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MODULAR-BASED MULTIFUNCTIONAL PRODUCT DESIGN MADE FROM FURNITURE WASTE TOWARD THE CIRCULAR ECONOMY: CASE IN INDONESIA

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Abstract:
The furniture industry is one of the industrial sectors that has a potential market in Indonesia. This industry requires a lot of wood raw materials but is faced with a wood legality verification system that limits raw materials. Industrial players still need to start using waste as raw materials, which will reduce the use of primary raw materials. The circular economy concept can be applied to waste treatment. This study aims to design a pump-gallon product made from waste, considering the relatively high level of gallon container consumption. With this design, it is hoped to utilize waste into economically valuable products while reducing the environmental impact it causes. The product design process uses an integrated QFD-TRIZ method combined with circular economy principles. QFD functions to determine consumer desires and make technical responses, while TRIZ resolves contradictions in technical responses. The circular economy attribute is used as a reference in making gallon pump products from wood waste. After the design process is complete, it is followed by an economic feasibility analysis using the cost-benefit ratio. The result of this research is the design of multifunctional and modular products for gallon pumps. The gallon storage is designed to store not only gallons but also a small table for placing dirty glass and a drawer at the bottom that can be used to keep the glass or other items. There is a detachable system between the upper and lower components, making it easier to repair and use. At the bottom, they mounted castor wheels to facilitate product movement. Designing products made from waste will increase the income of furniture SMEs. In addition, it is expected that this will overcome waste management problems and shortages of raw materials experienced by furniture SMEs. Future research can utilize powder and smaller pieces of wood.

Key words: *circular economy, furniture industry, modularity, product design, waste*

INTRODUCTION

The furniture sector is one of the industries currently growing in Indonesia. Based on CSIL data for 2016, the center of furniture production has shifted to developing countries, including Indonesia. The contribution of the Asia Pacific region to world furniture production reaches 55%, followed by Europe (14%), America (26%), and other areas corresponding to 5% [1]. In 2018, approximately half of the world's furniture exports originated from Asia, marking the region's largest share in global furniture exports. Asia, including China, and furniture manufacturers in Vietnam, Indonesia, and Malaysia played a significant role in this contribution [2]. Interestingly, in 2022, the top five exporters of wooden furniture were China, Vietnam, Indonesia, Malaysia, and Thailand, with Indonesia securing the third position as the world's largest exporter after China and Vietnam [3]. Notably, the value of Indonesia's furniture export products is largely dominated by wooden furniture, as Indonesia is recognized as one of the leading producers of tropical wood globally. Teak is the most sought-after raw material in producing this furniture [4].
On a national scale, Indonesia's furniture industry can absorb a workforce of 500 thousand direct workers and 2.5

million indirect workers [5]. The types of furniture produced in Indonesia are divided into three categories: wood furniture, rattan bamboo furniture, and furniture made from other materials, where wood furniture accounts for around 80% of the total production [6]. Furniture production with wood materials is dominant because Indonesia has a high potential for tropical wood, with log production reaching 29.4 million m^3 in 2015 [7]. Most wooden furniture is produced by Small and Medium Enterprises (SMEs), which account for around 95% of the total furniture production [8].

In general, furniture SMEs in Indonesia use solid wood, panel wood, and rattan as raw materials to produce tables, chairs, beds, and so on [1]. With the extensive use of natural wood materials in Indonesia, the Government of Indonesia has designed a timber legality verification system to reduce forest damage due to illegal logging and maintain the sustainability of sources of raw materials. With this restriction on the use of wood, to get legal wood, many furniture SMEs have to buy outside the region at a higher price. This condition requires industry stakeholders to be good at managing raw materials. On the other hand, many furniture SMEs still need to utilize their wood waste. The waste produced is sold at a low price, and if it is not sold, it will accumulate and disrupt the production process. With restrictions on raw materials, entrepreneurs should be able to utilize waste as raw material to manufacture new products to provide economic benefits, reduce the consumption of primary raw materials, and minimize waste discharged into the environment. The use of solid waste in the industry to improve ecological and economic principles is a necessary and essential step [9], and waste management is an element of the creation of a closed loop of supply chains [10].

The application of the circular economy (CE) concept can be a solution to problems in the furniture industry [11] because the use of resources, waste, emissions, and wasted energy is minimized by extending product life, design innovation, maintenance, reuse, remanufacturing, recycling into products originally, and recycled into other products [12]. Applying CE principles such as long-life use, extended lifespan, and product recovery [13] in product design, besides increasing economic value, will also minimize the use of materials. The CE concept creates opportunities for the SME sector to build relationships as part of an industrial network; a managed supply chain has common and realistic goals to achieve, and this is a priority in a business model based on sustainable development [14].

To overcome the waste problem, furniture SMEs can consider implementing the circular economy concept, namely processing wood waste into new products. This research will design circular economy-based products from waste by integrating the QFD (Quality Function Deployment) and TRIZ (Theory of Inventive Problem Solving) methods. QFD is a customer-centric approach [15]. It is well-suited for shaping design quality that prioritizes customer contentment and converting these consumer requirements into design objectives. QFD will transform consumer needs into technical responses and spread technical responses to subsequent production activities [16]. This method has been widely accepted and used for product innovation, research, and development [17, 18, 19, 20] because of its ability to consider consumer needs and improve product performance [21, 22, 23]. However, despite its inherent benefits, QFD exhibits pronounced subjectivity by relying upon individual designers to determine product specifications within the design process while failing to engage in distinctive methodologies for addressing innovative challenges [24].

TRIZ is one of the most potent systematic innovation strategies, which can complement the shortcomings of QFD [16]. TRIZ serves as an analytical instrument for identifying inventive challenges and deriving solutions [25]. Integrating these two methods is suitable for application in the product design process because QFD defines product contradictions, while TRIZ resolves these contradictions [26].

Some studies integrating QFD and TRIZ for product design mostly use primary raw materials and have yet to use circular economy principles. Hence, this research intends to design products made from waste by integrating the QFD and TRIZ methods combined with circular economy principles. Then, proceed with the benefit-cost ratio analysis to measure the effectiveness of the utilization of this waste.

Applying QFD-TRIZ with the circular economy principle utilizes furniture production waste into an innovative gallon pump product. The primary consideration for selecting this product is that the use of bottled water in meeting the community's water needs is high. With the use of bottled water, the market opportunity for innovative products in gallons is relatively high. In addition, several gallon storages made of wood today have the disadvantage that they are challenging to repair or extend their useful life; the product can only be used for one life cycle, finished when the product is damaged. Currently, many gallons of wood are circulating in the market for porcelain water and plastic dispensers. Because of its practicality, using gallons with a pump system is currently the people's choice. The utilization of gallon pumps within the community predominantly involves employing gallon receptacles arranged in a table-like configuration or employing them without auxiliary apparatus. This phenomenon arises due to the limited proliferation of inventive gallon storage solutions tailored for pump-integrated water collection mechanisms, particularly those constructed from wood. In the absence of a special place for pump-based water collection devices, users encounter a range of issues, specifically:

a) inadequate storage provision for drinking vessels,
b) residual markings and residue resulting from positioning water containers upon the ground, thereby presenting cleaning challenges,
c) a lack of designated areas for placing drinking receptacles during the water retrieval process.

Emerging from this challenge, a necessity arises for an innovative paradigm in the conception of a multifunction gallon pump. This innovation in the design of a multifunction gallon pump forged from discarded materials is expected to be a solution to meet market needs, overcome the scarcity of raw materials, and add economic value to the waste generated by furniture SMEs. Based on the above problems, this study aims to design a modular-based multifunction gallon pump product from wood waste that applies the circular economy principle using QFD-TRIZ integration.

LITERATURE REVIEW

QFD-TRIZ Integration in Product Design

QFD is a customer-based method developed by Akao in 1990. This method is suitable for creating design quality oriented toward customer satisfaction and translating these consumer needs into design goals [15]. Some researchers use QFD for product design. Ref. [27] used the QFD method for electric vehicle design. Ref. [20] developed two matrices based on QFD to reduce the number of tests in the product development process. Ref. [28] created a framework for prioritizing infrastructure user expectations. QFD is also used to support sustainable product-service system design [29], to analyze the healthcare service requirement [30], and to improve the halal meat industry [31].

TRIZ is an analytical tool for identifying inventive problems and sourcing solutions [25], created by Altshuller in 1956 to create innovative solutions in product design [32]. TRIZ is proven capable of solving a large number of innovative problems for companies around the world [20], such as low-carbon design [33], friction stir welding design [34], mouse design [35], and the elimination of technological contradictions of new wind generation devices [36]. Ref. [37] also used TRIZ for task completion, which resulted in the selection of appropriate solutions and possible optimization by reducing the weight of each part of the tire building drum.

Sustainable design aims to create physical objects, environments and services that optimize social, economic and ecological impacts [38]. QFD has the advantage of designing and improving user-centered systems by transforming user needs into product technical characteristics and measuring their priorities. However, QFD does not fully consider the correlation between technological elements, so it requires the TRIZ technique to compensate for the shortcomings of QFD by allowing creative problem-solving systematically by considering the correlation of technical contradictions [39]. A systematic design process is needed by integrating QFD and TRIZ techniques to produce efficient and practical system design solutions. This integration will produce technical optimization, which provides technological solutions that reduce complexity in product architecture; the resulting output is an optimized architecture. This integration is depicted in Fig. 1.

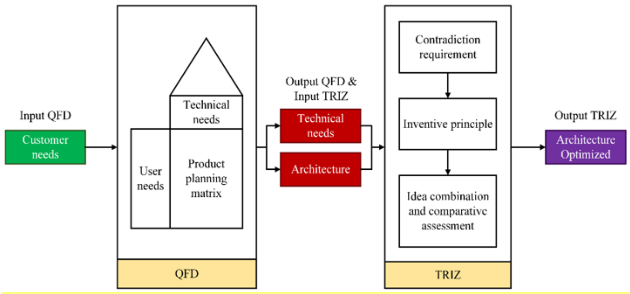

Fig. 1 QFD-TRIZ Integration System in Product Design

Since TRIZ's most prominent strength lies in its elimination of contradictions, the integration of QFD with contradiction analysis was carried out by many researchers. For example, Ref. [40] combined QFD and TRIZ in medical device innovation, and Ref. [41] developed a multifunctional smartphone by integrating these two approaches. Ref. [42] combines the two to improve service innovation performance and competitiveness. Ref. [43] designed an intelligent ship alarm system using the same approach. Ref. [44] developed a green design method for laptops with these two approaches. Ref. [45] apply this integration approach to the innovative design of ergonomic products. The integration of QFD and TRIZ is proven to offer guidance for generating innovative solutions to problems identified by QFD [24]. Solving the TRIZ problem through the contradiction matrix, the user can show the appropriate problem-solving principles and suggest ways to produce ideal solutions [46]. Integrating these two methods is suitable for application in the product design process because QFD defines product contradictions, while TRIZ resolves these contradictions [26]. The integration achieved between the four phases of QFD and TRIZ is a powerful tool for product development because it emphasizes error prevention [44].

Product Design Based on Circular Economy Principles

Sustainable product design is a design that considers the environmental and social impacts of a product, service, or system at the same level as economic considerations [47]. The key concept in circular economy product design is product lifetime, which includes long use, extended use, and recovery [13]. Product design based on circular economy has the principle that does not repair what is not broken, do not reproduce what can be repaired, do not recycle products that can be reproduced; the point is to keep the product in its original state as long as possible, thereby minimizing and eliminating environmental costs [48].

Product design based on the circular economy has two objectives, namely slowing down the rotation of material as measured by long-life product and product-life extension and closing the loop of existing material rotation as seen from the technological cycle, biological cycle, and product disassembly and reassembly [49]. The main principles in implementing the circular economy include product design, reuse, recycling, material classification, and renewable energy [50]. At the corporate level, companies can apply design methodologies based on the circular economy with the criteria of green design, design for durability, and design for reverse cycles [51].
Based on the opinions of experts/researchers about product design using circular economy principles, the criteria presented mutually support one another, so in this study, the circular economy-based product design process uses several criteria such as long-term use, extended and extended use, convenience for repair, and environment-based manufacture.

RESEARCH METHODS

This research began with determining the attributes and indicators of product design for a circular economy. This step reflected the characteristics used to convey the attributes and indicators of circular economy products to consumers. The circular economy attributes would be used as a reference in manufacturing gallon pump products made from wood waste, as shown in Table 1.
Determination of product attributes based on the circular economy criteria used literature study methods.

Table 1
Attributes of product indicator

No	Attributes	Indicators	Description
1	Long use The long-term use of the product is related to how strongly the product can be used and the display that convinces consumers [13, 49, 51, 52].	Product durability	The product's strength is that it can be used for a long time.
		Product display	The form of the product must be considered to attract consumer interest and put a sense of trust in buying.
		Product color	
2	Extended use The product is expected to be extended and expanded by its users [13, 49, 52].	Ease of product repair	Consumers can easily repair the products.
		Upgrade function (Additional function)	The product has additional functions; it can be regarded as an upgrade of the product.
		Extended lifespan	The product can be extended after the service life is over.
3	Recovery Product Ease of recovery process, both during use or after use [13, 50, 51, 52].	Product is recyclable	Products can be recycled according to circular economy principles to become new materials or products.
4	Disassembly and reassembly Products are made with a disassembled design system. It facilitates the product to be repaired. It also contributes to segregating materials that enter into biological or technological cycles [49, 50, 52, 53].	Products with disassembly system/modularity	The product uses the disassembly principle by dividing product components into sub-modules with various functions.
5	Biological & technological cycle Products are made with non-hazardous materials so that in the biological cycle, the product can decompose to start a new natural cycle [49, 52].	Product materials	Product material selection does not harm consumers and the environment.
6	Reduce material consumption Products are made using an optimal number of materials, resulting in a streamlined production process characterized by reduced temporal duration and volume. This approach serves to efficiently conserve the employed materials, attesting to a prudent employment of resources [52, 54, 55].	Compact product	The product uses a compact concept, only takes up a little space, and does not use excess material.

Data Collection

The voice of customers for QFD input was obtained by distributing questionnaires to consumers who use gallons and furniture. Interviews/deep interviews with SMEs were also conducted to prepare technical responses. The precise number of gallon users remains undetermined; hence, in order to ascertain the sample population for the voice of the customer respondents, the Lemeshow formula [56] is employed as in Equation 1.

$$n \geq \frac{Z^2 X p X q}{e^2} \quad (1)$$

In this study, a confidence level (Z) of 90% was applied, with α = 10%. Referring to the normal distribution table, Z was determined as 1.65. The proportion value of subjects using gallon (p) was 0.5, while the proportion of subjects not utilizing gallon (q) was also 0.5. The margin of error (e) was set at 10%. The sampling technique employed was purposive sampling, with respondent criteria encompassing adults aged 17 to 45 years, individuals who utilize gallon containers for daily needs, and those who have either owned or purchased furniture. Using Equation 1, the minimum sample size required in this study is 68 respondents. Respondents were provided with a questionnaire designed to assess the ranking levels of attributes pertaining to circular economy-based product design. The questionnaire was divided into two sections: part 1 encompassed respondent demographics, while part 2 encompassed inquiries concerning criteria for product design attributes. After distributing the questionnaires, validity and reliability tests were carried out. The questionnaire was valid if it revealed what would be measured. The validity test shows how valid the data from the questionnaire results are [57]. With a sample value of 70 and a significance level of 0.1, an obtained tabled correlation coefficient (r-table) of 0.1982 is derived. A variable is deemed valid when the computed correlation coefficient (r) exceeds the tabled correlation coefficient (r-table). Reliability testing is conducted to ascertain that the instruments utilized in this study can provide reliable information. A questionnaire is considered reliable when respondents' answers to a given question remain consistent [57]. A variable is deemed reliable when the Cronbach's alpha value exceeds 0.6.

QFD Steps

QFD began with determining product design attributes that function for attribute ranking and as a step in compiling the House of Quality (HoQ) matrix. HoQ is a structure with interrelated matrices that can transform customer needs into technical responses at all levels [58, 59, 60]. This ranking relates to priority attributes that must be prioritized to meet consumer needs. Things that must be considered in the process of assigning variables rankings include:

a. Importance to customers, to examine how strongly the subject considers very unimportant to very important with an indicator in the form of a Likert scale of 1 to 5.
b. Improvement ratio is an evaluation of indicators that aims to identify variables that do not meet the requirements obtained by dividing the plan/target value by importance to the customer.
c. Sales point to measure the influence of product indicators obtained from a commercial perspective, namely during the sales process. A value of 1 signifies insignificance of the indicators, 1.2 indicates moderate significance, and 1.5 indicates high significance in product sales.
d. The relative weight of the level of consumer importance determines each product indicator's relative importance and which indicator is prioritized. The relative weight of the indicator importance is obtained from the multiplication between customer importance, improvement ratio, and sales point, which is normalized to determine the percentage ranking of the indicator.

The next step was determining the technical response. The technical response serves as a reference for the actions to be undertaken for each indicator. Technical responses are solutions for manufacturers to answer consumer desires at the indicator level. Next was preparing the correlation matrix between the level of importance and technical response. This matrix determines the degree of relationship between each customer's desire and the employed technical response. In preparing the correlation matrix for the level of importance and technical response, several symbols are used, namely a solid circle depicting a strong relationship (+9), an empty circle representing a medium relationship (+3), and a triangle indicating a weak relationship (+1).

This was followed by the arrangement of the correlation matrix among technical responses. This matrix serves to identify interrelated technical requirements that either complement or conflict with one another. The construction of this matrix aims to determine the relationship that occurs (contradiction or support). The symbol (+) indicates a positive or supporting relationship between technical responses, and the symbol (–) indicates a negative or contradictory relationship between technical responses. The final step of QFD was determining the absolute and relative weight of the technical response. The absolute weight of the technical response is the sum of the multiplication of the symbol values in the relationship matrix between consumer and technical requirements and the importance of the customer for each customer requirement. The relative weight of the technical response for each customer requirement is obtained by dividing the absolute weight of each technical customer requirement by the total.

TRIZ Steps

The stages of using TRIZ in this study began with determining the specific problem. At this stage, the technical responses were sorted based on the ranking level in the

QFD. After that, several technical responses with a negative correlation would be taken as the top priority, and a solution would be sought. Technical responses, still in the form of specific problems, would be translated into general problem forms in the TRIZ parameters.
Based on the ranking, these parameters would be determined as improving or worsening features after the transition to the TRIZ parameter. The next step was to make a general solution by applying the TRIZ parameter to the contradiction matrix. This stage aims to determine the problems' contradictions and match them with the appropriate parameters of the 39 technical parameters specified in the matrix [61]. Several TRIZ principles would be determined in the contradiction matrix as a solution based on the 40 TRIZ principles [62]. The solution to the contradiction matrix that is known in general would be converted into a specific solution based on the actual conditions of the product to be made.

Product Design

Product design is carried out based on the results obtained from the QFD-TRIZ methodology. The product design process is carried out using Solidworks software, followed by making a prototype of the designed product. Next, calculate the production costs to make the product. The final step is to carry out a functional analysis, economic feasibility analysis, and circular economy analysis of the gallon pump products produced.

RESULTS

Respondent Characteristics

Respondents in this study were individuals living in Indonesia, aged between 20 and 45 years, who had previously used manual/electric pump gallons and had experience in purchasing furniture. A total of 70 respondents were included as the sample population. The respondent is predominantly male, accounting for 57%, with an age range of 20-25 years constituting 53%.

Customer Response of Design Circular Attribute

Respondents were asked to choose their preferences for the solutions provided. The results of respondents' preferences for the best solution regarding design attributes are shown in Table 2.

Table 2
Customers Response

No.	Indicators	Preference	Amount (person)	Percentage (%)
1	Durability	Material thickness	6	8.57
		Material strength	38	54.28
		Type of wood material	23	32.85
		Material connection	3	4.28
2	Product design	Simple	48	70.00
		Carving	22	30.00
3	Product paint (type)	Water-based	53	75.71
		Solvent-based	17	24.28
	Product paint (color)	Walnut brown	12	17.14
		Yellow OX	21	30.00
		Red mahogany	30	42.85
		Papua rose	7	10.00
4	Ease of repair	Disassembly/modularity system	26	37.14
		Use of screws	11	15.71
		Screw combination with disassembly system	33	47.14
5	Additional functions (extra functions)	Extra gallon slot	31	44.28
		Mini table slots	39	55.71
	Additional functions (main functions)	Castor	43	61.42
		Footstool	24	34.28
		No pedestal	3	4.28
6	Extended lifespan	Drawer	32	45.71
		Table	17	24.28
		Another gallon storage	8	11.42
		Rack	13	18.57
7	Recycle	Selection of materials	39	55.71
		Material processing	31	44.28
8	Modularity	Slots system	31	44.28
		Joint system	25	35.71
		Inter-lock system	14	20.00
9	Product materials	Teak wood waste	48	68.57
		Mahogany wood waste	17	24.28
		Raintree wood waste	5	7.14
10	Compact	Flexible	40	57.14
		Precision	30	42.85

Data Processing

Validity and Reliability

A validity test was used to measure whether a questionnaire was valid. The result of the validity test in Table 3 shows that all variables from sales points, consumer importance, and benchmarks are valid because the r-count is greater than the r-table.

Table 3
Validity Result

No.	Variables	r-count Sales Point	r-count Consumer Importance	r-count Benchmark
1	Product durability	0.41	0.55	0.57
2	Product display	0.35	0.61	0.58
3	Product color	0.42	0.41	0.63
4	Ease of Product repair	0.50	0.43	0.52
5	Upgrade function (Additional function)	0.42	0.41	0.62
6	Extended lifespan	0.38	0.41	0.62
7	Product is recyclable	0.57	0.58	0.41
8	Products with disassembly system/Modularity	0.58	0.59	0.42
9	Product materials	0.44	0.59	0.46
10	Compact product	0.63	0.50	0.49

The reliability test determined whether the questionnaire could be consistently employed by respondents across multiple instances, yielding consistent outcomes. This test was conducted using SPSS software and produced a Cronbach alpha value greater than 0.6. It can be concluded that the questionnaire was reliable. The sales point has a Cronbach alpha value of 0.61, consumer importance of 0.67, and a benchmark of 0.71.

Making the HoQ Matrix

The results of calculating the value of consumer importance, improvement ratios, sales points, and the weight of consumer desires, along with the ranking of the attributes of consumer desires, are shown in Table 4.

The next step was to translate the attributes the customer wanted into a technical response. The technical response is a detailed specification used to meet the needs. The design of this technical response was collaboratively undertaken with the SME producers/owners through interview methodology. Technical responses for durability included material quality, material type durability, and assembly method. Product design was translated into product dimensions, shape, and weight. Variations in color and type of paint constituted technical responses to product color.

Table 4
Consumer Importance Value

No	Variables	Importance	Plan	Improvement Ratio	Sales Point	Absolute Weight	Relative weight (%)	Ran-king
1	Product durability	4.41	4	0.91	1.42	5.70	9.55	8
2	Product display	4.31	4	1.16	1.26	6.30	10.56	4
3	Product color	3.57	5	1.40	1.16	5.80	9.72	7
4	Ease of Product repair	4.37	5	1.14	1.29	6.43	10.77	3
5	Upgrade function	4.26	5	1.17	1.25	6.23	10.44	5
6	Extended lifespan	4.09	5	1.22	1.33	6.64	11.12	1
7	Product is recyclable	3.93	5	1.27	1.20	5.99	10.04	6
8	Products with disassembly system/Modularity	4.14	5	1.21	1.29	6.46	10.83	2
9	Product materials	4.30	4	0.93	1.34	5.36	8.98	9
10	Compact product	4.17	4	0.96	1.19	4.76	7.98	10

Ease of repair was translated into five technical responses, which included product size, product shape, assembly method, repair time, and number of components. Additional functions were responded to with product form, dimensions, and innovation. The technical response to extended lifespan was product form and function innovation. Recycling was translated into material types and assembly methods. The assembly/modularity system was divided into four technical responses, which include the number of components, product shape, product dimensions, and assembly method. The technical response of material type and quality was product material. The final consumer needs were addressed by configuring compact products in terms of product form and dimensions.

After determining the technical response, the subsequent step involved determining the correlation between consumer importance levels and technical responses, followed by identifying correlations among different technical responses. Next, the calculation of absolute weight for technical responses is conducted, derived from the multiplication of symbols within the HoQ matrix. The comprehensive results of the house of quality (HoQ) matrix can be found in Fig. 2.

From the result of the technical response, some contradictions made it difficult to manufacture the product. This contradiction occurs when the technical responses contradict each other (have a negative relationship). Contradictory technical responses include (C1) product weight and product dimensions, (C2) repair time and product dimensions, (C3) product weight and function innovation, (C4) repair time and function innovation, (C5) assembly method and quantity components, (C6) repair time and number of components, (C7) function innovation and number of components, (C8) variations in color and type of paint and the last contradiction, and (C9) number of components and modularity. The conflicting technical responses would then be resolved using the TRIZ method.

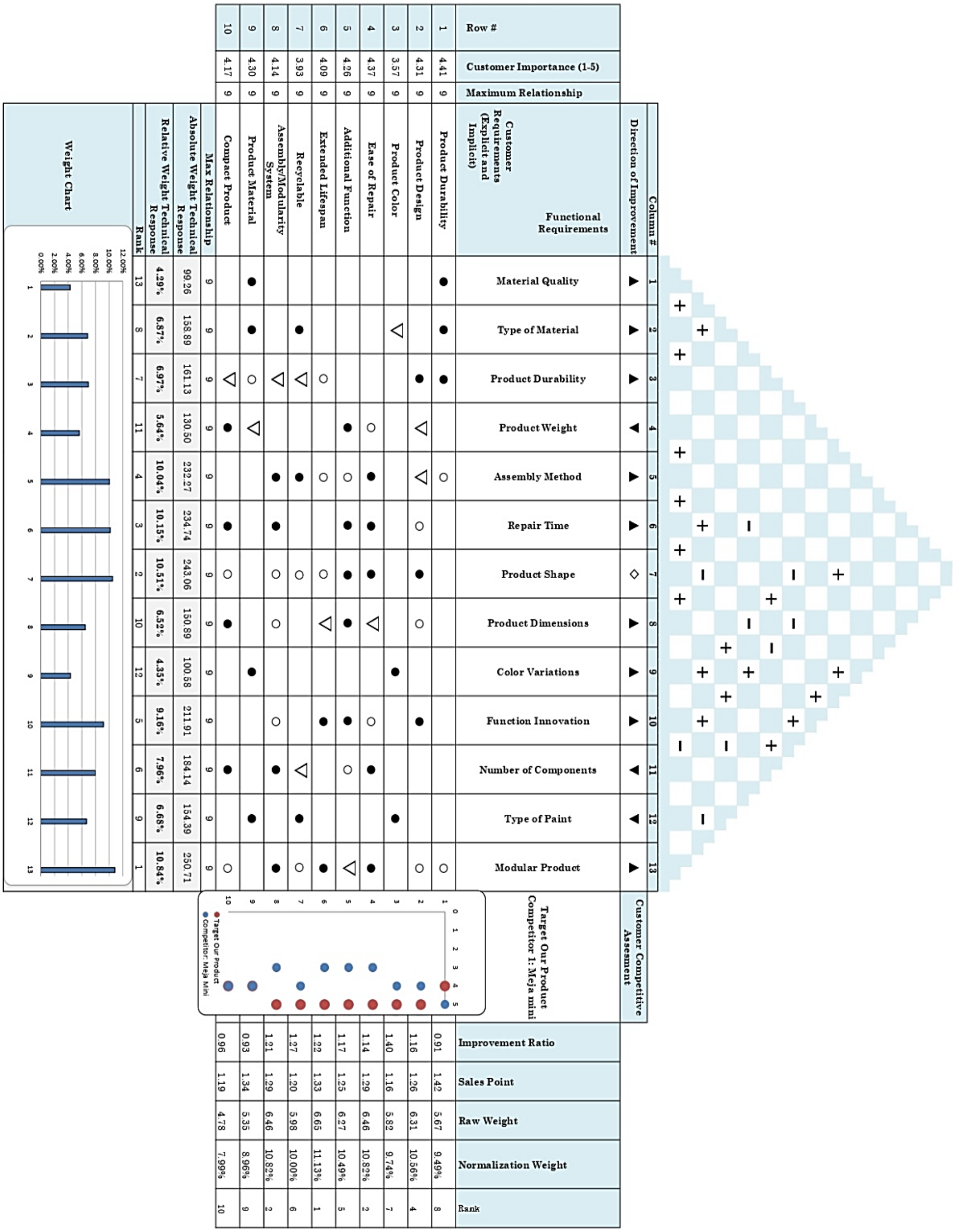

Fig. 2 House of Quality Matrix

TRIZ Contradiction Resolution

The TRIZ methodology resolved contradictions that arise in fulfilling technical responses in QFD. This problem can be overcome by solving TRIZ, starting from determining specific problems, general problems (parameter contradictions), general solutions (matrix contradictions), and specific solutions. Resolving contradictions with the TRIZ methodology is presented in Table 5.

After comparing the contradictions between the TRIZ parameters and the TRIZ principles, as shown in Table 5, eight solutions were selected out of the 40 inventive TRIZ principles regarding the explanation of Ref. [63] to complete the manufacture of this gallon storage innovation product. The eight principles chosen were segmentation, discarding and recovering, composite material, homogeneity, the other way around, local quality, parameter change, and taking out. These eight principles were the basis for making a gallon innovation place that solves the contradictions of QFD's technical response.

The gallon storage innovation product used the principle of segmentation by creating a part system for each component. Installation of the assembly system was made easy with a slot system. Several product components were made modular so that the placement of parts becomes very flexible. The principle of discarding and recovering was applied to the system of additional mini table parts according to the wishes of consumers, which can be removed without affecting the product's function, where gallons storage can be used flexibly. The change from using whole wood material to a combination of waste pieces and wood glue with the maximum adhesive strength of the waste was an application of the composite material principle. The principle of homogeneity was demonstrated through the utilization of homogeneous materials. Consumers desired the use of teak waste, thereby necessitating the incorporation of teak waste in all parts. The principle of the other way round was intended to enable the maneuverability of products or product parts, thereby facilitating ease of use and repair. The mini table used hinges in this design, and the product legs used castors to facilitate movement. For the principle of local quality in the product painting process, customers chose water-based paint types to be more environmentally friendly without using solvent content. Then, finally, the principle of parameter change was demonstrated by making flexible parts so that some parts can be placed interchangeably, maximizing the modular concept. Products were made flexible by converting the product into four-drawer furniture to extend their useful life.

Table 5
Resolving Contradictions with the TRIZ Method

Contra-diction	Improving Factor	Improving Parameter	Worsening Factor	Worsening Parameter	Solution Principle Number	Solution Selection (TRIZ Principle)
C1	Product dimensions	P8: Volume of Stationary Object	Product weight	P13: Stability of the object	34; 28; 35; 40	Discarding and recovering. Composite material.
C2	Function innovation	P12: Shape	Product weight	P13: Stability of the object	33; 1; 18;4	Segmentation Homogeneity.
C3	Assembly method	P32: Ease of Manufacture	Number of components	P26: Quantity of substance	1; 23; 24; 35	Segmentation.
C4	Repair time	P34: Ease of Repair	Product dimensions	P8: Volume of stationary object	1	Segmentation.
C5	Repair time	P34: Ease of Repair	Function innovation	P12: Shape	1; 2; 4; 13	The other way round. Segmentation.
C6	Repair time	P34: Ease of Repair	Number of components	P26: Quantity of substance	2; 10; 25; 28	Taking out.
C7	Paint type	P31: Object-Generated Harmful	Color variations	P26: Quantity of substance	1; 3; 10; 25	Local quality.
C8	Function innovation	P12: Shape	Number of components	P26: Quantity of substance	33; 1; 18; 4	Segmentation. Homogenity.
C9	Modular product	P33: Ease of Operation	Number of components	P26: Quantity of substance	12; 35	Parameter change.

Product Design

After the solution results from the QFD-TRIZ method were obtained, an innovative product design of gallon storage would be made using Solidworks 2017 software. The product display of the design results can be seen in Fig. 3, the complete engineering drawings of the designed product are shown in Fig. 4, and the prototype of the product in Fig. 5.

Fig. 3 Display of product usage without and with gallons

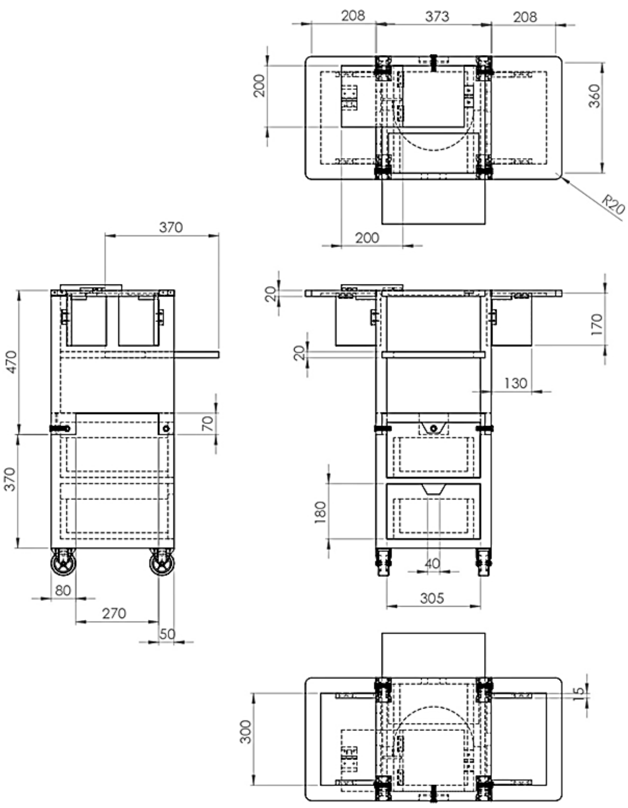

Fig. 4 Engineering Drawing

Fig. 5 Product prototype

Prototype design of product (Fig. 5) was made based on Solidworks design (Fig. 3) with actual size based on engineering drawings (Fig. 4). The gallon storage prototype is designed using assembly-modular principle that have three parts which are lower, upper, and additional components. The detailed description about the product is discussed in functional analysis section.

DISCUSSION

Functional Analysis

This innovative gallon storage product made from waste has a total dimension of 400 mm x 375 mm x 850 mm. This product applied the principle of an assembly-modular system. The product is divided into lower, upper, and additional components. Each component is composed of several types of parts.

At the bottom are two drawer slots containing storage areas for items like glasses. Castor wheels are installed on the lower side to make moving the product more accessible. This bottom component can be combined and removed from the upper component, rendering it more flexible in its utilization.

The upper component has a function as a cap for the gallon when joined with the bottom component. This component also has a function as a supporting foundation for additional components, where the glass will be placed when taking water. This upper component also serves as the foundation for the expandable folding side table slot to expand the product's top surface area. The table expansion slot expands the top area so that consumers can place numerous items on the top side of this product. The upper component consists of two parts of table expansion slots. In addition, there is a wooden part designed to support the table expansion component. These four support parts feature slots that secure the table expansion part, employing a hinge system integrated with an interlocking mechanism between adjacent parts, thus effectively stabilizing the table expansion component.

Additional components consist of two board parts on the primary and lower components and can be moved around according to the existing slots. The first additional component is the top cover, which functions as a glass rest during water retrieval and as the top surface of the product when it is in table mode. Meanwhile, the second additional component functions as a holder for used glasses, a base for taking water from a large/tall container, and as a support for the drawer slot when the product is transformed into a drawer by the consumer.

Cost Benefit Analysis

One method that can be used to analyze and evaluate the effectiveness of waste management is Cost Benefit Analysis [64]. Cost Benefit Analysis (CBA) is a measurement method aimed at determining the value of benefits derived from an activity, assessed from a comprehensive perspective. CBA uses theory, data, and models to test products and sacrifice costs to assess relevant goals [65]. Several researchers used CBA to measure the effectiveness of waste management, such as the scenario of waste management in Romania [66], specifically on food waste in Singapore [67], and in waste management in a broader scope, namely developing countries in Asia. Ref. [68] conducted a life cycle costing assessment for a solid waste management system. Ref. [69] used CBA to measure the integration of waste and energy management.

In the process of manufacturing the product, several costs are taken into consideration, including material costs, labor costs, and others. The product is made from pieces of waste that relate to a total material requirement of 0.066 m^3, with details of material requirements as follows:

- The top part requires two pieces of sideboards and one piece of backboards.
- Drawer boards require two boards, four sideboards, four baseboards, and two backboards.
- Three pieces of baffle-board slots and two pcs table expansion board slots.

Cost requirements for product manufacture include the need for raw materials, supporting materials, and labor costs. The raw materials are waste wood scraps, while the supporting materials include mini hinges, slot locks, wood glue, castor wheels, paint varnish, nails, nuts, and bolts. The total raw materials and supporting materials to make one product is IDR 64,556. Meanwhile, the labor cost per product is IDR 30,000. So, the total cost for making one unit of product is IDR 94,556.

Based on a market survey, this product can be sold for IDR 161,000, so one unit of product will provide a profit of IDR 66,189 with a profit margin of 70%. Every week, SMEs produce an average of ± 13 sacks of waste wood chips, which are sold at IDR 3,000 per sack. One product unit requires 0.066 m^3 of waste or the equivalent of 66 kg of waste, which will require two sacks of 100 kg of wood pieces sold for IDR 6,000. With 52 sacks of cut waste monthly, 39 product units can be made monthly. The profit earned by SMEs per month is IDR 2,581,371. Meanwhile, if it is sold as wood waste, it only sells for IDR 156,000.

Gallon storage innovation products have a price range of around IDR 161,000. With an estimated monthly production of 39 products, furniture SMEs have the potential to earn 2,583% more profit than those selling scrap wood. The price range for gallon porcelain products for SMEs is around IDR 150,000-IDR 200,000, depending on the level of complexity of the carving. Gallon storage products manufactured by SMEs tend to be relatively expensive due to their use of teak wood and complicated carvings. For a general gallon dispenser table, which is a minimalist table with no other functions, the price ranges around IDR 140,000.

On the other hand, the innovative gallon storage product for electric and manual gallon pumps is sold at a higher price of IDR 161,000. This higher price is attributed to the fact that this product offers more functions that were not present in the previously manufactured gallon container products by SMEs. By implementing a circular design that implements a modular, assembly, and life-extending system, this product gains a competitive edge due to its ease of repair and prolonged usability for consumers. Through the modular and assembly system, when a product is damaged, customers do not need to transport the entire product for repair or dispose of it merely due to the difficulty in repair. Instead, they can focus on repairing or replacing the specific faulty part, ensuring efficient resource utilization.

In the case of previous products that were singularly focused and lacked versatility, when the customer no longer needed the gallon container product, the product would be discarded or stored in warehouses. However, in the case of this innovative gallon storage product, its design enables full conversion into a modular drawer table when no longer needed by the consumer. Additionally, this product offers several functions absent from its predecessors, such as storage space and the incorporation of castor wheels, facilitating effortless mobility and cleaning. Thus, despite being fashioned from residual wood boards, this product surpasses current SME products, justifying its price of IDR 161,000, which lies within the desired consumer range. This price point also remains below that of porcelain gallon container products with unique carvings.

Analysis of Circular Design

In making this innovative gallon product, it applies a circular design system, where this design concept is based on the circular economy concept. The circular principles applied in QFD are long-use, extended lifespan, recovery, disassembly and reassembly, biological cycle and technological cycle, and reduced material consumption.

Long-use has three indicators used in the product design concept for this gallon container, which are product durability, product appearance, and product color [13, 49, 51, 52]. In applying the durability to the gallon innovation product, a combination of combining waste with a unique wood resin glue with high adhesiveness is used. In contrast, the type of wood waste used will be equated according to the type of wood to produce strength in each evenly distributed part. In the product design view, the lower part components are made to a minimum the parts that compose it so that the bottom part of the product, which is used to hold gallons, is not easily damaged. The color selection for this product also uses water-based paint, so it is safe for the environment and does not damage the product.

Extended lifespan consists of 3 indicators, which are ease of repair, function upgrades, and life extension [13, 49, 52]. The assembly system for this product makes it easy to make repairs because the components can be separated easily. When a damaged product is to be repaired, it is sufficient to repair only the component which can be removed from the main product. The functional upgrade of this product is demonstrated by the castor wheels, which make the product easier to move; there are drawers for storing items, as well as mini table slots that can expand the top of the product and be removed when not in use. Separation of the upper and lower components does not affect the product's function. If the top part is separated, it can turn into a mini table, while the bottom part can still be a 2-level mini drawer. At extended service life, the product can be transformed into other products by repositioning the accessory slot board into a drawer. Customers have the option to configure the product into four different configurations. Through this extended usage, the product can be used optimally by consumers. The extended lifespan of this innovative product is shown in Fig. 6.

The modular system is the leading indicator of the disassembly and reassembly criteria [49, 50, 52, 53]. The gallon product innovation uses the assembly principle with components that can be assembled, namely the bottom and top components. The modular concept also includes drawer parts, slot board additional components, and table expansion parts. Components can be dismantled and exchanged according to consumer tastes.

Fig. 6 Extended Lifespan of Product

The biological and technological cycle, as well as product recovery in the product manufacturing process, is indicated by the selection of environmentally friendly materials [49, 52] that are recyclable [13, 50, 51, 52]. This includes the use of wood waste as an organic and environmentally benign component, as well as the choice of water-based paint without solvent content, ensuring the product's safety for consumers. Additionally, the product can be safely recycled into backlog mushrooms or compost without worrying about hazardous substances. Reduced material consumption is shown by making products that minimize material usage [52, 54, 55]. The material used is wood waste, so it can save the primary material.

Furthermore, the design to produce this gallon container is rendered minimalist to align with the form of the gallon. The shape is crafted with flexibility, incorporating a folding mechanism for the table extension and allowing for disassembly and reassembly of the product without compromising its core functionality.

CONCLUSION

In the design process, consumers desire a product characterized by simplicity, constructed from teak wood waste, possessing durable materials, water-based components, and modular combination screws, featuring a mini table and castors, incorporating a drawer with a slot system that's recyclable, and flexible. These requirements yield technical responses encompassing material durability, paint selection, product design, ease of repair, and additional functionalities, resulting in technical responses associated with durability, extended usability, modularity, production materials, and compactness. Nine contradictions in the QFD technical response were resolved using the TRIZ method with the final solution for several TRIZ principles including segmentation, discarding and recovering, composite material, homogeneity, the other way round, local quality, parameter change, and taking out. The resulting output is a design of an innovative gallon storage product design for manual and electric gallon pump types.

The result of this pump-gallon product design made from waste can be a reference for application in several large countries producing and exporting wooden furniture such as China, Germany, Italy, Poland, USA, Mexico, and Vietnam which have not utilized waste optimally. However, the results of this research are still limited to the furniture industry using teak wood, which has the advantages of being durable, easy to shape, and easy to maintain. Future research could be explored for other types of waste materials. The principle of the circular economy in this study is presently confined to the concept of product design using circular design methodologies. In future research, this can be expanded to include mathematical calculations within the circular economy framework.

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