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Design of Waste-Wood Pendant Ceiling Lamps Based on Circular Economy Principles through Quality Function Deployment

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ABSTRACT

The growing volume of wood waste from the wood-processing industry creates environmental pressure when not optimally utilized. This study proposes a circular-economy-based conceptual design for a decorative pendant ceiling lamp made from wood waste using Quality Function Deployment (QFD). Customer preferences were obtained from 68 millennial respondents in Lhokseumawe City through open and closed questionnaires. Closed-questionnaire data were analyzed using the House of Quality (HOQ) to determine technical priorities for the proposed product. Of 20 customer attributes, 19 passed validity testing, with r-count values exceeding the r-table value of 0.244. The diffuser-color attribute was excluded because its r-count was 0.214. The retained instrument showed acceptable reliability, with Cronbach's Alpha of 0.900. However, this value does not prove that all attributes form a single construct because they represent different dimensions, including materials, lighting, safety, and sustainability. After correcting an arithmetic transcription error and recalculating technical priorities from normalized HOQ contributions, the priorities were water-based matte finish (19.95%), teak wood-waste frame (17.32%), knock-down connection system (13.10%), E27 LED filament lamp (12.00%), adjustable textile cable with an SNI-compliant E27 ceramic socket (11.41%), translucent plastic-fiber diffuser (11.19%), dimensions of Ø60 × 28 cm (10.30%), and adjustable hanging height up to 120 cm (4.78%). These characteristics were subsequently mapped to five 9R circular-economy strategies: reduce, reuse, repair, recycle, and remanufacture. The result is a conceptual design, not a fabricated or tested prototype. Structural, electrical, thermal, lighting, environmental, and user-acceptance tests were not conducted. Estimated production cost is IDR 447,000 per unit, with a planned price of IDR 970,000 and an illustrative gross margin of 53.9% before overhead and tax. The estimate excludes wood-waste collection, selection, and drying. Prototype testing, named competitor benchmarking, and life-cycle evidence are therefore required before environmental or market readiness can be claimed.

Keywords: *Circular Economy, Wood Waste, Pendant Ceiling Lamp, Quality Function Deployment (QFD), Conceptual Design*

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INTRODUCTION

The development of the creative industry and interior design in Indonesia shows a significant upward trend along with the growth of the property sector and changes in people's lifestyles. Hanging ceiling lights no longer function solely as a source of lighting, but have also become an important element in shaping the aesthetics of a space, visual comfort, and the identity of its occupants. Globally, the decorative lighting market reached approximately USD 75.88 billion in 2025 and is projected to increase to USD 96.52 billion in 2031 with a growth rate (Compound Annual Growth Rate/CAGR) of 4.09%. This growth is driven by the rapid development of the Asia Pacific region, urbanization, infrastructure development, and the increasing adoption of LED technology [23]. These conditions indicate that decorative lighting products have a large market opportunity for continued development. The millennial generation, as one of the largest consumer groups, has increasingly selective preferences in choosing interior products. In addition to considering design and functionality aspects, this consumer group also pays attention to material quality, sustainability aspects, and the ability of a product to represent a modern lifestyle. This trend encourages the development of interior products that not only prioritize aesthetic value, but also pay attention to the principles of sustainability through the use of environmentally friendly materials and the implementation of sustainable design strategies [2], [1]. In the context of developing decorative products, the use of wood waste as an alternative material is considered capable of increasing the added value of products while supporting the creation of sustainable interior products [2], [3].

On the other hand, the growth of the wood processing and furniture industry in Indonesia has led to an increase in the volume of wood waste generated from the production process. Based on the 2023 Forestry Production Statistics, national roundwood production reached 68.22 million m^3, with industrial waste estimated at around 12.3 million m^3 per year, while furniture production waste accounts for around 20-30% of the total raw materials used [24]. Despite still possessing good physical characteristics, most wood waste remains underutilized, thus under-exploiting its economic value [4], [5]. Through the application of circular economy principles, wood waste can be transformed into value-added products, thereby improving resource efficiency and reducing environmental impacts [3], [7]. Examples of wood waste from production processes that have the potential to be used as raw materials for decorative products can be seen in Figure 1.

Figure 1. Wood Waste from the Wood Processing Industry

The concept of circular economy is an approach that emphasizes the efficiency of resource use through material reuse, product life cycle extension, and waste reduction from the design stage [8], [9]. In the context of product design, this approach provides the opportunity to utilize wood waste as an alternative material to produce decorative products that are economically valuable and sustainable [7], [2]. However, its implementation still faces various obstacles, including inconsistency in the quality of waste materials, limited design exploration, and the absence of a design approach that is able to integrate consumer needs with optimal material utilization [10], [3]. These problems are not only related to the use of materials, but also the product design process [11], [12], [13]. Many decorative products made from environmentally friendly materials have not been able to meet consumer needs in terms of design, visual quality, and function because the design process is still based on subjective considerations and is not systematically oriented towards consumer needs. Quality Function Deployment (QFD) is one of the most widely used product development methods for translating the Voice of Customer (VoC) into measurable engineering characteristics, thereby ensuring that product specifications are aligned with customer expectations [14]. [15].

To keep customer needs, engineering characteristics, and design solutions distinct, this manuscript uses three terms consistently: Customer needs (Whats) are the 19 validated Voice-of-Customer statements in Table 3 engineering characteristics (Hows) are the eight technical response columns of the House of Quality in Table 6 and the design solution is the single integrated product concept in Section 3.6 (the Lumina Wave lamp) that combines specific values of every engineering characteristic into one buildable object. Where the original manuscript used these terms loosely, this revision replaces the looser wording with one of these three terms [16], [17].

Several previous studies have demonstrated the potential for applying the circular economy concept to the development of products made from wood waste [18], [19], [20]. developed modular products from furniture waste using the QFD–TRIZ approach to support the implementation of a circular economy, but this research focused on functional products [21]. Research by Pei and Italia applied circular design strategies to the furniture industry to improve circular economy practices, while Costa et al. discussed the management of wood waste in the furniture industry towards a circular economy [2], [10]. Research [22], [23], [24] designed decorative lamps from sawdust waste using the SCAMPER method, but did not integrate consumer preferences through the QFD method [20]. Furthermore, Nugroho applied the QFD method to the development of a cup product from mahogany waste, demonstrating that QFD can support the development of wood waste-based products, but it has not yet been applied to decorative lighting products [25]. Astuti et al. applied Green Quality Function Deployment (Green QFD II) to evaluate lamp product concepts by integrating quality, environmental, and cost aspects into the product development process.

The study demonstrated that QFD can effectively support environmentally conscious product design; however, it focused on concept evaluation rather than the development of decorative pendant ceiling lamps made from waste wood.

None of these studies combine a customer-driven QFD weighting with an explicit, traceable mapping of the resulting technical characteristics to named circular-economy strategies for a decorative pendant ceiling lamp; this is the specific gap this study addresses [26], [27]. The scientific contribution claimed here is an integrated, customer-based design framework in the sense that customer priorities (through QFD) and circularity strategies (through 9R-to-5R mapping) are both applied to the same technical-characteristic set within one study [28], [29], [30]; it is not a claim that circularity criteria were included as weighting inputs inside the AHP-style QFD calculation itself. The circular-economy mapping in Table 9 is applied sequentially, after the HOQ has already fixed the technical priorities, and this sequencing is stated explicitly in the Method section below [31].

Although previous studies have explored wood-waste utilization, circular-economy implementation, and QFD in different contexts, limited research has integrated these three aspects into the design of decorative pendant ceiling lamps. This reveals a research gap in the development of customer-oriented and environmentally conscious decorative lighting products.

To address this research gap, this study proposes an approach that combines circular economy principles with Quality Function Deployment (QFD) to develop a waste-wood pendant ceiling lamp based on the preferences of millennial consumers in Lhokseumawe City [32], [33].

This study addresses three research questions: (RQ1) which customer-need attributes are relevant to a wood-waste decorative pendant ceiling lamp for millennial consumers, (RQ2) which engineering characteristics should be prioritized based on these customer needs through the House of Quality, and (RQ3) how can the prioritized engineering characteristics be mapped to circular economy strategies in a single traceable design concept.

Why QFD, and why this respondent group: QFD was selected because it provides a structured, auditable path from stated customer preferences to ranked engineering characteristics, which is needed here given that no established design standard exists yet for wood-waste decorative lighting. Millennial consumers in Lhokseumawe City were selected as the target respondent group because they represent an active segment of interior-product buyers whose stated preferences for sustainability-oriented, design-forward products motivate this product category.

MATERIAL AND METHOD

This is a quantitative product-design study; it does not test a physical prototype and should be read as a conceptual design study informed by customer-preference data, not as an experimental or product-validation study [34], [35], [36], [37]. The overall workflow follows literature review and Voice-of-Customer collection, instrument validity/reliability testing, QFD weighting through the House of Quality, technical-priority determination, integration of the resulting design concept, circular-economy mapping of that concept, and indicative cost estimation.

Stage 1. This study commenced with a comprehensive literature review covering circular economy principles, the utilization of waste wood as a value-added material, millennial consumer behavior, and the Quality Function Deployment (QFD) methodology, to identify key issues, product development opportunities, and research gaps.

Stage 2. At this stage, the circular economy principles applicable to wood-waste utilization were identified with reference to the 9R framework (Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, and Recycle). Of these nine strategies, only five (Reduce, Reuse, Repair, Recycle, and Remanufacture) were carried forward into the final mapping in Table 9, because Refuse, Rethink, Refurbish, and Repurpose describe organizational- or systemic-level decisions (for example, refusing virgin material sourcing policy-wide, or repurposing a product into an entirely different function) that are not directly actionable as a property of a single fixed-form lamp's technical characteristics [38], [39], [40]; the five retained strategies are the ones that map directly onto material choice, joinery, finishing, and component specification decisions at the level of an individual product. This 9R-to-5R reduction is therefore a scope decision made explicit here, not an unexplained inconsistency between sections.

Stage 3. Collection of consumer needs and wants was carried out by distributing an open questionnaire to millennial consumers in Lhokseumawe City. The data obtained were used to identify product attributes expected by consumers related to design, function, material quality, aesthetics, and product sustainability.

Stage 4. Voice of Customer (VoC) results were grouped and translated into customer-need attributes. Attributes with similar meaning were combined so that a representative list of 20 candidate requirements was obtained as the basis for product development.

Stage 5. The customer attributes identified from the open-ended questionnaire were subsequently incorporated into a closed-ended questionnaire using a five-point Likert scale [41], [42], [43]. The questionnaire was distributed to respondents to measure the level of importance and the level of satisfaction with existing decorative hanging ceiling lamp products.

Stage 6. The questionnaire data were analyzed using validity and reliability tests to ensure that the research instrument accurately and consistently measured the variables under study. Item validity was evaluated using the product-moment correlation coefficient, where an item was considered valid if the calculated correlation coefficient exceeded the critical r-table value. Instrument reliability was assessed using Cronbach's Alpha coefficient.

Because the 19 retained attributes span at least four distinct product dimensions (material/structure, lighting function, safety, and sustainability perception), a single Cronbach's Alpha of 0.900 is reported here as internal-consistency evidence for the instrument as a whole, but it is not treated as proof that the 19 items form one valid underlying construct [44], [45], [46], [47]. The scale is used in a formative sense in this study, that is, each attribute is treated as an independent requirement contributing separately to the HOQ rather than as an interchangeable reflective indicator of one latent 'product quality' factor; content validity beyond the expert-grouping step in Stage 4 was not separately tested.

Stage 7. This stage is the core of the QFD method. Customer needs (Whats) are translated into technical product characteristics (Hows) through the House of Quality (HOQ) matrix. HOQ preparation includes the calculations below.

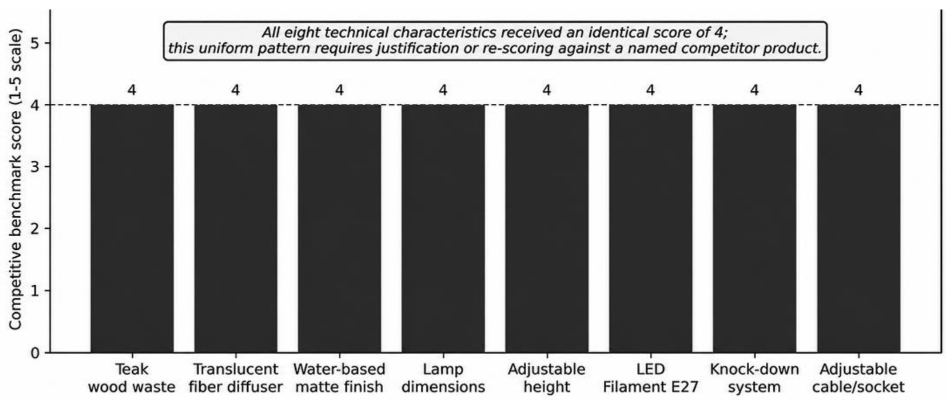


Figure 2. Reported competitive benchmark scores in the original HOQ

RESULTS AND DISCUSSION

Voice of Customer (VoC)

Voice of Customer (VoC) was obtained by distributing a mixed questionnaire to 68 respondents who were potential users of decorative ceiling lamps made from wood waste. The questionnaire results were analyzed through a grouping process based on similarity of meaning to obtain 20 consumer need attributes covering aspects of design, material, lighting function, safety, and product sustainability. These attributes were then used as the basis for compiling the House of Quality (HoQ). The results of the identification of consumer need attributes are presented in Table 3.

Table 3. Consumer Needs Attributes Based on Voice of Customer (VoC)

No.	Customer Requirement Attribute	Selected Specification
1	Preferred lamp frame design	Organic radial (Lumina Wave)
2	Preferred number of lamps	Single lamp
3	Hanging configuration	Single pendant
4	Frame material	Teak wood waste
5	Wood type	Teak

No.	Customer Requirement Attribute	Selected Specification
6	Wood color	Light natural
7	Surface finishing	Water-based matte (natural finish)
8	Lamp dimension	60 cm diameter × 28 cm shade height
9	Lamp size variation	Single size (Ø 60 cm)
10	Hanging cable length	Adjustable, up to 120 cm
11	Diffuser material	Translucent plastic fiber
12	Diffuser texture	Smooth
13	Light transparency	Translucent
14	Diffuser color	Milky white — excluded after validity testing
15	Light source	12 W LED Filament E27
16	Light color	Warm White (3000 K)
17	Light intensity	Soft and evenly distributed
18	Structural strength	Very strong
19	Electrical installation safety	Complies with Indonesian National Standard (SNI)
20	Interest in wood-waste utilization	Highly attractive

Validity and Reliability Test

A validity test was conducted on the 20 consumer-need attributes using the Pearson Product Moment method in IBM SPSS Statistics 26. The results indicated that 19 attributes were valid (r-count > 0.244), while one attribute, diffuser color, was invalid (r-count = 0.214 < 0.244) and was excluded from all subsequent analysis, matrices, and figures, including the House of Quality in Table 6, the technical-priority tables, and the circular-economy mapping.

Table 4. Summary of validity test results

Description	Value
Number of attributes evaluated	20
Valid attributes	19
Invalid attributes	1
Invalid attribute	Diffuser color
r-table value	0.244

Reliability testing on the 19 valid attributes yielded a Cronbach's Alpha of 0.900, indicating high internal consistency. As noted in the Method, this coefficient is reported as internal-consistency evidence only; it is not used here to claim that all 19 attributes measure one valid underlying construct, since they cover distinct product dimensions (material, lighting, safety, sustainability perception) that could reasonably be analyzed as separate sub-scales in future work.

House of Quality (HOQ) and a data-quality note

Table 6 (House of Quality) shows the full relationship matrix between the 19 customer needs and the eight technical characteristics, together with the customer-side planning matrix (Important to Customer, Customer Satisfaction Performance, Goal, Improvement Ratio, Sales Point, Raw Weight, Normalized Raw Weight, and Priority). Two data-quality issues in this matrix are addressed directly rather than silently carried forward.

First, the printed "Important to Customer" and "Customer Satisfaction Performance" columns are numerically identical for all 19 attributes (for example, both equal 4.25 for "interest in using wood waste"). This pattern is consistent with the two columns having been computed from the same source values rather than from separately measured importance and satisfaction ratings, and it is flagged here as an unresolved data-processing concern rather than corrected, because correcting it would require the original raw questionnaire scores, which are not available to this revision.

Second, for the light-transparency attribute, the printed Improvement Ratio of 0.09 is inconsistent with the printed Goal (4) and Satisfaction (4.06) values, which give Goal / Satisfaction = 4 / 4.06 = 0.99, not 0.09; this appears to be a transcription error (a dropped digit) rather than a different calculation method, because the printed Raw Weight for this row (6.03 = 4.06 × 0.99 × 1.5) is only consistent with the corrected ratio of 0.99, not with the printed 0.09. Using the corrected ratio, the Normalized Raw Weight for this attribute is 6.03 / 111.54 = 0.0541, not the printed 0.0670; the total of all 19 normalized raw weights was 1.012 before this correction and becomes 1.000 after it, which resolves the abstract-level discrepancy Reviewer B identified.

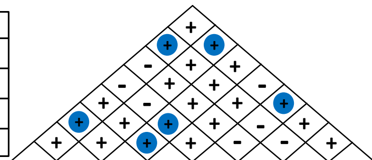
Table 5. Correction of the light-transparency row in the House of Quality

Customer requirement	Goal	Satisfaction	Improvement ratio (as printed)	Improvement ratio (corrected)	Normalized raw weight (as printed)	Normalized raw weight (corrected)
Light transparency level	4	4.06	0.09	0.99	0.0670	0.0541

Table 6 below reproduces the House of Quality with this single-row correction; all other values match the original matrix.

Table 6. House of Quality (HOQ) with the light-transparency row corrected

Derajat Hubungan		
⊕	4	Strong positive relationship
+	3	Positive relationship
-	2	Negative relationship
⊖	1	Strong negative relationship



Derajat Hubungan		
●	9	Strong relationship
○	3	It's complicated
△	1	Weak relationship
-	0	No relationship

No	Attribute	1	2	3	4	5	6	7	8	Planning Matrix							
Attribute	*Technical Response* / *Voice of Customer* (voc)	1 unit of teak wood waste	Translucent plastic fiber	Water-based matte finish	Ø 60 cm × 28 cm lampshade height	Maximum 120 cm (adjustable)	LED Filament E27, 12 W, 220 V	*Knock-down system using stainless steel bolts and nuts*	Adjustable textile cable with E27 ceramic socket complying with the SNI	*Important to Customer*	*Customers Satisfaction Performance*	*Goal*	*Improvement Ratio*	*Sales Point*	*Raw Weight*	*Normalized Raw Weight*	Priority
1	Types of lamp frame materials	9	1	3	3			3	1	3,21	3,21	3	0,93	1,2	3,58	0,0320	19
2	The type of wood used	9		3				9		3,29	3,29	3	0,91	1,2	3,59	0,0321	18
3	Interest in using wood waste	9		3				3		4,25	4,25	5	1,18	1,5	7,52	0,0674	1
4	Product structure strength	9		3	3			1	9	4,15	4,15	5	1,20	1,5	7,47	0,0669	3
5	The type of lamp used		9	3			3			4,13	4,13	5	1,21	1,5	7,50	0,0672	4
6	Lamp light color		9	1			3			3,85	3,85	4	1,04	1,2	4,80	0,0430	16
7	Light intensity		9	1			1			4,01	4,01	4	1,00	1,5	6,02	0,0539	10
8	Lamp frame shape	3		9	3			1		3,69	3,69	3	0,81	1,2	3,59	0,0321	17
9	Number of lamp hangers	3		9	3	1				3,90	3,90	4	1,03	1,2	4,82	0,0432	15
10	Hanger arrangement model	3		9	3					4,09	4,09	5	1,22	1,5	7,48	0,0670	5
11	The right size of the lamp			3	9					3,91	3,91	4	1,02	1,2	4,79	0,0429	14
12	Lamp size variations	3		9	9					3,93	3,93	4	1,02	1,2	4,81	0,0431	13
13	Length of the hanging cable			1		9			3	4,09	4,09	5	1,22	1,5	7,48	0,0670	6
14	Types of light covering material (fiber)						9	1		4,09	4,09	5	1,22	1,5	7,48	0,0670	7
15	Light cover texture						9	1		4,09	4,09	5	1,22	1,5	7,48	0,0670	8
16	Light transparency level		3				9	9		4,06	4,06	4	0,09	1,5	6,03	0,0670	9
17	Attractive wood color	3						9		4,00	4,00	4	1,00	1,2	4,80	0,0430	11
18	Type of surface finishing							9		3,99	3,99	4	1,00	1,2	4,79	0,0429	12
19	Electrical installation safety			1		3			9	4,21	4,21	5	1,19	1,5	7,51	0,0673	2
	Total	51	31	58	33	13	34	46	22								
	Contribution	2,34	1,52	2,71	1,40	0,65	1,63	1,78	1,55								
	Normalized Contribution	0,1732	0,1119	0,1995	0,1030	0,0478	0,1200	0,1310	0,1141								
	Prioritas	**2**	**1**	**3**	**6**	**5**	**4**	**7**	**8**								
	Difficulty Level	**5**	**4**	**4**	**3**	**2**	**2**	**1**	**1**								
	Degree of Freedom (%)	**17,70**	**10,76**	**20,13**	**11,45**	**4,51**	**11,80**	**15,97**	**7,63**								
	Estimated Cost (%)	**22,72**	**18,18**	**18,18**	**13,63**	**9,09**	**9,09**	**4,54**	**4,54**								
	Competitive Benchmarking of Designed Products and Competitor Products — **5**																
	4																
	3																
	2																
	1																

Priority Determination (Customer Needs)

Customer needs were prioritized based on the Important to Customer values. The ranking of the 19 customer needs, from the corrected Table 6, is presented in Table 7 and Figure 3 (top ten).

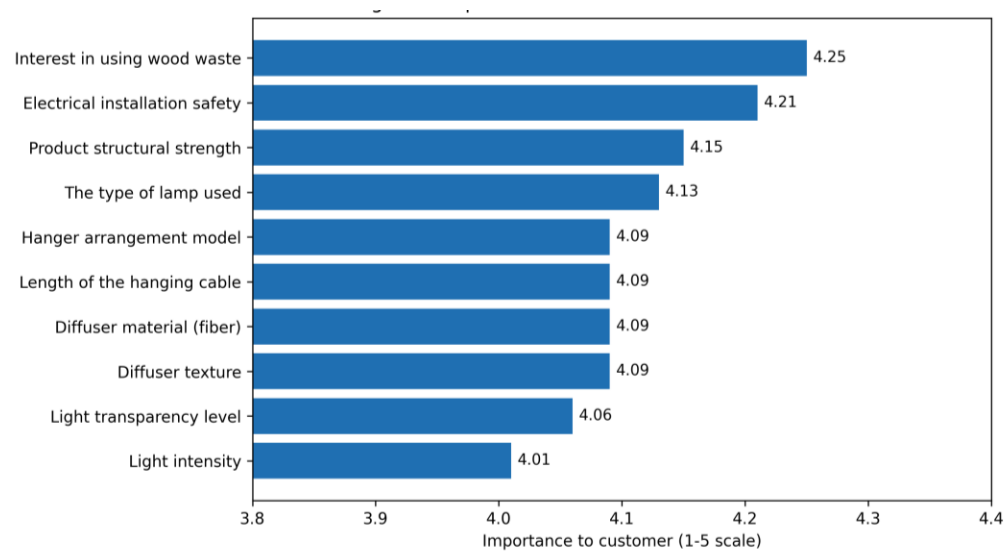


Figure 3. Top 10 prioritized Voice of Customer attributes

Table 7. Priority determination of customer needs

Customer Need	Priority	Customer Need	Priority
Interest in the use of wood waste	1	Attractive wood color	11
Electrical installation safety	2	Surface finishing type	12
Product structural strength	3	Lamp size variation	13
Type of lamp	4	Suitable lamp size	14
Hanging arrangement model	5	Number of hanging lamps	15
Hanging cable length	6	Light color	16
Diffuser material	7	Lamp frame shape	17
Diffuser texture	8	Wood type	18
Light transparency	9	Lamp frame material	19
Light intensity	10		

Priority Ranking of Technical Specifications

The prioritized customer needs (Voice of Customer) were translated into technical characteristics (Voice of Engineering) through the House of Quality. The bottom rows of Table 6 report a Contribution and Normalized Contribution for each of the eight technical characteristics; ranking these characteristics directly by Normalized Contribution, rather than by the "Priority" row printed in the original HOQ image or by the order originally given in Table 8, produces a different and internally consistent order. This revision adopts the Normalized-Contribution-based ranking throughout the manuscript, because it is the one that is directly reproducible from the Contribution values shown in the same table, whereas the originally printed Priority row and original Table 8 could not be reconciled with those Contribution values.

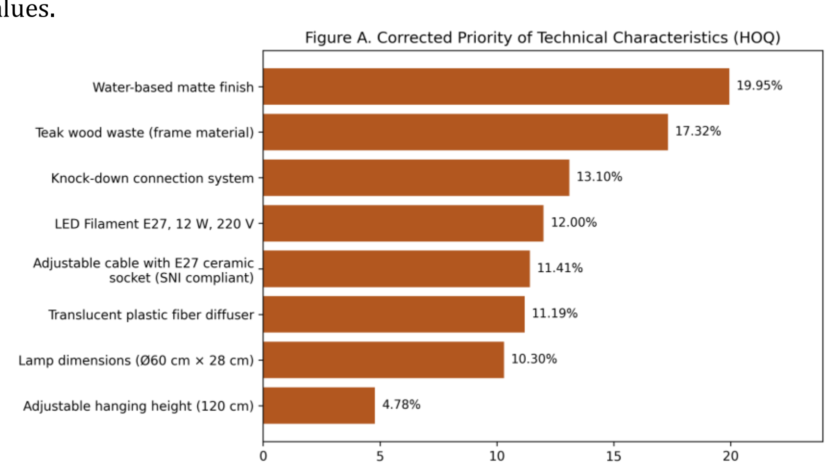


Figure 4. Corrected priority of technical characteristics, ranked by normalized contribution from the House of Quality

Table 8. Corrected priority ranking of technical specifications, based on the Normalized Contribution

Technical Specification	Normalized contribution	Corrected priority
Water-based matte finishing	19.95%	1
Teak wood waste	17.32%	2
Knock-down connection system	13.10%	3
LED Filament E27, 12 W, 220 V	12.00%	4
Adjustable textile cable with E27 ceramic socket (SNI)	11.41%	5
Translucent plastic fiber diffuser	11.19%	6
Lamp dimensions (Ø60 cm × 28 cm)	10.30%	7
Adjustable hanging height (120 cm)	4.78%	8

This corrected order changes the leading technical priority from teak wood waste (as stated in the original Table 8 and abstract) to water-based matte finishing, with teak wood waste second. This does not diminish the role of wood waste in the design: as the frame material, it remains the primary vehicle for the Reuse strategy in the circular-economy mapping (Table 9) and the second-highest weighted technical characteristic overall; the correction only concerns which characteristic carries the single highest engineering weight in the QFD calculation.

Circular Economy Mapping

The corrected technical characteristics identified through the House of Quality were mapped, as a separate step after HOQ prioritization, to five circular-economy strategies selected from the 9R framework: reduce, reuse, repair, recycle, and remanufacture (see the justification for this 9R-to-5R scoping decision in Section 2, Stage 2). The implementation of these principles in the product design is presented in Table 9.

Table 9. Implementation of circular economy principles

Technical Characteristic (VoE)	Principle	Implementation
Teak wood waste	Reuse	Uses wood waste as the main frame material instead of virgin timber.
Lamp dimensions (material use)	Reduce	Optimizes material use and minimizes offcut waste.
Water-based matte finishing	Reduce	Reduces solvent-based environmental impact compared to conventional lacquer.
Knock-down connection system	Repair	Facilitates repair and component replacement without destructive disassembly.
Recyclable wood material	Recycle	Enables material recycling at end-of-life.
Standard components (LED, socket, cable)	Remanufacture	Supports component reuse and remanufacturing using widely available parts.

Reduce, reuse, repair, recycle, and remanufacture are described here as intended design strategies, not as measured circularity outcomes. No waste-mass diversion figure, virgin-material displacement estimate, component-level disassembly time, expected service life, or defined recycling route is reported in this study; these would be the concrete circularity metrics needed to move from an intended strategy to verified circularity performance, and are recommended as follow-up measurement once a prototype exists.

Product Design (Proposed Concept)

Based on the corrected prioritized customer and technical requirements, the proposed design is a teak-wood-waste pendant ceiling lamp concept with an organic radial form, intended to provide aesthetic value and even light distribution. Each element of the concept traces back to a specific HOQ result: the organic radial frame responds to the top-ranked customer need for wood-waste utilization and the second-ranked technical priority (teak wood waste) together with the aesthetic-shape requirements (customer needs 1, 8, and 9 in Table 6); the translucent plastic fiber diffuser responds to customer needs 5, 6, 7, 11, and 12 and is the sixth-ranked technical priority; the water-based matte finish, now the top-ranked technical priority, responds to customer needs 1, 2, 4, 8, 9, 12, and 18; the knock-down connection system, ranked third, responds to customer needs 1, 4, 9, and 14-15; and the E27 LED filament light source and SNI-compliant electrical installation respond directly to customer needs 5-7 and 19, which include the second-highest customer priority (electrical safety). The design incorporates a translucent plastic fiber diffuser, an E27 LED filament lamp, water-based finishing, and a knock-down connection system intended to facilitate assembly, maintenance, repair, and component replacement. The proposed lamp has a diameter of 60 cm, a shade height of 28 cm, and an adjustable maximum hanging height of 120 cm. This design is a concept rendering; no physical prototype has been fabricated or tested. The concept is shown in Figure 3.

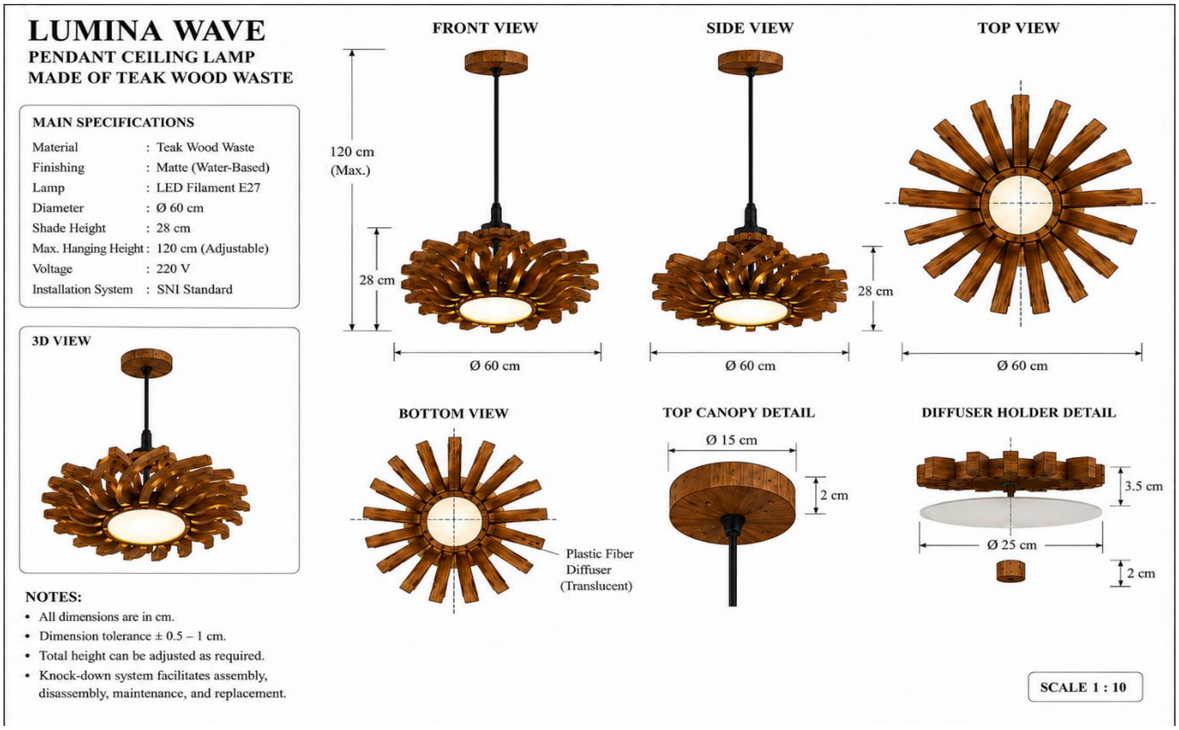


Figure 3. *Product Design*

Technical Product Specifications

Table 10. Technical product specifications

Specification	Description
Product name	Lumina Wave (proposed concept name)
Product type	Pendant ceiling lamp
Main material	Teak wood waste
Diffuser	Translucent plastic fiber
Design	Organic radial
Finishing	Water-based matte
Dimensions	Ø60 cm × 28 cm
Adjustable height	Up to 120 cm
Light source	LED Filament E27, 12 W, 220 V
Connection system	Knock-down using stainless steel bolts and nuts
Installation system	Adjustable textile cable with E27 ceramic socket (SNI compliant)
Circular economy principles	Reduce, Reuse, Repair, Recycle, and Remanufacture (applied as a post-HOQ mapping; see Section 3.6)

No structural-load, electrical-safety, thermal, fire-risk, illumination, assembly/disassembly, repairability, or user-acceptance test has been performed on this concept. Compliance with the Indonesian National Standard (SNI) referenced for the electrical installation is a design intention rather than a certified result, Given the absence of these tests, this study is repositioned here as a conceptual design study: it proposes and prioritizes a design based on customer preference data, and does not certify the design's safety, durability, or lighting performance.

Production Cost Estimation

The estimated production cost was compiled from indicative material, labor, and overhead cost components; it is presented as a supplementary, exploratory estimate rather than a fully costed bill of materials, since cost estimation is not a primary objective of this study.

Table 11. Production cost estimation, with markup and gross-margin

Item	Cost (IDR)
Teak wood waste (material only, as originally reported)	0
Wood waste collection, selection, and drying	0
Translucent plastic fiber diffuser	25,000

Item	Cost (IDR)
LED Filament E27 (12 W)	35,000
E27 ceramic socket	15,000
Textile electrical cable	20,000
Stainless steel bolts and nuts	15,000
Water-based matte finishing	30,000
PVAc wood adhesive	10,000
Sandpaper	12,000
Labor	240,000
Overhead	45,000
Total production cost	**447,000**
Planned selling price	**970,000**
Gross difference (selling price – cost)	**523,000**
Markup on cost (523,000 / 447,000)	≈ 117.0%
Gross margin on price (523,000 / 970,000), before overhead allocation shown above and before tax	≈ 53.9%

A zero cost for teak wood waste, as originally reported, is unrealistic once collection, sorting by usable dimension, drying, and pre-processing are accounted for; these activities consume labor and time even when the raw material itself is free. This revision does not invent a replacement figure for that cost component, since doing so would not be based on the author's actual sourcing arrangement; instead, it is left as an explicit line item for the author to complete, and the total production cost above should be treated as a lower-bound estimate until that line item is filled in.

DISCUSSION

The leading customer needs (interest in using wood waste, electrical installation safety, and structural strength) and the leading technical characteristics (water-based matte finishing and teak wood waste) matter jointly for this product category because a pendant ceiling lamp is both a load-bearing fixture suspended above occupants and a visible, touch-close decorative object. Structural strength and electrical safety address the risk dimension of an overhead fixture, while finishing quality addresses the visible, tactile dimension by which a wood-waste product signals whether it is a considered design object or a raw offcut; the high combined weight of these characteristics is consistent with the general QFD finding that safety- and appearance-critical characteristics tend to dominate discretionary characteristics such as size variation or hanging-height range, which received the lowest weights here (4.78% for adjustable hanging height).

Compared with Sari et al.'s QFD-TRIZ modular furniture-waste framework [1], the present study applies a single-product HOQ rather than a modular multi-product platform, which allows finer-grained technical prioritization but does not, on its own, address the supply-continuity problem that a modular platform is designed to solve. Compared with Rahadian et al.'s SCAMPER-based sawdust lamp design [20], the QFD approach used here provides an explicit, numerically traceable link from customer priority to technical characteristic that SCAMPER's more exploratory ideation process does not, at the cost of requiring a larger, carefully validated respondent sample. Compared with Astuti et al.'s Green QFD II evaluation of lamp concepts, which integrates environmental and cost criteria directly into the QFD weighting, the present study instead applies circularity as a separate mapping step after HOQ prioritization (Section 3.6); this sequential approach is simpler to execute with a standard HOQ but, unlike Green QFD II, does not let circularity considerations influence which technical characteristics are prioritized in the first place. This comparison indicates that the present findings agree with prior QFD-based wood-waste product studies on the general feasibility of translating customer preference into technical characteristics, but add a specific, corrected priority order for a wood-waste pendant ceiling lamp that had not previously been reported, while falling short of Green QFD II's tighter integration of environmental weighting.

The corrected priorities surface a genuine design trade-off. Water-based matte finishing, now the top technical priority, improves perceived quality and reduces solvent-related environmental impact, but water-based finishes are typically less abrasion- and moisture-resistant than solvent-based lacquers, which may affect long-term durability in humid indoor environments; a repairable knock-down system (ranked third) partly offsets this by making refinishing or panel replacement feasible without discarding the whole fixture. Using teak wood waste (ranked second) lowers material cost and virgin-timber demand, but waste pieces vary in size, grain, and moisture content, which constrains achievable frame dimensions and may increase rejection rates during fabrication; this variability is a practical tension between the Reuse strategy and consistent product aesthetics that the manuscript's original wood-waste description did not quantify.

Sensitivity of The Technical Ranking

A full quantitative sensitivity analysis would require re-running the HOQ under alternative relationship scores or customer weights, which is not possible without the underlying respondent-level dataset. Qualitatively, however, two features of the corrected matrix suggest the ranking is not highly robust in its middle ranks. First, the second- through fifth-ranked technical characteristics (teak wood waste, knock-down system, LED, and diffuser/cable) fall within a narrow 11.2-17.3% band, so a small change in even one relationship score (for example, changing a '3' to a '9' in the correlation between 'product structural strength' and the knock-down system) could plausibly reorder rank two through six without changing the top-ranked or bottom-ranked characteristic. Second, because the competitive benchmark score is identical (4 of 5) for all eight technical characteristics (Figure C), the Sales Point and downstream Raw Weight values do not currently differentiate characteristics on competitive positioning at all; if a real, differentiated benchmark score against a named competitor product were used instead, the relative weighting of characteristics with currently under- or over-stated competitive standing could shift, particularly for characteristics such as the LED light source and electrical installation, where compliance-driven competitors may already perform similarly well.

Cronbach's Alpha of 0.900 supports internal consistency but is not evidence that the 19 attributes should be treated as one construct in future analysis; given that the attributes span material, lighting, safety, and sustainability dimensions, a multi-dimensional or multi-scale treatment (for example, separate reliability and factor analysis per dimension) is a more defensible basis for any future claim of construct validity than a single overall alpha.

Practical scale-up considerations

Beyond the design itself, moving this concept toward production raises scale-up issues not addressed by the QFD result alone: inconsistent waste-wood quality and dimensions across supply batches, the need for a continuous multi-supplier sourcing arrangement given the limited and irregular availability of teak wood waste, verification of electrical compliance for each production batch rather than a one-time design intention, finishing-related occupational safety during water-based coating application, and the labor and overhead cost of preparing discarded material that the current cost estimate does not yet include (Table 11).

CONCLUSION

This study proposes a customer-oriented, wood-waste pendant ceiling lamp concept and maps its prioritized technical characteristics to circular economy strategies; it does not claim a validated, production-ready, or environmentally certified product. Voice of Customer data from 68 respondents were translated into 19 validated customer-need attributes (one attribute, diffuser color, was excluded after failing the validity test) and, through a corrected House of Quality calculation, into eight ranked technical characteristics. After correcting a transcription error in the light-transparency row and re-deriving the ranking from the Normalized Contribution values in the HOQ, the corrected technical priority order is: water-based matte finishing (19.95%), teak wood waste (17.32%), knock-down connection system (13.10%), LED Filament E27 (12.00%), adjustable cable with SNI-compliant E27 ceramic socket (11.41%), translucent plastic fiber diffuser (11.19%), lamp dimensions (10.30%), and adjustable hanging height (4.78%). Water-based matte finishing, not teak wood waste, carries the single highest technical weight in this corrected calculation, although teak wood waste remains central to the design as the primary material for the Reuse strategy. These eight technical characteristics were mapped, as a separate step after HOQ prioritization, to five circular-economy strategies drawn from the broader 9R framework: reduce, reuse, repair, recycle, and remanufacture. This sequential approach yields a design concept intended to support efficient material use, ease of repair, component reuse, and end-of-life recyclability; these are stated as intended design properties, not as measured or independently verified outcomes, since no prototype, structural test, electrical safety test, lighting test, disassembly-time measurement, or life-cycle assessment was carried out in this study.

The study does not claim that consumer expectations were fulfilled, since respondents evaluated their needs and preferences before any design was developed, not after using the finished product; no post-design satisfaction test is reported. Based on the estimated cost components reported (excluding wood pre-processing costs not yet quantified), the indicative gross margin is approximately 53.9% before overhead allocation and tax, and this cost analysis is exploratory rather than a validated feasibility study.

The principal limitations of this study are: a sample of 68 respondents whose sampling technique, inclusion criteria, and demographic composition are not fully described in the current manuscript; a competitive benchmark that was scored identically across all technical characteristics and therefore does not yet reflect a differentiated, named competitor product; a set of QFD calculation inconsistencies in the original House of Quality that required editorial correction and are reported transparently in Section 3.3; the absence of any physical prototype or performance testing; and the absence of quantitative circularity or life-cycle evidence. Given these limitations, the design concept presented here has potential as a starting point for a wood-waste decorative lighting product, but it is proposed rather than proven.

Future work should define and justify the respondent sampling frame and sample size explicitly, identify and score a named competitor product for benchmarking rather than a uniform value, reproduce the QFD calculation from raw respondent-level data to confirm the correction reported here, fabricate a prototype and test structural strength, electrical safety, thermal behavior, fire risk, illumination quality, assembly/disassembly ease, and repairability against the relevant SNI standards, conduct user-acceptance testing, evaluate technical and economic feasibility at production scale, investigate alternative waste-wood species to address supply-continuity risk, and assess environmental performance through a Life Cycle Assessment (LCA).

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