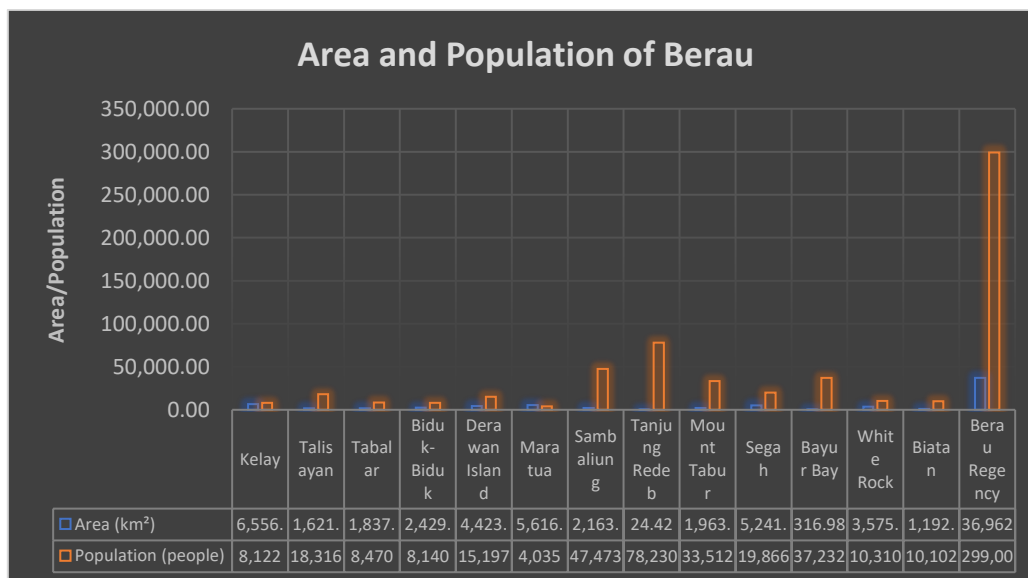


Fig. 1. Area and population of Berau in 2024/2025  
(Central Statistics Agency of Berau Regency, 2024)

Considering the differences in area and population density in each subdistrict, the most suitable location for testing smart trash bins is Tanjung Redeb Subdistrict, especially in Tepian Teratai and Tepian Segah (Darmono, 2025). Tanjung Redeb has a small area but is the center of government and economic activities, so the level of visits, citizen mobility, and intensity of waste disposal are much higher than in other subdistricts (Bangkiang & Ningrum, 2025). The ease of access and convenience for sanitation workers to reach these two places makes them perfect as the first experimental zone. In addition, the dense population in Tanjung Redeb allows for accurate observation of waste disposal patterns and determination of the appropriate number of research participants (Nurrohman et al., 2025).

Therefore, Tepian Teratai and Tepian Segah are the best options for the initial stage before expanding to a larger scale (Ramadhani et al., 2025).

This requires design research by young changemakers who can provide smart technology-based innovations for waste management that is comfortable (ergonomic), functional, yet aesthetic and integrated. The goal of this innovation is to create smart trash bins that not only facilitate waste management for the community as waste disposers but also for sanitation workers through an automatic notification system. This will create a sustainable clean environment for the future smart city ecosystem and increase community income through the integration of points from waste that has been converted into points and can be exchanged for basic necessities or transaction tools. The methodology used to achieve the objectives of this study is Quality Function Deployment (QFD), which is a structured methodology used in the product planning and development process to determine consumer needs and desires and systematically evaluate the capabilities of a product or service in meeting consumer needs and desires (Kalembo et al., 2025). Meanwhile, research conducted by Teles (2025) states that QFD is a methodology for translating consumer needs and desires into a product design that has certain technical requirements and quality characteristics.

The research conducted by Yahaya & Mohammad (2025) states that QFD is a product development system that starts from product design, manufacturing processes, to the product reaching consumers, where product development is based on consumer desires. Meanwhile, Guan et al. (2025) research conducted by states that the implementation of the QFD methodology basically consists of three stages, where all activities in each stage can be applied as in a project by first carrying out the planning stage. The three stages that are passed are the first stage, namely collecting the Voice of Customers, the second stage, namely compiling the House of Quality (HOQ), and the final stage is analyzing and implementing the product results obtained. This stage is carried out by entering the data obtained into the House of Quality, which is then analyzed so that it can be implemented properly (Nugraha et al., 2025). Meanwhile, research conducted by Apriliani et al. (2026) states in his journal that QFD is a method used to translate user requirements into technical specifications that convert user needs, desires, and expectations into measurable technical parameters that can be realized in product design. Meanwhile, research conducted by Ullah et al. (2025) states in his research that the QFD methodology is used to determine product development priorities. Meanwhile, research conducted by Phokha et al. (2025) states in his research that the purpose of implementing QFD is to increase customer satisfaction by minimizing the risk of mismatch between the designed product and market expectations. Meanwhile, research conducted by Lyu et al. (2025) states in his research that the use of QFD can support data-based decision making, where its use involves quantitative weighting and calculation so that design decisions are more objective and measurable. Meanwhile, research conducted by Etukuru et al. (2024) states in his journal that applying QFD ensures that the designed product is truly user-oriented. Therefore, product quality must be taken into account, as researched by the Journal. Noor et al. (2025) controlling product quality.

## 2. Methods

### 2.1 Research flow

This research was conducted in Berau Regency, specifically in the center of government and economic activities. The object of research to create a product design desired by users is an integrated and convenient trash bin. The data collection method used to meet the needs of this research is the QFD method, which involves observation or observation stages, namely direct observation of the source objects, including the activities of users who use conventional trash bins. Next, direct interviews were conducted with the source objects, namely the users of the trash bins. Furthermore, data was collected by distributing questionnaires to obtain additional data, and a literature study was conducted to assist in

the research, which was obtained from journals as the main reference for research that synergized with the object being studied. The research flow chart is shown in Figure 2.

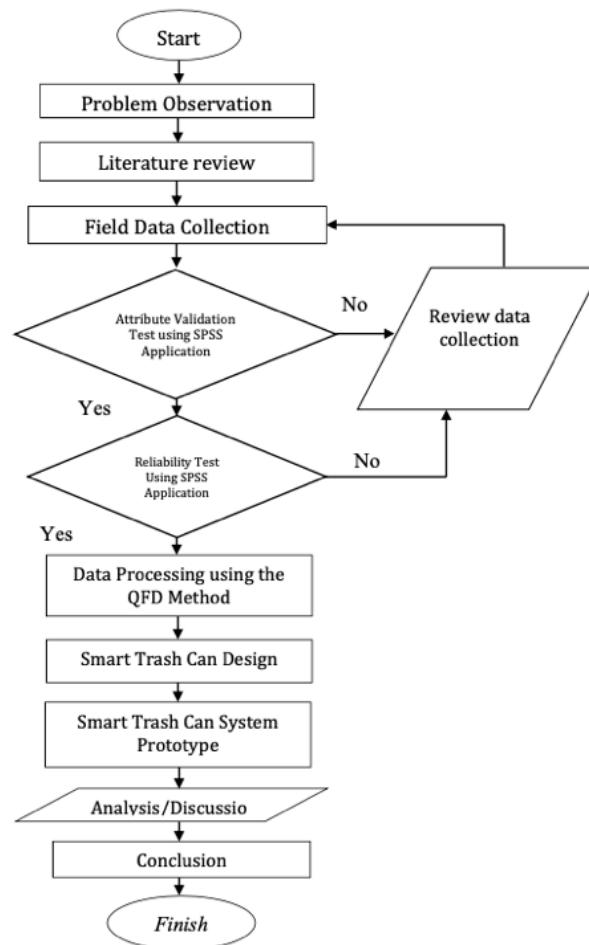


Fig. 2. Research flow chart

In this study, a series of stages were carried out based on Figure 2. The start column indicates the start of the research activities, followed by observation at the research location. The next stage was a literature review aimed at finding and adding references to the titles and methods to be used. In the research column, a series of data collection activities were carried out, such as interviews, questionnaires, and documentation. The number of respondents was then determined based on the sampling method used. To ensure that the data obtained was accurate, validation and reliability testing was conducted using the SPSS program. If the data was invalid, the data collection process was reviewed. However, if the data was valid and reliable, the process continued to the next stage until all data passed verification. After everything is done, it will proceed to the next stage, which is data processing using the QFD method and designing images based on the data processing results, then analyzing and discussing the problems that occur along with the design solutions offered through the designed images, then concluding the research results in accordance with the objectives to be achieved at that time, which also signifies that the research activities have been completed.

## 2.2 Research framework

The framework thinking flowchart is shown in Figure 3, which has several activity and research processes. The thinking framework pattern is broadly grouped into problems, actions, and final conditions or solutions. Complaints from users of trash bins were the starting point for the problem, which was then followed by a search for the root cause

through interviews. The results of the interviews showed that users were not interested in disposing of trash in the trash bins provided, which became the basis for the research problem. The problem-solving process is based on a series of data collection and processing using methodology related to design, making the QFD method one of the most appropriate methods for this research problem. To design a smart trash bin that meets user needs, various relevant reference sources and the results of data collection and processing are required, which are in line with user expectations and then translated into a design that will serve as a solution to the problem in this research.

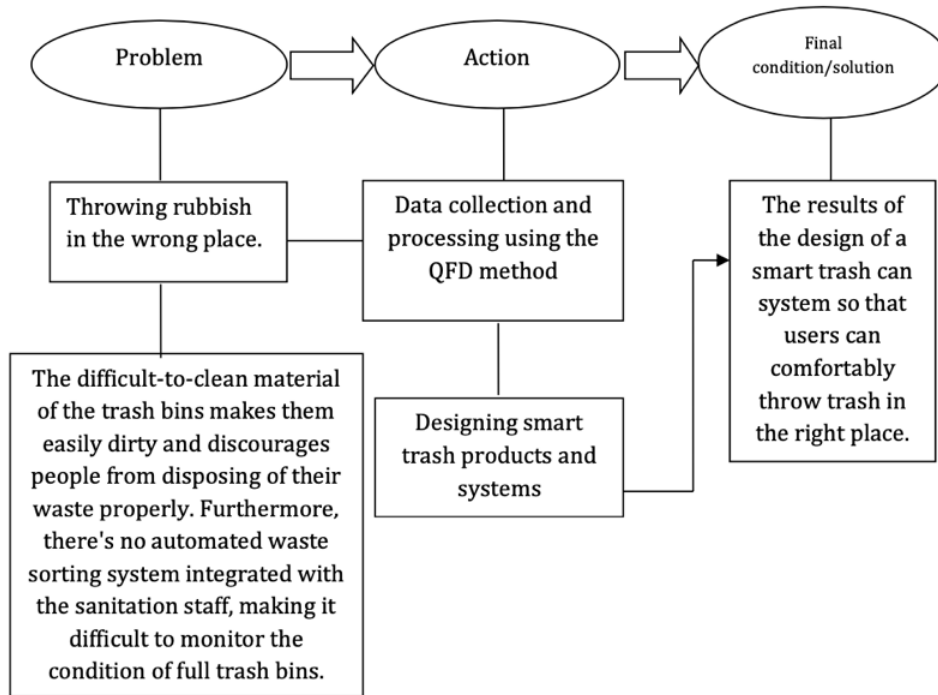


Fig. 3. Research framework

### 3. Results and Discussion

#### 3.1 User needs

The correspondents in this study were users of trash bins in public areas in the Berau region, specifically in the Tanjung Redeb area, namely the coast, airport, and park areas. Based on observation data, there were 184 trash bin users in one week. To determine the number of respondents in this study, judgment sampling was used, which is a type of sample selection where respondents are selected based on certain considerations due to their abilities/advantages over others in providing specific data and information needed by researchers (Kalembo et al., 2025). For complete data, see the appendix. After determining the number of respondents, the research continued to the next stage of collecting the voice of customers by interviewing users based on their needs. Figure 4 shows field observations and interviews with users of trash bins and trash officers at the Bujangga Berau landfill.



Fig. 4 (a) Field observation and interviews with trash can users; (b) Interview with the garbage officer at the Bujangga Berau Landfill

Next, the collection of user needs attributes was carried out. The research correspondents were the main users of the product, namely customers who use conventional trash cans. The results of the collection of user needs attributes are presented in Table 1. Results of the interpretation of trash can users. Based on the needs data obtained, it can be concluded that the desired product must prioritize ease of maintenance through easy-to-clean materials, equipped with clear instructions for use, and be comfortable and practical when used.

Table 1. Results of interpreting waste bin user needs

No	Needs	Description
1	Material that is easy to clean	Open questions
2	Includes usage instructions	Open-ended questions
3	Comfortable to use and practical	Open questions
4	Has audio information	Open questions
5	Using renewable and environmentally friendly energy	Open questions
6	Flexible and lightweight	Open questions
7	Discarded waste can be a point.	Open questions
8	Waste can be separated automatically.	Open questions
9	Integrated (officers know the volume of waste in real time)	Open questions
10	Attractive (Aesthetic Appearance)	Open questions

In addition, the product is also expected to have supporting features such as audio information, an automatic waste identification system, and technology integration that allows officers to combine waste volumes in real time. The aspect of desire is an important consideration with the use of renewable energy and an environmentally friendly concept, including an incentive system in the form of points for discarded waste. On the other hand, problems, light weight, and an aesthetic appearance are also supporting factors so that the product is not only functional, but also attractive and attractive.

### 3.2 Validity test

The next step is to determine valid and reliable user requirement attributes by distributing the results of the interviews using preliminary questionnaire attributes to users and waste management officers. The preliminary questionnaire aims to identify valid and reliable user requirement attributes. This preliminary questionnaire was compiled using five fixed answer options, namely a score of 5 with the criterion of very important, a score of 4 with the criterion of very important, a score of 3 with the criterion of important, a score of 2 with the criterion of less important, and a score of 1 with the criterion of not

important. Next, validity and reliability testing will be carried out using the SPSS program tool. The validity test in this study uses the SPSS program tool. 31, where attribute requirements are declared valid if there is a star 1 or star 2 symbol (\* or \*\*) in the total table, while invalid data will be eliminated because it does not represent the relative preferences of smart trash can users. However, all data managed and input into SPSS at is declared valid, so no values are eliminated. The results of the validity test for product attribute types using the SPSS program can be seen in Table 2.

Table 2. Questionnaire attribute validation results

No	Voice of customer	r Value	Description
1	Easy-to-clean material	0.389	Valid
2	Has usage instructions	0.466	Valid
3	Comfortable to use and practical	0.645	Valid
4	Has audio information	0.511	Valid
5	Using renewable and environmentally friendly energy	0.418	Valid
6	Flexible and lightweight	0.442	Valid
7	Discarded waste can be points.	0.418	Valid
8	Waste can be separated automatically.	0.701	Valid
9	Integrated (staff know the volume of waste in real time)	0.661	Valid
10	Attractive (Aesthetic Appearance)	0.629	Valid

A variable is considered valid if the calculated r value is greater than the table r value. Based on the results obtained from 30 users (N), the table shows a significant level of 5% with a value of 0.359 as the calculated r value when compared to the variables obtained in Table 2. Therefore, the validity of the questionnaire attributes can be confirmed as valid.

### 3.3 Reliability test

A questionnaire attribute is considered reliable if a person's answers to the questions are consistent over time. According to research conducted by Nugraha et al. (2025), a questionnaire is considered reliable if it can provide a value of a > 0.60. From the reliability test results, a value of 0.551 > 0.359 was obtained, so this questionnaire is declared reliable.

### 3.4 Quality function deployment (QFD)

After collecting data and conducting validation and reliability tests on the data regarding user preferences for smart trash bins, the results were then used as input in the QFD analysis, which consists of several stages. The first stage is to determine satisfaction with competitors by conducting an average assessment and comparing satisfaction with each product that has certain qualifications for each user need based on the data collected on existing trash bins, namely the preference for disposing of trash in its proper place. Figure 5 shows a conventional trash bin at a tourist attraction, which is declared as competitive product 1. The questionnaire results obtained from respondents regarding their previous product usage served as the basis for determining Product 1 as the main competitor in this study. This determination was made by considering the level of similarity in market segments, product characteristics, and the intensity of use by respondents. The collected data were then analyzed to identify user perceptions and experiences of Product 1.



Fig. 5. Conventional trash bin

Furthermore, an evaluation of the level of user satisfaction with Competitor 1 is presented systematically and structured in Table 3, which contains assessment indicators such as product quality, price, features, ease of use, and after-sales service. This presentation aims to provide a comprehensive overview of Competitor 1's position based on user perceptions. With a weighting of 5 points, the result is very good; with a weighting of 4 points, the result is good; with a weighting of 3 points, the result is neutral; with a weighting of 2 points, the result is poor; and with a weighting of 1 point, the result is very poor.

Table 3. Questionnaire results on competitive satisfaction of product 1

No	Voice of customer	Mean	Rounded value	Description
1	Easy-to-clean material	3.11767	3	Neutral
2	Has usage instructions	1.11972	1	Very poor
3	Comfortable to use and practical	2.41971	2	Poor
4	Has audio information	1.11231	1	Very poor
5	Using renewable and environmentally friendly energy	1.01219	1	Very poor
6	Flexible and lightweight	4.47234	4	Good
7	Discarded waste can be a point.	1.12241	1	Very bad
8	Waste can be separated automatically	1.02311	1	Very poor
9	Integrated (staff know the volume of waste in real time)	2.18614	2	Poor
10	Attractive (Aesthetic Appearance)	1.44191	1	Very poor

Therefore, from Table 3, the user satisfaction assessment of competitive product 1 shows that flexibility and light weight receive a score of 4, meaning they are satisfactory or good, while easy-to-clean material receives a score of 3, meaning the material used is neutral, and comfort of use, practicality, and real-time waste volume information receive a score of 2, meaning they are unsatisfactory or poor. while having usage instructions, audio information, using renewable and environmentally friendly energy, waste that can be scored, waste that can be separated automatically, and having appeal (aesthetic appearance) received a score of 1, which means that the condition of the trash bin is very unsatisfactory or very poor. Meanwhile, the satisfaction of competitive product 2 is shown in Figure 6. IoT-based smart trash bin with renewable energy.

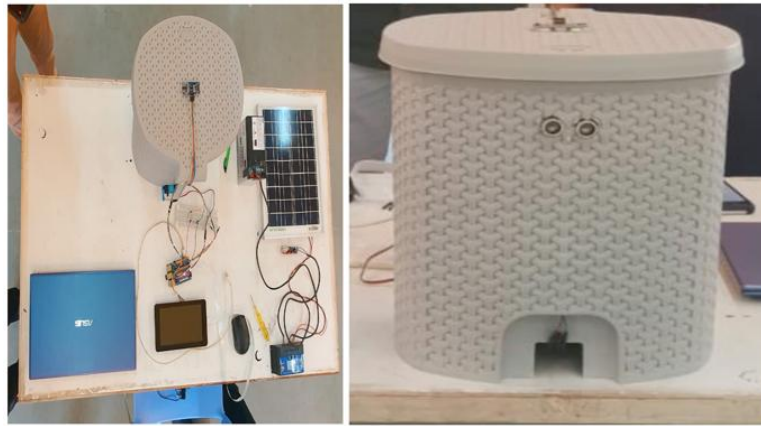


Fig. 6. IoT-Based smart waste bin with renewable energy  
(Patel et al., 2025)

In the research on IoT-based Smart Trash Bins utilizing renewable energy, the results of questionnaires obtained from respondents based on their experience using such products served as the basis for determining Product 2 as a relevant competitor for further implementation. This determination took into account the balance of features, technology used, and market segmentation comparable to the product developed in the research. The collected data were then processed to determine user perceptions and levels of satisfaction with the performance of Product 2, including aspects of IoT system effectiveness, efficiency of renewable energy use, ease of operation, design, and product durability. The results of the satisfaction evaluation are presented systematically and in detail in Table 4 to provide a comprehensive overview of Product 2's competitive position based on the assessment of smart trash bin users.

Table 4. Questionnaire results on competitive satisfaction of product 2

No	Voice of customer	Mean	Rounded value	Description
1	Easy-to-clean material	2.129621	2	Poor
2	Has usage instructions	3.455343	3	Neutral
3	Comfortable to use and practical	3.722310	4	Good
4	Has audio information	2.056211	2	Poor
5	Using renewable and environmentally friendly energy	4.977165	5	Very good
6	Flexible and lightweight	3.629411	4	Good
7	Discarded waste can be a point.	1.924572	2	Bad
8	Trash can be separated automatically	2.196431	2	Poor
9	Integrated (staff know the volume of waste in real time)	4.975563	5	Very good
10	Attractive (Aesthetic Appearance)	3.623314	4	Good

Therefore, from Table 4, the user satisfaction rating for competitive product 2 are: Using renewable energy and being environmentally friendly, and Integrated (staff know the volume of waste in real time) received a score of 5, meaning it meets the criteria and is Very Good, while being comfortable to use and practical, Flexible and lightweight, and having appeal (Aesthetic appearance) received a score of 4, meaning it meets expectations and is Good, while having instructions for use received a score of 3, meaning Neutral or Average, while being easy to clean, having audio information, waste that can be discarded can be a point, and waste that can be separated automatically received a low score of 2, meaning Poor. The second stage involves processing data on the importance of attributes to users (importance to the customer), which describes how important each classification is to users in terms of the degree of importance used to prioritize each user's wants or needs with a weighted assessment, where a weighting of 5 results in Very Important, a weighting of 4

results in Very Important, a weighting score of 3 results in Important, a weighting score of 2 results in Less Important, and a weighting score of 1 results in Not Important. The results of the smart trash can user data processing are shown in Table 5.

Table 5. User importance of smart waste bins

No	Voice of customer	Mean	Rounded value	Description
1	Easy-to-clean material	4.832133	5	Extremely Important
2	Has usage instructions	5.133242	5	Extremely Important
3	Comfortable to Use and Practical	4.422317	4	Very important
4	Has audio information	4.743652	5	Extremely Important
5	Using renewable and environmentally friendly energy	4.177164	4	Very important
6	Flexible and lightweight	2.342213	2	Less important
7	Discarded waste can be a point.	4.983212	5	Extremely Important
8	Trash can be separated automatically	5.193254	5	Extremely Important
9	Integrated (staff know the volume of waste in real time)	4.975563	5	Extremely Important
10	Has Appeal (Aesthetic Appeal)	4.322134	4	Very important

From Table 5, the importance of smart trash bins to users in terms of easy-to-clean materials, user instructions, audio information, points for discarded trash, automatic trash separation, and integration (staff monitoring trash volume in real time) received a weighting of 5 points, meaning that these features are very important and must be present in smart trash bins. Meanwhile, being comfortable to use and practical, using renewable energy and being environmentally friendly, and having aesthetic appeal received a weighting score of 4 points, indicating that these features are very important. Flexibility and light weight received a weighting score of 2 points, indicating that these features are less important for the trash bins being developed. The third stage is the customer satisfaction stage (Customer Satisfaction Performance), where customer satisfaction is an assessment of the product's ability to satisfy users. The criteria for user satisfaction are as follows: a score of 5 indicates that the user is extremely satisfied, a score of 4 indicates that the user is very satisfied, a score of 3 indicates that the user is satisfied, a score of 2 indicates that the user is somewhat dissatisfied, and a score of 1 indicates that the user is dissatisfied with the product that has been developed. The results of user satisfaction are shown in Table 6.

Table 6. Results of the smart waste bin user satisfaction questionnaire

No	Voice of customer	Mean	Rounded value	Description
1	Easy-to-clean material	4.484795	4	Very satisfied
2	Includes usage instructions	4.723332	5	Extremely satisfied
3	Comfortable to use and practical	4.652778	5	Extremely Satisfied
4	Has audio information	4.765784	5	Very satisfied
5	Using renewable and environmentally friendly energy	3.927723	4	Very satisfied
6	Flexible and lightweight	4.356329	4	Very satisfied
7	Discarded waste can be a point.	4.029887	4	Very satisfied
8	Trash can be automatically separated	5.001221	5	Extremely satisfied
9	Integrated (staff know the volume of waste in real time)	3.977852	4	Very satisfied
10	Attractive (Aesthetic Appearance)	3.235570	3	Satisfied

From the table of user satisfaction survey results for smart trash bins, it was found that having user instructions, being comfortable to use and practical, and automatically separating waste received a score of 5, indicating that users are highly satisfied. While the features of being easy to clean, using renewable and environmentally friendly energy, being flexible and lightweight, allowing discarded waste to earn points, and being integrated received a score of 4, indicating that users are very satisfied with the product. Meanwhile, the feature of being attractive (aesthetic appearance) received a score of 3, indicating that users are satisfied with the smart trash bin that was built.

The fourth stage is the fulfillment target (goal), which is the level of satisfaction of each user need that must be achieved by a product being developed while still paying attention to the target value that needs to be determined by the product designer. The target value is adjusted according to the designer's ability to meet customer needs, and the weighting criteria are as follows: a score of 5 indicates that users are extremely satisfied, a score of 4 indicates that users are very satisfied, a score of 3 indicates that users are satisfied, a score of 2 indicates that users are less satisfied, and a score of 1 indicates that users are dissatisfied with the product that has been built. The results of user satisfaction with smart trash bins are shown in Table 7.

Table 7. Smart trash can satisfaction targets

No	Voice of customer	Average target score	Description
1	Easy-to-clean material	5	Very satisfied
2	Comes with usage instructions	5	Very satisfied
3	Comfortable to Use and Practical	5	Very satisfied
4	Has audio information	5	Very satisfied
5	Uses renewable and environmentally friendly energy	5	Very satisfied
6	Flexible and lightweight	4	Very satisfied
7	Discarded waste can be a point.	5	Extremely satisfied
8	Trash can be separated automatically	5	Very satisfied
9	Integrated (trash can monitor waste volume in real time)	4	Very satisfied
10	Attractive (Aesthetic Appearance)	4	Very satisfied

The fifth stage is the improvement ratio, which is the effort required to increase user satisfaction for each user need. The improvement ratio aims to determine the value that designers must achieve to reach the target fulfillment value that has been set. The assessment indicator is that if the user satisfaction value is greater than or equal to the target fulfillment value, then no further improvements are needed, but if the user satisfaction value is less than the target value, then improvements need to be made. The improvement ratio is shown in Table 8.

$$\text{Improvement ratio} = \frac{\text{Target is provided}}{\text{User satisfaction performance}} \quad (\text{Eq. 1})$$

The improvement ratio is a measure of the amount of effort required to improve user satisfaction for each identified need. This ratio is used to determine the value designers must achieve to meet established targets. The assessment indicators are: if the user satisfaction level is greater than or equal to the target, no improvement is necessary; conversely, if the satisfaction level is still below the target, evaluation or improvement is necessary.

Table 8. Improvement ratio for smart waste bins

No	User response	Improvement ratio	Description
1	Easy-to-clean material	1.25	No repair needed
2	Includes usage instructions	1.0	No repairs needed
3	Comfortable to use and practical	1.0	No need for repairs
4	Has audio information	1.0	No need for improvement
5	Uses renewable and environmentally friendly energy	1.25	No repairs needed
6	Flexible and lightweight	1.0	No repairs needed
7	Discarded waste can be turned into points.	1.25	No need for improvement
8	Waste can be separated automatically.	1.0	No repairs needed
9	Integrated (staff can monitor waste volume in real time)	1.0	No improvements needed
10	Has appeal (aesthetic appearance)	1.34	No improvements needed

The sixth stage is the sales stage, which is the ability to sell the product being developed and is based on how well each customer need can be met. The weighting value is 1, which means no sales, 1.2 means moderate sales, and 1.5 means high sales. The sales level is shown in Table 9. Sales volume is an important indicator in the product development process, used to assess a product's potential to attract consumer interest and be successfully marketed competitively. This stage illustrates a product's ability to create appeal based on its level of conformity to previously identified customer needs, desires, and expectations. In other words, the more optimally a product is able to meet and provide solutions to customer needs, the higher the product's chances of having a strong selling point in the market. This sales volume assessment is carried out using a specific weighting system, where a weighting value of 1 indicates that the product has no significant influence on increasing appeal or does not make a significant contribution to sales potential; a weighting value of 1.2 indicates that the product has a medium sales volume, meaning it is sufficiently capable of competing and attracting consumer interest although there are still aspects that need to be improved; while a weighting value of 1.5 indicates a high sales volume, indicating that the product has a strong competitive advantage, is able to meet customer needs more comprehensively, and has great potential to increase sales volume and strengthen the product's position in the market.

Table 9. Sales level of smart trash bins

No	User Response	Sales level	Description
1	Easy-to-clean material	1.5	High sales volume
2	Includes usage instructions	1.5	High sales volume
3	Comfortable to Use and Practical	1.5	High sales volume
4	Has audio information	1.5	High sales volume
5	Uses renewable and environmentally friendly energy	1.5	High sales volume
6	Flexible and lightweight	1.5	High sales volume
7	Discarded waste can be a point.	1.5	High sales rate
8	Waste can be separated automatically	1.5	High sales volume
9	Integrated (staff can monitor waste volume in real time)	1.5	High sales volume
10	Attractive (Aesthetic Appearance)	1.2	Moderate sales level

The seventh stage is the raw weight assessment stage, which is the result obtained from multiplying importance, users, and increase ratio by sales level. The raw assessment is shown in Table 10. Raw Value is the initial measure used to evaluate a product or feature based on three key interrelated factors: user importance, improvement ratio, and sales rate. The user importance factor describes how important a need or feature is to their experience, with the higher the importance, the greater the impact on user satisfaction.

$$\text{Raw value} = (\text{importance to users}) \times (\text{increase ratio}) \times (\text{sales level}) \quad (\text{Eq. 2})$$

The improvement ratio factor indicates the amount of effort required to improve user satisfaction for a particular need; if current user satisfaction is close to the target, this ratio is low, but if there is a gap, this ratio will be high, indicating the need for greater improvement. The sales rate factor reflects the product's potential for market success, measured by the extent to which it meets customer needs, with weights ranging from low, medium, to high. The combination of these three factors through the Raw Value formula provides a comprehensive indicator for determining product development priorities, allowing the most strategic features or aspects to be prioritized to improve user satisfaction while maximizing sales performance.

Table 10. Raw assessment of smart waste bins

No	Consumer voice	Raw assessment
1	Easy-to-clean material	9.38
2	Includes usage instructions	7.50
3	Comfortable to use and practical	6.00
4	Has audio information	7.50
5	Uses renewable and environmentally friendly energy	7.50
6	Flexible and lightweight	3.0
7	Discarded waste can be points.	9.38
8	Trash can be separated automatically.	7.50
9	Integrated (staff know the volume of waste in real time)	7.50
10	Attractive (Aesthetic Appearance)	6.44

The eighth stage is the normalized assessment stage (normalized raw weight), which in this study is a value that shows the level of importance of each customer's needs to the user itself, where the higher the value obtained, the more important the needs are to the user itself. Table 11 shows the normalized assessment of smart waste bins.

$$\text{Normalized Scoring} = \frac{\text{Raw assessment}}{\sum \text{Raw assessment}} \quad (\text{Eq. 3})$$

Normalized scoring is a method for converting the raw scores of a product, feature, or user need into a proportional form so that each item can be compared more objectively. This process is done by dividing each item's raw score by the total of all the raw scores. The raw scores themselves reflect an initial score based on factors such as user importance, upgrade rate, and sales level, but are absolute and do not indicate each item's relative contribution to the overall score.

Table 11. Normalized assessment of smart trash bins

No	Consumer Voice	Normalized
1	Easy-to-clean material	0.131
2	Has usage instructions	0.105
3	Comfortable to use and practical	0.084
4	Has audio information	0.105
5	Uses renewable and environmentally friendly energy	0.105
6	Flexible and lightweight	0.042
7	Discarded waste can be a point.	0.131
8	Waste can be separated automatically.	0.105
9	Integrated (staff can monitor waste volume in real time)	0.105
10	Attractive (Aesthetic Appearance)	0.090

By normalizing, each item will receive a score between 0 and 1, representing its proportionate contribution to the total score. A higher normalized score indicates that the item has a greater priority or impact than other items. This method facilitates decision-making and prioritization in product development, as it can focus on the items that make the most significant contribution to user satisfaction and overall market performance. The next step is to determine the technical requirements to help designers determine the design needed by users of smart waste bins. Table 12 shows the technical requirements from the Voice of the Customer.

Table 12. Technical requirements of voice of customer

No	Voice of the customer	Technical requirements
1	Easy-to-clean material	Using stainless steel material that is corrosion resistant and easy to clean
2	Includes usage instructions	Uses LEDs to display visual instructions for using the trash can
3	Comfortable to use and practical	The size of the trash can is adjusted to the height and reach of the user
4	Equipped with audio information	Installing a sound system on the smart trash bin to encourage the public to dispose of trash properly
5	Uses renewable and environmentally friendly energy	Using solar panels and lithium batteries that are environmentally friendly
6	Flexible and lightweight	Using thick fiberglass material that is impact-resistant
7	Waste can be converted into points.	Uses Radio Frequency Identification (RFID)
8	Waste can be separated automatically	Mechanical rotating selection to determine the type of waste
9	Integrated (staff can see the volume of waste in real time)	Uses an IoT system for integration between waste bins and waste management personnel
10	Attractive (Aesthetic Appearance)	Selecting bold colors and transparent materials so that the internal operations of the smart trash bin are visible to users

After collecting and processing data, it was found that users need smart waste bins with an automatic waste sorting system, ergonomics, functionality, aesthetics, and an integrated IoT point system as shown in Table 13. The design reference values are used as the basis for designing smart waste bins.

Table 13. Design reference values for smart waste bins

No	Requirement	Improvement ratio	Sales level	Raw assessment	Normalized technical response and correlation
1	Easy-to-clean material	1.25	1.5	9.38	0.131
2	Has instructions for use	1.0	1.5	7.50	0.105
3	Comfortable to Use and Practical	1.0	1.5	6.00	0.084
4	Has audio information	1.0	1.5	7.50	0.105
5	Using renewable and environmentally friendly energy	1.25	1.5	7.50	0.105
6	Flexible and lightweight	1.0	1.5	3.0	0.042
7	Discarded trash can be points.	1.25	1.5	9.38	0.131
8	Waste can be separated automatically	1.0	1.5	7.5	0.105
9	Integrated (staff know the volume of waste in real time)	1.0	1.5	7.5	0.105
10	Has Appeal (Aesthetic Appeal)	1.34	1.2	6.44	0.09

Based on Table 13, the improvement ratios that need to be prioritized are those with the lowest values, namely having usage instructions, being comfortable and practical to use, having audio information, being flexible and lightweight, automatically separating waste, and being integrated (staff know the volume of waste in real time). These specifications need to be considered when designing smart waste bins. While for the sales level, only one requirement is classified as moderate with a value of 1.2. The rest are the highest requirement values, which are design specifications that take priority over other requirements. As for the normalized technical response and correlation aspects, these values indicate the level of importance of each user requirement to the user themselves, where the higher the value obtained, the more important the requirement is to the smart trash bin user. The next stage is the design results offered to users based on the processed data obtained. The design drawings were created using the CAD Fusion 360 program, which is 3D design software that integrates Computer-Aided Design, Computer-Aided Manufacturing, and Computer-Aided Engineering. The front view of the smart trash bin is shown in Figure 8.



Fig. 8. Front view of smart trash can

The smart trash bin design has specifications consisting of a clear fiber cover with a wall thickness of 5 mm, a frame made of lightweight iron and stainless steel that is corrosion-resistant and easy to clean, with a total height of 1000 mm and a width of 500 mm. The complete specifications and dimensions of the smart trash bin are shown in Figure 13.



Fig. 9. Side view of the smart waste bin

To make it visually appealing, the researchers selected premium stainless steel material that is easy to clean. The design features a circular shape to accommodate the automatic waste sorting system.

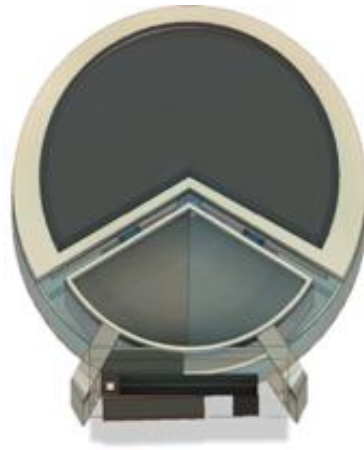


Fig. 10. Top view of the smart waste bin

The top of the smart trash bin has a waste sorting container that aims to sort waste types, which are then placed in designated containers. It is equipped with a lid that serves as a solar panel container and is placed on top to get optimal sunlight. On the top, there is also a container made of transparent fiber designed to protect and store energy, the electrical system, and the microcontroller within the smart trash bin.



Fig. 11. Rear view of the smart waste bin

The design is made transparent so that users can see the system inside the smart trash bin, aiming to encourage users to dispose of trash properly. To ensure the trash bin is sturdy and durable, material selection is carefully considered. The lower frame uses a combination of iron on the inside and stainless steel on the outside to prevent corrosion. Implementing the designed smart trash bins, which are IoT-based and integrated with the point conversion system and the Berau Regency Waste Bank, has enormous potential to improve the effectiveness of waste management and encourage behavioral change among the community. However, there are a number of challenges that need to be carefully considered in the implementation process, including technical, operational, cost, and long-term maintenance issues. From a technical perspective, the main challenge lies in IoT control, which is highly dependent on internet network stability. Real-time monitoring of waste volume and data integration with the Waste Bank system in Berau Regency requires consistent connectivity. In some areas of Berau Regency, network limitations can hinder data synchronization and even reduce the effectiveness of the system. In addition, the automatic waste selection system requires sensors that are accurate and resistant to environmental conditions in order to avoid dust, humidity, and wet waste. If the sensor experiences interference or identification errors, user confidence in the system will decline.

The use of renewable energy such as solar panels also presents its own challenges, particularly in relation to dependence on light intensity and the need for reliable and dependable power storage batteries.

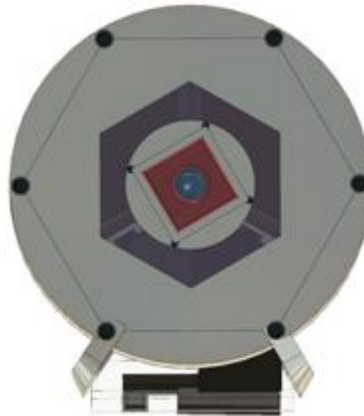


Fig. 12. Bottom view of the smart waste bin

From an operational perspective, the success of implementation is not only determined by the sophistication of the technology, but also by the readiness of human resources. Sanitation workers need to understand how to operate the monitoring system and respond to simple technical problems. In addition, the community as users need to be educated and socialized about how to use the system, the point conversion mechanism, and the benefits of the smart waste bin system. Where behavioral change does not happen instantly, a continuous socialization approach is needed so that the system is truly utilized optimally. Cost implications are also a very important consideration. In the early stages of implementation, a relatively large investment is required, as it includes the procurement of sensors, IoT modules, audio systems, solar panels, batteries, software development, as well as ergonomic physical design and materials that are resistant to environmental conditions. In addition, there are operational costs that must be taken into account, such as server and data storage costs, internet connectivity, system maintenance, and processing of incentive point schemes. If the point system is not designed with a sustainable financing model, it has the potential to burden the regional budget in the future.

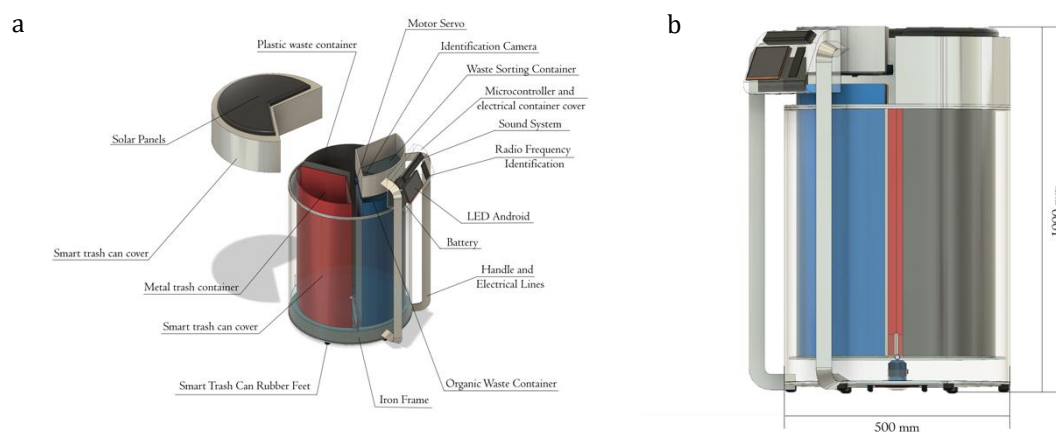


Fig. 13 (a) Specifications of smart waste bins; (b) Dimensions of smart waste bins

In the long term, maintenance is a key factor in the sustainability of smart waste implementation. Electrical components such as sensors, IoT modules, and communication modules require regular inspection and calibration to ensure they continue to function optimally. Solar panel components need to be cleaned regularly, while batteries have a

limited lifespan and need to be replaced when they are no longer usable. Software also needs to be updated periodically to maintain data security and improve system performance for maximum effectiveness. From a manufacturing or physical standpoint, smart waste bins are at risk of damage due to vandalism or improper use, requiring regular monitoring and maintenance strategies. Implementing these smart trash bins on a large scale requires budget support, partnerships, and even a systematic and clear financing scheme. Periodic evaluations of the system's effectiveness, community participation levels, and cost-benefit comparisons need to be conducted to ensure that the technology implemented truly has a positive impact. In order to implement smart trash bins in Berau Regency, the researchers created a basic prototype design to determine the effectiveness of the research and design that had been carried out. The smart trash bin prototype is shown in Figure 14. This study realizes the design that has been produced into a basic or simple prototype. Therefore, prototype testing data collection will be carried out in the next study.

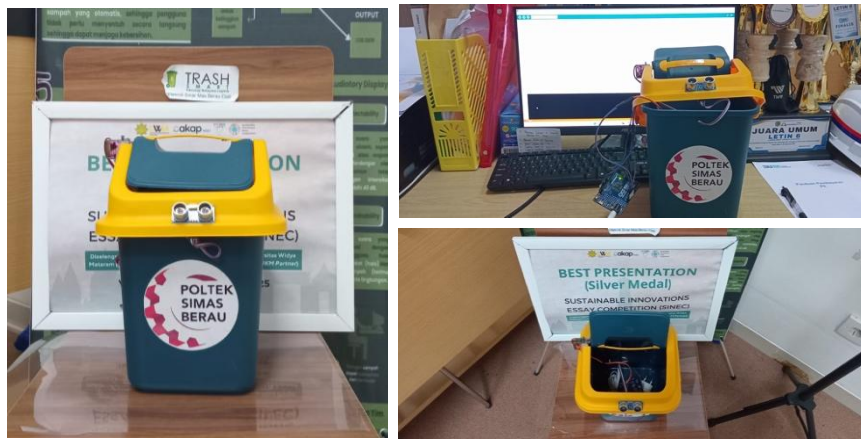


Fig. 14. smart waste bin prototype

#### 4. Conclusions

Based on Voice of Customer analysis using the Quality Function Deployment (QFD) method, it was found that smart trash bin users need a product made of easy-to-clean materials, equipped with usage instructions, comfortable and practical to use, with audio information features, using environmentally friendly renewable energy, and lightweight and flexible. In addition, the trash bin is expected to be able to convert trash into points, sort trash automatically, and be integrated with cleaning staff so that trash volume can be monitored in real time. Users also want an aesthetic design to increase interest in disposing of trash in its proper place. Based on the results of data processing, user needs were translated into the design of, an integrated Internet of Things (IoT) technology-based smart trash bin. This design aims to facilitate sanitation workers and increase user comfort and interest through a system that converts trash into points that can be exchanged as a means of transaction, integrated with the Berau Regency Trash Bank, and supported by a transparent system.

This finding confirms that the importance of implementing smart waste bins is not only determined by technological sophistication, but also by the extent to which ergonomic aspects are optimized to provide comfort, convenience, and a positive user experience. Ergonomic designs can minimize physical and cognitive barriers for users, thereby encouraging more consistent behavioral changes in waste disposal and sorting. The next study is recommended to develop and realize the design that has been produced in the form of a functional and standardized prototype so that it can be distributed to the people of Berau Regency. It is important to carry out further research and development, where direct testing is conducted on ergonomics, automatic selection system performance, IoT integration testing, point conversion system effectiveness testing, as well as user satisfaction and acceptance levels through field testing. This further research can evaluate

the reliability of the system in practice, and further testing will identify potential technical and operational obstacles. Thus, further research validating through prototypes will strengthen scientific contributions while ensuring technological readiness for implementation in the Berau Regency community.

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Conceptualization: Z.N., and J.; Methodology: H.N., and A.K.U.; Software: Z.N., and A.K.U.; Investigation and observation: Z.N., J., H.N., and A.K.U.; Writing, Reviewing, and Editing: Z.N., J., and H.N.; Visualization and Design: Z.N.; Project Administration: J., and H.N.

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The authors declare no conflict of interest.

### **Declaration of Generative AI Use**

During the preparation of this work, the author(s) used a generative AI tool to assist in paraphrasing certain sections for clarity and Grammarly to assist in improving the grammar and academic tone of the manuscript. After using these tools, the author(s) reviewed and edited the content as needed and took full responsibility for the content of the publication.

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