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Sustainable Product Design Concept Metrics for Developing the Eco-Bag from Pineapple Leaf Fiber

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Sustainability is a critical issue to be considered by the product designer. Due to the increase in environmental impact caused by the production, sustainability should be implemented in the early phase which is concept development. This study aims to develop the eco-bag concept using the sustainable QFD method and evaluate the developed concept by using metrics for sustainable product design. QFD is used to measure and select the quantitative target and sustainability criteria, whereas the metrics are used to measure the concept evaluation; material, production, use, and end of life. The respondents of this study are career women and students (50 respondents). According to the sustainable House of Quality (HoQ) method, the criteria selected are material, bag size, and price. The score of the metrics concept evaluation is 6.25, which means the concept is good enough to apply sustainable design. This research improves the consideration of the sustainable aspect to facilitate designers in early product concept development.

1. Introduction

Environmental pollution is a critical issue that catastrophically affects the world (Zeinalnezhad et al., 2021). One of the causes of this problem is the consumption of raw materials that have a negative impact on the environment, such as atmospheric pollution, discharge to the natural environment, and harmful effects on biodiversity (Sari et al., 2021). Consideration of the sustainability aspect in the product design concept is important (Jiang et al., 2021). Sustainability assessment in concept design can identify the product that has the lowest impact on the environment but provides social and economic aspects (Ahmad et al., 2018).
The sustainability concept would have parameters such as safety and using non-toxic materials (Norddahl, 2021). So far, a lot of plastic has been used with all pros and cons (Klemeš et al., 2020). Product designers shall be responsible for the design of a good product and thinking of the environment and society. Most of the harvested fruit, such as pineapple, have not been used in all parts (Nguyen et al., 2021). Indonesia has become one of the largest pineapple-producing countries in the world (Salsabila et al., 2021). Some studies were conducted related to the usefulness of pineapple leaf fiber as a fashion material (Jawaid et al., 2020). Pineapple leaf fiber is a good and strong material that can be used in products (Jawaid et al., 2020).
The customers have started to consider of sustainability aspect of the product (Chofreh et al., 2015). The designers need to consider the sustainability requirements of the concept. The early stage of design is the most challenging step because it consumes time and cost; it needs a tool that makes it easier for the designer to combine the voice of the customer and design requirements (Moubachir and Bouami, 2015). QFD is a tool to turn intangible customers' needs into tangible customers' needs. It has been shown in the work of Puglieri et al. (2020), which can be applied in an automotive company in Brazil. This tool is easy to find the relationship among customers' needs but cannot consider the product's whole life cycle. Based on the previous study, QFD is an effective tool to enhance customer satisfaction by combining the ergonomics aspect and comfortability product,

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and it can minimize the time of concept design (Zadry et al., 2015). Ergonomics is about how to design the product and service to become safer, easily useful, and attractive (Faradilla and Purnomo, 2017). Shvetsova et al. (2021) stated that QFD is used to generate a new design concept criterion. Liu et al. (2021) proved that QFD could be integrated with the Analytic Network Process. This study is about how to design furniture for urban people, especially in the pandemic era. It was conducted in China because this country had successfully prevented COVID-19. However, this study does not show the sustainable criteria clearly of the product, but the result proved that the method of QFD-ANP is applicable and effective in the conceptual design process.

Table 1: Sustainable QFD measurement in design concept

Authors	Methods	How the methods measure the sustainable product development concept
Shvetsova et al. (2021)	QFD+AHP (Analytic Hierarchy Process)	In developing the concept, this study was used QFD and AHP and then designed the best concept of competitiveness and design development efficiency
Han et al. (2021)	Sustainable Metrics	This study has aimed to develop the measurement of sustainability aspect in concept development, i.e., production, material, use, and end life
Liu et al. (2021)	QFD+ANP (Analytical Network Process)	This study aims to design urban furniture using QFD combines ANP, which considers usability, health, and sustainability
Frizziero et al. (2021)	QFD+IDeS (Industrial Design Structure)	QFD is used to develop the bicycle concept, but the assessment of the sustainability aspect is assessed implicitly. According to the result, the sustainability assessment of this concept is the use of bicycles did not cause the pollution, low cost, and new habits for health awareness
Rihar and Kušar (2021)	QFD +Concurrent Engineering	Sustainable HoQ is used to assess the changes in the sustainable requirement of the old and new versions of the product
Donnici et al. (2021)	QFD+SDE (Stylistic Design Applications)	SDE was performed to obtain the new concept of the car. The sustainability aspect is considering the ecological (fuel consumption) included in the HoQ matrix as the criterion
Rianmora and Werawatganon (2021)	QFD Kano Model	The customer's wants into product characteristics were translated in HoQ. Then, classify the product's characteristics into three categories; must have, attractive, and expected. The sustainability aspect is explained implicitly
Ocampo et al. (2020)	Fuzzy QFD (FQFD)	The framework was developed by combining the QFD and Fuzzy as multiple attribute decision making. The sustainability criteria were proposed are energy use, waste of food, and resource consumption
Hsu and Lin (2021)	Fuzzy QFD (FQFD)	This study combines Fuzzy and QFD to construct the model of consumer brand attachment and brand experience
Alinizzi et al. (2020)	Fuzzy QFD (FQFD)	This method has been used to combine the requirement of sustainability aspect (socio-economic and environment) and customer requirement
Zadry et al. (2015)	QFD	Design Long Spinal Board (LSB) using QFD based on criteria to improve the customers' satisfaction

The sustainable aspect of product design is sometimes stated at the abstract level, for example, green products and global warming. It needs the tools to measure the level of the sustainable aspect in the concept development phase. Metrics sustainable product design concept is developed to measure the score of sustainability aspect in early design concept (Han et al., 2021). The result of the concept that was developed will measure the sustainable aspect such as material, production, use, and end of life. Table 1 presents the application of QFD in designing the concept product. It shows that QFD can be combined with the sustainable criteria, but the result was shown yet how knowing the sustainability has an impact on the concept product.

The study case of this paper is how to design the concept of the bag for the working woman and the student, which considers the sustainability aspect. The material that is used is pineapple leaf which many found in Indonesia. Respondents for the preliminary study are used, career women and woman students. The chosen

respondents are performed because career women and woman students have many activities using the bag. Therefore, it would be able to support their activities, such as working, hangout and going to campus. The Previous studies used sustainability QFD to develop the concept but did not measure the sustainable score of the concept, and this paper aims to develop the eco-bag concept from pineapple leaf material using sustainable QFD and then evaluate that concept using metrics for sustainable product design.

2. Methods

The stages of this study were conducted in four phases; Identity customer needs, developing the sustainable House of Quality (HoQ), developing the concept, and evaluating the concept metrics for sustainable product design. The respondents of this study are 50, which are 13 career women and 37 students (N = 50).

2.1 Identify customer needs

It is important to understand what customers need, perceptions, expectations, and behaviours about the eco-bag. The voice of the customer's questionnaire was spread to the respondents to obtain the customer's needs. The questions of questionnaires are about the function, the likely-unlikely, and the expectation of the eco-bag. The answer statement of the customers will be translated into the customer's needs which are entered into the HoQ matrix.

2.2 Developing the sustainable HoQ

In the HoQ matrix, there is a relationship between customers' needs and importance ratings from the previous questionnaire. The importance rating used is a 1 (low) to 5 (high) scale (Bossert, 1991). In determining the requirements of the eco-bag, one needs to consider the trade-off of the cases. For example, based on the requirements, the eco-bag has to be unique, low in price, high quality, and use green material. Some people want to eco-bag, which is high quality as the primary criterion, but some people state that the price is the primary criterion. Designers must prevent this trade-off from fulfilling the primary criteria without considering the other side.

Benchmarking is important to be rated and analyzed. The function is to find the weakness of competitors' eco-bag that can be considered to develop in the new product. It can be strategies to emphasize the strength and improvement of eco-bag. These bags used green material, but according to the questionnaire, the respondents stated that these bags are not ergonomic, the price is high, the detail design is unspecified, and just has one design: a shoulder bag.

2.3 Developing the concept

This stage is developing several eco-bag concepts based on sustainable HoQ. In this study, the method is used by using a classification tree. Then, it continued by using a combination table to provide the alternative concepts. After that, the screening concept method was used to select the best concept that fulfilled all of the requirements (Ulrich et al., 2020).

2.4 Evaluating the concept using sustainable product design metrics

The chosen concept was measured by using sustainable product design metrics. These metrics are provided for material, production, use, and end of life, and every metric has a different attribute for assed, as shown in Table 2 (Han et al., 2021). The concept is analyzed and calculated using Eq(1), Eq(2), Eq(3), and Eq(4).

The formulation used for calculating every metric is shown as

$$Metric_{Material} = \frac{9 \times \left(\frac{\sum_{i=1}^{N}(M_1 + M_2) \times M_3}{N}\right)}{8} + 1 \quad (1)$$

$$Metric_{Production} = \frac{9 \times (P_1 \times P_2 \times + P_3) \times P_4}{12} + 1 \quad (2)$$

$$Metric_{Use} = \frac{9 \times U_1 \times (U_2 + U_3)}{8} + 1 \quad (3)$$

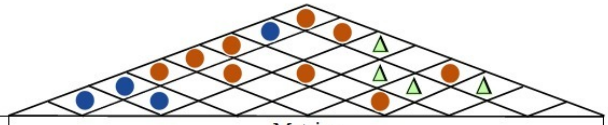
$$Metric_{End\ of\ Life} = \frac{9 \times (E_1 + E_2 + E_3) \times E_4}{12} + 1 \quad (4)$$

3. Result and Discussion

There are two results of this study, sustainable HoQ, and sustainable concept metrics measurement. According to the statistical analysis, the data is sufficient and valid. The sufficient score of N' is 11.94 (N' <N), and the valid score is 0, which means there is no error in the data. The sustainable HoQ required the criteria of the bag, such as function, design, sustainability and economics, as shown in Figure 1. The sustainable concept metrics measurement was used to evaluate the bag in sustainability aspects such as material, production, use, and end of life, as shown in Table 2.

3.1 The sustainable HoQ and product selected concept

The sustainable HoQ was developed according to the voice of the customer, as shown in Figure 1.



Customer Need		Importance Rating	Metrics							
	Needs		Bag Size	Bag Design	Color Variations	Bag Strap Length	Material	Color Material	Bag Hook Design	Price
Function	Easy to Carry	4	●	●		●			△	
	Can be Used in Many Occasions	4	●	●	●	●				●
	Adjustable	5	●			●				
	Comfortable	4	△			●	●			
Design	Aesthethic	4	●	●	●		●			●
	Many Colors Variations	3			●					
Sustainable	Green Material	4					●			●
	Non-Toxic Color	4						●		●
	Design of Bag Hook Can be Reused	4					●		●	
Economic	Low Price	4	●	●			●			●
1	Weak Relation : △	Our Importance Rating	83	64	39	69	84	20	24	79
3	Medium Relation : ●									
5	Strong Relation : ●									

Figure 1: Sustainable HoQ for the eco-bag concept

Sustainable HoQ was developed and obtained that the highest scores of importance rating are material (84), bag size (83), and price (79), as presented in Figure 1. Besides that, the triangle at the top of the table shows the criteria strongly related to material, bag size, and price. The concept must be developed by considering the green material and bag size that can be appropriate when used on any occasion. The price also becomes the priority aspect, which means this concept has a low price than the competitors.

3.2 The sustainable concept metrics measurement

According to the previous result, the concept was selected which has certain criteria. In this section, the concept will be measured the sustainability score regarding four metrics, i.e., the material metric is 5.5, production metric is 10, use metric is 5.5, and end of life metric is 4. Then, the average of all the metrics is 6.25 (Han et., 2021). It means this concept has good enough to consider the sustainability aspect, as shown in Table 2.

4. Conclusions

This study proposed a sustainable product design concept using the QFD method to design an eco-bag using pineapple leaf fiber. According to the statistical analysis, the data have shown the respondents were sufficient and valid. As the result of sustainable HoQ, the concept has material, bag size, and price. This concept measured the sustainability aspect using the sustainable concept metrics and obtained the metrics: material is 5.5, production is 10, use id 5.5, and end of life is 4. The average score of 6.25 means the concept is good enough to apply the sustainability aspect. The indicators should be improved in every metric to increase the score. For example, stainless steel is used in this concept which is categorized as eco-material. If the score wants to be increased, it needs to change become eco-material. This result can contribute to improving the sustainability issue, especially in the early stage. This eco-bag concept used green material, which is pineapple leaf fiber. This material is including of degradable material, thus having a low impact on the environment. This concept uses non-toxic colors. It will be safe to use the people and environment. This eco-bag also uses the

modular design of the bag hook. The material is stainless steel, but it was designed to be reused. This study will be extended by developing the prototype of the eco-bag based on these criteria. This eco-bag concept was made in prototype and produced the bag that involves disabled people. The following study will add some methods to measure the sustainability aspect to improve the sustainability score in designing the concept. The limitation of this study is the concept did not perform the maximum capacity and durability of the eco-bag in carrying the goods. The application of this study in designing the concept of eco-bag is using pineapple leaf fiber. But it can be used in similar products and green materials that can be adjusted based on another country.

Table 2: Sustainable concept metrics measurement

Metrics	Attributes	Concept
Material	Material Origin (M1)	Pineapple leaf fiber cloth (1); Stainless steel (0); Bamboo (2); Natural dye (2)
	Material Property (M2)	Pineapple leaf fiber cloth (1); Stainless steel (1); Bamboo (2); Natural dye (2)
	Use of Material – Quantity (M3)	Pineapple leaf fiber cloth (1); Stainless steel (1); Bamboo (2); Natural dye (2)
	Use of Material – Type (N)	4
Material Metric		5.5
Production	The balance between the Number of Parts and Complexity (P1)	2
	Parts Standardisation (P2)	2
	Parts Design for Assembly (P3)	2
	Suitable Fabrication Method (P4)	2
Production Metric		10
Use	Product Use Time /Lifetime	1
	Energy Consumption during Time	2
	Robustness, Reliability and Maintenance	2
Use Metric		5.5
End of Life	Reuse	1
	Recycling, Remanufacturing, and Repair	1
	Disposal	2
	Ease of Disassembly	1
End Of Life Metric		5.5
Average		6.25

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References

Ahmad S., Wong K.Y., Tseng M.L., Wong W.P., 2018, Sustainable product design and development: A review of tools, applications, and research prospects, Resources, Conservation & Recycling, 132, 49–61.

Alinizzi M., Haider H., Almoshaogeh M., Alharbi F., Alogla S.M., Al-Saadi G.A., 2020, Sustainability assessment of construction technologies for large pipelines on urban highways: Scenario analysis using fuzzy QFD, Sustainability, 12, 1–20.

Bossert J.L., 1991, Handbook of Quality Function Deployment A Practitioners Approach, ASQC Quality Press, New York, USA.

Chofreh A.G., Goni F.A., Shaharoun A.M., Ismail S., 2015, A review on sustainability transformation roadmaps using project management methodology, Advanced Science Letters, 21, 133–136.
Donnici G., Frizziero L., Liverani A., Buscaroli G., Raimondo L., Saponaro E., Venditti G., 2020, A new car concept developed with stylistic design engineering (SDE), Inventions, 5, 1–22.
Faradilla A., Purnomo M.R.A., 2018, Development of ergonomic website for engineering education, MATEC Web of Conferences, 154, 1–5.
Frizziero L., Liverani A., Donnici G., Giuliano I., Picciariello M.G., Tucci M.L., Reimer D., Ali A., 2021, Application of ides (Industrial design structure) to sustainable mobility: Case study of an innovative bicycle, Inventions, 6, 1–27.
Han J., Jiang P., Childs P.R.N., 2021, Metrics for measuring sustainable product design concepts, Energies, 14, 1–19.
Hsu T.H., Lin L.Z., 2021, A multidimensional fuzzy quality function deployment design for brand experience assessment of convenience stores, Mathematics, 9, 1–24.
Jawaid M., Asim M., Tahir P.M., Nasir M., 2020, Handbook of Pineapple Leaf Fibers Processing, Properties and Applications, Springer, Singapore.
Jiang P., Dieckmann E., Han J., Childs P., 2021, A bibliometric review of sustainable product design, Energies, 14, 1–16.
Klemeš, J.J., Fan, Y.V., Jiang, P., 2020. Plastics: friends or foes? The circularity and plastic waste footprint, Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 1–17.
Liu J., Kamarudin K.M., Liu Y., Zou J., 2021, Developing pandemic prevention and control by ANP-QFD approach: A case study on urban furniture design in China communities, International Journal of Environmental Research and Public Health, 18, 1–26.
Moubachir Y., Bouami D., 2015, A new approach for the transition between QFD phases, Procedia CIRP, 26, 82–86.
Nguyen C.T.X., Bui K.H., Truong B.Y., Do N.H.N., Le P.T.K., 2021, Nanocellulose from pineapple leaf and its applications towards high-value engineering materials, Chemical Engineering Transactions, 89, 19–24.
Norddahl B., 2021, Chemical product design in a sustainable environment, Chemical Engineering Transactions, 26, 1339–1344.
Ocampo L.A., Labrador J.J.T., Jumao-as A.M.B., Rama A.M.O., 2020, Integrated multiphase sustainable product design with a hybrid Quality Function Deployment – Multi Attribute Decision Making (QFD-MADM) framework, Sustainable Production and Consumption, 24, 62–78.
Puglieri F.N., Ometto A.R., Salvador R., Barros M.V., Piekarski C.M., Rodrigues I.M., Netto O.D., 2020, An environmental and operational analysis of quality function deployment-based methods, Sustainability, 12, 1–18.
Rianmora S., Werawatganon S., 2021, Applying quality function deployment in open innovation engineering, Journal of Open Innovation: Technology, Market, and Complexity, 7, 1–18.
Rihar L., Kušar J., 2021, Implementing concurrent engineering and QFD method to achieve the realization of sustainable project, Sustainability, 13, 1–28.
Salsabila P.R., Boonraksa A., Indriani I., Ilma S., Sakina S.I., 2021, Cradle-to-gate life cycle assessment of pineapple leaf fibers, Atlantis Press, 625, 130–139.
Sari E., Ma'aram A., Shaharoun A.M., Chofreh A.G., Goni F.A., Klemeš J.J., Marie I.A., Saraswati, D., 2021, Measuring sustainable cleaner maintenance hierarchical contributions of the car manufacturing industry, Journal of Cleaner Production, 312, 1–16.
Shvetsova O.A., Park S.C., Lee J.H., 2021, Application of quality function deployment for product design concept selection, Applied Sciences, 11, 1–19.
Ulrich K., Eppinger S., Yang M.C., 2020, Product Design and Development, 7th (Ed.), McGraw-Hill Education, New York, USA.
Zadry H.R., Rahmayanti D., Susanti L., Fatrias D., 2015, Identification of design requirements for ergonomic long spinal board using Quality Function Deployment (QFD), Procedia Manufacturing, 3, 4673–4680.
Zeinalnezhad M., Chofreh A.G., Goni F.A., Hashemi L.S., Klemeš J.J., 2021, A hybrid risk analysis model for wind farms using Coloured Petri Nets and interpretive structural modelling, Energy, 229, 120696.