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Sustainable Waste Management

Integrating Quality Function Deployment and 3D CAD for Composter Machine Design

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A B S T R A C T

Organic waste management in urban residential areas remains a serious challenge, including at the temporary waste collection site (TPS) of The Vitka City Complex, Batam, where about 7.3 tons of organic waste per week is largely unprocessed, causing odor, maggot infestation, leachate accumulation, and potential soil and water pollution. This study aims to identify user requirements for a composter machine using the Quality Function Deployment (QFD) method and to develop a 3D Computer-Aided Design (CAD) based design that improves organic waste processing at the site. A descriptive quantitative approach was applied through field observation, structured interviews, and a five-point Likert questionnaire administered to 16 site managers and officers. All 15 user-need items (Voice of Customer) were valid, with item-total correlations of 0.70 to 0.88, and reliable, with a Cronbach's alpha of 0.89. QFD analysis produced seven technical characteristics, with large capacity and strong construction obtaining the highest relative weight (25%), followed by an optimal shredding system (19%) and a simple control system (19%). The design was developed in SolidWorks 2021 as a 1,000 kg capacity machine with steel shredding blades, a simple control panel, an aeration system, and an emergency stop. Static simulation using AISI 4340 steel showed that the dominant working stress remained below the material yield strength, indicating a structurally safe design. Integrating QFD and 3D CAD thus produces a composter design that matches actual user needs and can serve as a model for sustainable organic waste management in other residential areas.

1. INTRODUCTION

Waste management has become a serious challenge in many countries as rapid population growth and urbanization continuously increase waste generation. In Indonesia, the population grew from 270.20 million in 2020 to 278.70 million in 2023 (Fitri et al., 2023), and this growth directly drives higher volumes of domestic waste through increased consumption and urban activities (Utari et al., 2022). Meanwhile, final disposal sites and waste treatment facilities have not developed at the same pace, and organic waste, which constitutes the largest fraction of total generation, remains poorly processed in the existing management system, posing a serious challenge to sustainable urban waste management (Wildawati & Hasnita, 2020).

Composting is considered one of the most effective methods for managing organic waste, since it converts organic residues into a natural soil amendment that improves soil quality (D. Wang et al., 2024). Beyond reducing waste volume, composting supports environmentally friendly practices and reduces dependence on chemical fertilizers. However, traditional composting practices applied at many temporary waste collection sites (locally called TPS) are slow, inconsistent, and often yield low-quality compost, which motivates innovation and mechanization of the composting process (Andraskar et al., 2023; Manea et al., 2024).

This study focuses on the TPS of The Vitka City Complex, a residential area in Sekupang District, Batam City. Waste is collected using three-wheeled carriers with a capacity of about 800 kg per trip and an open-bed pickup of about 1.5 tons,

transporting waste from the ITEBA and BTP campuses, canteens, dormitories, and surrounding commercial areas. Field observation recorded around 9,600 kg per week transported by the three-wheeled carriers and 5,000 kg per week by the pickup, or approximately 14.6 tons of waste per week in total. Assuming that 50% of this amount is organic (0.5 × 14.6 tons), the site receives about 7.3 tons of organic waste weekly. Piles of unprocessed organic waste left open at the site generate pungent odor within hours, attract maggots, flies, and rodents, release methane, and produce leachate that risks polluting drains and soil, triggering complaints from surrounding residents.

Commercial composter machines are widely available, but they do not necessarily match the conditions and needs of local users. A design that is derived directly from the *Voice of Customer* is more likely to be functionally and economically appropriate for the site. Quality Function Deployment (QFD) is a structured method that links customer needs with technical product specifications so that the resulting product more accurately meets user expectations (Ginting et al., 2020). In parallel, 3D Computer-Aided Design (CAD) enables detailed visualization, virtual functional testing, and structural simulation of the machine before manufacturing, minimizing fabrication errors, accelerating design revision, and providing complete technical documentation (Hunde & Woldeyohannes, 2022).

Based on this background, the objectives of this study are: (1) to identify and prioritize user needs for a composter machine at the TPS of The Vitka City Complex using the QFD method, and (2) to develop a 3D CAD-based composter machine design and determine its key technical parameters, namely the processing capacity per batch, the shredding and mixing mechanism, the drive power and transmission, the structural material and its safety under the maximum working load, and the control, aeration, and operator safety features. The design is expected to accelerate composting and improve compost quality, thereby reducing organic waste accumulation at the site, and to serve as a model for sustainable organic waste management in other residential areas in Batam City and other urban regions.

2. LITERATURE REVIEW

2.1. *Organic Waste Management and Composting*

Organic solid waste is increasingly viewed as a resource within the circular economy, recoverable through aerobic and anaerobic biological treatment (Wainaina et al., 2020). In aerobic composting, process duration and product quality are strongly influenced by operating parameters such as microbial activity, moisture, aeration, and the carbon-to-nitrogen ratio of the feedstock (Cai et al., 2024; Kurniati et al., 2022; Shen et al., 2024). Aeration strategy in particular affects nitrogen conversion, gaseous emissions, and overall process performance (F. Wang et al., 2024; Y. Wang et al., 2024). Mechanized composters, such as rotary drum or rotary kiln systems, have been shown to accelerate food waste treatment and improve compost quality compared with open manual methods (Purwono et al., 2024). Composting close to the waste source also delivers social, economic, and environmental benefits (Jalalipour et al., 2024), and optimization of composter machines at Indonesian community-scale waste facilities (TPS3R) confirms their relevance for local waste management practice (Widja et al., 2023).

2.2. *Quality Function Deployment*

QFD translates customer requirements (What's) into technical characteristics (How's) through the House of Quality (HoQ), which contains the customer needs and their importance, the technical responses, a relationship matrix, a correlation roof, competitive benchmarking, and the resulting technical priorities (Ginting et al., 2020). Methodological development of QFD remains active, including its integration with multi-criteria decision-making approaches (Hariri et al., 2023) and consensus-based group decision mechanisms (J. Wang et al., 2024), and it is widely applied to sustainable new product development (Santoso et al., 2024). Directly relevant to this study, QFD has been used to develop a household food waste composter combined with fertilizer nutrient analysis (Pitjamit et al., 2025) and is commonly embedded in user-centered design methodologies (Imbesi & Scataglini, 2021). In Indonesia, QFD has guided the design of organic waste shredders (Agustina Lubis, 2022), laboratory-scale plastic shredders (Masruri et al., 2021), dustbin composters (Mayelsa et al., 2023), and portable grass cutters (Nurhayati & Prihastono, 2023), demonstrating its effectiveness in translating user needs of local operators into appropriate technical designs.

2.3. *Computer-Aided Design in Product Development*

Parametric 3D CAD models shorten development cycles and improve design consistency in mechanical product development (Fabian & Kupec, 2021). Simulation tools integrated with CAD, such as finite element analysis, allow early validation of mechanical designs and reduce prototyping cost and risk (Rasu, 2022). SolidWorks-based static analysis has been applied to evaluate frame structures under load (Restu Pahlawan et al., 2021), and CAD/CAE approaches have been used specifically for compost stirring mechanisms (Basuki et al., 2024) and for optimizing home-scale biodigester-composters through design for manufacturing and assembly combined with finite element analysis (Wijaya et al., 2024). These studies support the use of 3D CAD and structural simulation as the design and verification stage following QFD.

3. METHODOLOGY

3.1. *Research Design*

This study is applied product design engineering research using a descriptive quantitative approach. It was conducted at the TPS of The Vitka City Complex, Batam, from February to August 2025. The research stages were: problem identification through field observation; structured interviews to capture the *Voice of Customer* (VoC); validity and reliability testing of the questionnaire data; construction of the House of Quality; derivation of technical specifications; 3D CAD modeling; and structural simulation of the design. If the simulation did not satisfy the technical criteria, the CAD design was revised and re-simulated before proceeding to the analysis of the final result.

3.2. *Data Collection and Instrument*

Primary data were obtained through direct observation of waste handling conditions at the site and through structured interviews with 16 respondents consisting of foundation managers, site supervisors, and cleaning service officers involved in daily waste management. Secondary data were drawn from scientific journals and technical documents related to QFD, 3D CAD, and composter machines. The instrument was a questionnaire containing 15 user-need attributes covering machine functionality, ease of use, maintenance and reliability, safety and comfort, and environment and efficiency. Each attribute was rated on a five-point Likert scale for the level of importance and the level of satisfaction with current practice; the Likert scale was chosen because it has been shown to produce valid and reliable measurements in comparable studies (Putra Harwanto et al., 2025; Tahir et al., 2022). The questionnaire was administered through guided interviews to ensure that every respondent understood each item.

3.3. *Data Analysis*

Item validity was tested using the Pearson item-total correlation, where an item is declared valid if the calculated correlation exceeds the table value at a 5% significance level. Reliability was tested using Cronbach's alpha, with a value of at least 0.60 indicating a reliable instrument (Hakim & Sulistiyowati, 2022). The validated data were then processed through the QFD stages: identification of the VoC, determination of importance ratings, translation into technical characteristics, construction of the relationship matrix using strong, moderate, and weak relationship values of 9, 3, and 1, analysis of the correlation roof, and technical benchmarking against comparable commercial machines using a three-point ordinal scale (1 = worse than, 2 = equal to, 3 = better than the proposed design; Imbesi & Scataglini, 2021; Pitjamit et al., 2025). The resulting technical priorities were used as the basis for 3D modeling in SolidWorks 2021, followed by a static structural simulation of the frame using AISI 4340 steel under a maximum working load of 1,000 kg.

4. RESULTS AND DISCUSSION

4.1. *Validity and Reliability of the Voice of Customer*

All 15 user-need items showed positive item-total correlations between 0.70 and 0.88 with p-values below 0.05, so every item was declared valid. The reliability test produced a Cronbach's alpha of 0.89, well above the minimum threshold, indicating a highly reliable instrument. The average importance rating of each validated user need is presented in Table 1. The highest ratings were given to operational safety (4.44) and compost quality (4.44), followed by ease of operation, maintainability, waste volume reduction, and energy efficiency (4.25 each), confirming that operators prioritize a machine that is safe, dependable, and productive.

Table 1. Average importance rating of user needs (*Voice of Customer*)

No	User need statement	Mean
1	Able to process organic waste in large quantities	4.19
2	Fine and uniform shredding of the waste	3.94
3	Accelerates composting compared with manual methods	4.13
4	Easy to operate by TPS officers	4.25
5	Simple and easy-to-understand control panel	4.19
6	Requires no special technical skills	4.31
7	Not easily damaged under continuous use	4.19
8	Easy to maintain	4.25
9	Durable against heat, humidity, and rain	4.13
10	Safe to operate without high risk to the user	4.44
11	Produces no excessive noise	4.06
12	Produces no pungent odor	4.06
13	Significantly reduces organic waste volume at the TPS	4.25
14	Energy efficient and environmentally friendly	4.25
15	Produces good quality compost	4.44

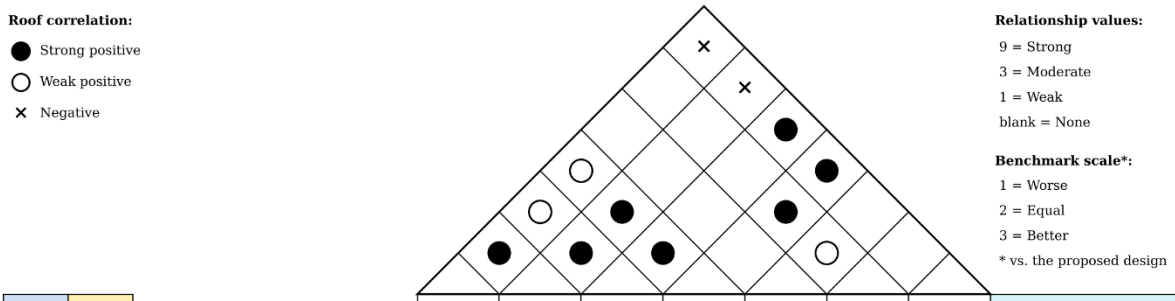
(Source: questionnaire data processing, 2025)

4.2. *House of Quality*

The 15 validated user needs were translated by the design team into seven technical characteristics (How's): (1) large capacity and strong construction, realized as a processing volume of up to 1,000 kg with an AISI 4340 steel frame, case hardening, and anti-corrosion coating; (2) an optimal shredding system using steel blades with a 4 cm blade spacing producing particles smaller than 4 cm, driven by a three-phase 5 HP (3.7 kW) motor with a 1:50 gearbox ratio delivering about 1,300 Nm of torque at approximately 25 rpm; (3) a simple control system with three functions (on, off, emergency); (4) aeration and process control devices, including temperature and humidity monitoring in a closed processing vessel; (5) high operator safety through an emergency stop and enclosed design; (6) low-noise operation using rubber and spring mounts as vibration dampers; and (7) energy efficiency through the option of a solar-assisted drive.

The complete House of Quality, which integrates the importance of user needs, the relationship matrix, the correlation roof, the competitive benchmarking, and the resulting technical priorities, is presented in Figure 1. The technical importance scores, relative weights, and priority ranks are summarized in Table 2. Large capacity and strong construction obtained the highest relative weight (25%), followed by the optimal shredding system (19%) and the simple control system (19%), while energy efficiency received the lowest weight (6%). The correlation roof revealed strong positive interactions between the shredding system and the aeration and process control devices, since finer particles accelerate aeration and decomposition, and between the control system and both the aeration devices and energy use. Two notable trade-offs were identified: large capacity conflicts with

energy efficiency, and a powerful shredding motor tends to increase energy consumption, so these aspects must be balanced in detailed engineering.



Mean rating	Weight	Functional requirements (How's) → / Customer requirements (What's) ↓	H1 Large capacity and strong construction	H2 Optimal shredding system	H3 Simple, easy-to-understand control system	H4 Aeration and process control devices	H5 High operator safety	H6 Low-noise operation	H7 Energy efficiency and eco-friendliness	Competitive benchmarking		
										TMK-1000	OKLIN GG-1000	TOGO-CC-1000
4.19	9.88	1. Able to process organic waste in large quantities	**9**	**1**						2	1	2
3.94	9.29	2. Fine and uniform shredding of the waste	**1**	**9**		**3**				1	2	1
4.13	9.73	3. Accelerates composting compared with manual methods		**3**		**9**				1	3	1
4.25	10.03	4. Easy to operate by TPS officers			**9**					2	3	2
4.19	9.88	5. Simple and easy-to-understand control panel			**9**					2	3	2
4.31	10.18	6. Requires no special technical skills			**9**					2	3	2
4.19	9.88	7. Not easily damaged under continuous use	**9**	**1**						2	1	2
4.25	10.03	8. Easy to maintain	**9**		**3**					2	2	2
4.13	9.73	9. Durable against heat, humidity, and rain	**9**							2	1	2
4.44	10.47	10. Safe to operate without high risk to the user					**9**	**3**		2	2	2
4.06	9.59	11. Produces no excessive noise						**9**		2	2	1
4.06	9.59	12. Produces no pungent odor				**9**				1	3	1
4.25	10.03	13. Significantly reduces organic waste volume at the TPS	**9**	**9**				**3**		2	3	2
4.25	10.03	14. Energy efficient and environmentally friendly							**9**	2	3	2
4.44	10.47	15. Produces good quality compost		**3**						2	3	2
		Technical importance	150.84	114.75	113.67	73.61	73.08	39.96	38.25			
		Relative importance (%)	25%	19%	19%	12%	12%	7%	6%			
		Priority rank	**1**	**2**	**3**	**4**	**5**	**6**	**7**			
		Current performance	3.06	1.73	2.00	1.40	0.60	1.00	0.60			

Figure 1. House of Quality of the proposed composter machine

Table 2. Technical characteristics, technical importance, relative weight, and priority

No	Technical characteristic	Technical importance	Weight	Rank
1	Large capacity and strong construction	150.84	25%	1
2	Optimal shredding system	114.75	19%	2
3	Simple, easy-to-understand control system	113.67	19%	3
4	Aeration and process control devices	73.61	12%	4
5	High operator safety	73.08	12%	5
6	Low-noise operation	39.96	7%	6
7	Energy efficiency and eco-friendliness	38.25	6%	7

(Source: House of Quality analysis, 2025)

Technical benchmarking compared the proposed design against three commercial machines, TMK-1000, OKLIN GG-1000, and TOGO-CC-1000, across the 15 customer requirements using the three-point ordinal scale. As summarized in Table 3, OKLIN GG-1000 achieved the highest average score (2.5) owing to its full automation, 24 to 48 hour processing time, and closed fermentation with odor filtering, but it has a much smaller capacity (80 to 100 kg per day) and lower durability in outdoor conditions. TMK-1000 (1.8) and TOGO-CC-1000 (1.7) are broadly comparable to the proposed design in capacity and

robustness but weaker in shredding fineness and composting speed. The proposed QFD-based design is therefore competitive for the operational context of the TPS, which demands large capacity and high environmental durability, while automation and energy-saving features remain the main directions for future improvement.

Table 3. Summary of technical benchmarking against commercial composters

No	Machine	Avg. score	Position relative to the proposed design
1	TMK-1000	1.8	Comparable capacity and durability; coarser shredding and slower process
2	OKLIN GG-1000	2.5	Superior automation, speed, and odor control; smaller capacity and lower outdoor durability
3	TOGO-CC-1000	1.7	Comparable capacity; noisier operation and slower composting

(Source: data processing based on manufacturer specifications, 2025)

4.3. *3D CAD Design and Structural Simulation*

The technical priorities from the House of Quality were used as the reference for 3D modeling in SolidWorks 2021. Figure 2 shows the exterior of the machine, consisting of a horizontal rotary drum mounted on a steel frame, a belt-driven motor and gearbox unit, and a control panel positioned at operator height. Figure 3 shows the interior configuration, in which shredding and mixing blades are arranged along the central shaft inside the closed drum to cut incoming organic waste into particles smaller than 4 cm and to homogenize the material during composting.

The key technical parameters of the proposed machine, derived from the House of Quality priorities and specified in the CAD model, are summarized in Table 4.

Table 4. Key technical specifications of the proposed composter machine

Parameter	Specification
Processing capacity	Up to 1,000 kg per batch in a closed horizontal rotary drum
Shredding and mixing mechanism	Steel blades on a central shaft with 4 cm blade spacing, producing particles smaller than 4 cm
Drive and transmission	Three-phase electric motor 5 HP (3.7 kW), gearbox ratio 1:50, output torque about 1,300 Nm, drum speed about 25 rpm, belt and pulley transmission
Structural material	AISI 4340 steel frame with case hardening and anti-corrosion coating
Structural safety	Dominant von Mises stress about 693.8 MPa, below the 710 MPa yield strength reference, at a 1,000 kg working load
Process control	Aeration with temperature and humidity monitoring; estimated composting time 14 to 56 days depending on target quality
Control panel and safety	Three functions (on, off, emergency stop) and an enclosed processing vessel
Noise and vibration	Rubber and spring mounts on the machine legs
Energy option	Optional solar-assisted brushless DC (BLDC) drive
Expected service life	Frame about 10 years and moving parts 3 to 10 years with regular maintenance

(Source: House of Quality and 3D CAD design, 2025)

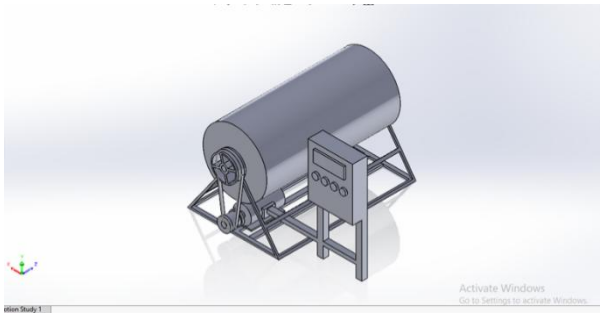


Figure 2. Exterior view of the composter machine 3D CAD model

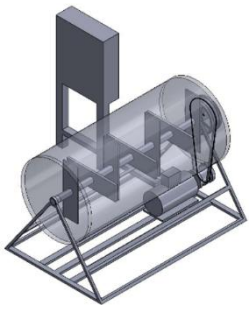


Figure 3. Interior configuration of the shredding and mixing mechanism

AISI 4340 steel was selected for the load-bearing structure because it combines high tensile and yield strength with good toughness and fatigue resistance, can be tailored through heat treatment, and is widely available at a more economical price than very high strength alternatives. A static structural simulation was performed with a maximum working load of 1,000 kg, representing a fully loaded drum. As shown in Figure 4, the dominant von Mises stress in the structure was approximately 693.8 MPa, below the 710 MPa yield strength reference used in the simulation, with a localized peak of 867.3 MPa at a stress concentration. Since the dominant working stress remains below the yield strength, the structure is considered safe under the

specified load, while the local concentration area is noted for reinforcement in the detailed engineering stage.

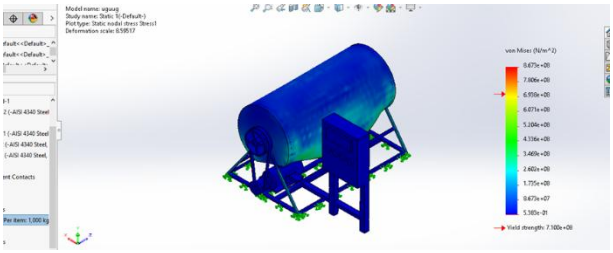


Figure 4. Static simulation result of the frame under a 1,000 kg working load

4.4. *Discussion*

The results confirm that QFD effectively bridges user needs and the technical aspects of the composter design. Large capacity and strong construction emerged as the top priority because organic waste generation at the site averages 7.3 tons per week; without sufficient capacity the machine cannot cope with the incoming volume. The optimal shredding system ranked second because uniform, fine particles enlarge the surface area available to microorganisms and thereby substantially accelerate decomposition (Kurniati et al., 2022; Purwono et al., 2024). The high weight of the simple control system reflects the fact that most site officers have no technical background, so an ergonomic and user-friendly interface is a key success factor for adoption in the field (Imbesi & Scataglini, 2021). Operator safety and low environmental disturbance, addressed through the emergency stop, enclosed vessel, and vibration dampers, respond directly to the complaints of odor and noise around the site. Energy efficiency received the lowest weight, which is understandable since users focus primarily on throughput and safety; nevertheless, energy efficiency remains important in the long term for operating cost and sustainability, and the identified trade-offs with capacity and motor power should be managed in future design iterations.

The CAD stage demonstrates that the design is not only technically responsive but also practical to implement. 3D modeling accelerated design validation, enabled load simulation before any fabrication, and produced complete technical documentation, consistent with previous findings on the benefits of CAD and simulation in mechanical design (Fabian & Kupec, 2021; Rasu, 2022; Restu Pahlawan et al., 2021). Compared with commercial machines, the proposed design is structurally and functionally competitive for the operating conditions of the TPS, and future development should add control automation and energy-saving features comparable to those of OKLIN GG-1000 without sacrificing capacity and durability.

5. CONCLUSION

This study successfully identified user needs for a composter machine at the TPS of The Vitka City Complex using the QFD method. Fifteen valid and reliable user-need attributes (item-total correlations of 0.70 to 0.88; Cronbach's alpha of 0.89) were translated into seven technical characteristics, with large capacity and strong construction as the top priority (25%), followed by an optimal shredding system (19%) and a simple control system (19%). A 3D CAD design was then developed in SolidWorks 2021 as a machine with a capacity of up to 1,000 kg equipped with steel shredding blades, a simple three-function control panel, aeration and process monitoring, and an emergency stop, and the static simulation with AISI 4340 steel confirmed that the structure is safe under the specified working load. The integration of QFD and 3D CAD therefore produces a composter machine design that matches actual user needs and is expected to accelerate composting and reduce organic waste accumulation at the site. Future work should include field prototyping, technical and economic feasibility analysis, operator training, and stakeholder support so that the design can be implemented and replicated at other temporary waste collection sites.

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