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INTEGRATION OF ECQFD IN CONCEPTUAL DESIGN ACTIVITIES FOR ENABLING ENVIRONMENTALLY CONSCIOUS DESIGN

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ABSTRACT

Eco-products are products that were created as a step to overcome an environmental problem which is getting serious nowadays. However, there is no standard procedure or guideline for designers to consider an environmental aspect in the design stage. In this study, Environmentally Conscious Quality Function Deployment (ECQFD) approach has been proposed to be integrated in conceptual design activities, so that an improvement in terms of environmental aspects can be considered for a new design of an important product component. ECQFD methodology which consists of four phases is applied before new alternative concepts are generated. In the conceptual design activities, morphological chart is used to generate several possible concepts, then the selected concept is evaluated using weighted decision matrix based on criteria in the phase III of ECQFD. Thus, there is no need to redesign all components of a product if the most critical part can be identified at the early conceptual design stage. An example of a portable vacuum cleaner is used to illustrate the proposed approach. This approach provides a new and much more meaningful basis for developing eco-products in the design platform for designers.

Keywords: eco-design, ECQFD, conceptual design.

INTRODUCTION

In recent years, sustainable development has rapidly become a fundamental product design topic for new product development. Developing an eco-product is a part of achieving sustainable improvement where the topics of interest are focusing on environmentally conscious design (eco-design) or Design for Environment (DfE) for a newly designed product (Byggeth and Hochschorner, 2006). Generally, the eco-products are products that use recyclable materials, less material and energy consumption, or not harmful to the environment. Therefore, the importance of environmentally friendly products is necessary in the modern world because every day the earth is exposed to pollution, consumption of natural resources, which is causing uncontrolled human depression every day.

Conceptual design is an early design phase characterized by a fuzzy knowledge of design information and tolerating high degree of vague ideas and uncertainty (Xu *et al*., 2006). Hassan *et al*. (2013) have stated that conceptual design is essential for product design to generate new variants for design elements of products, structuring them into a complete configuration and evaluating the alternate concepts. This phase is very important since the future product as much as 85% of the life-cycle cost is determined at this stage (Hassan *et al*., 2012). Thus, considering any design improvement of a product in the conceptual design activites is the best movement towards sustainable development.

In this study, the recently developed Environmentally Conscious Quality Function Deployment (ECQFD) approach is applied for enabling environmentally conscious design of a new product concept by integrating in the conceptual design activities. Based on the ECQFD decision, a list of suggestions is referred in generation of new concepts and evaluation using weighted decision matrix based on criteria in the phase III of ECQFD. A brief review of relevant previous work is presented in the next section, followed by a methodology of the proposed approach, with an example case study in the subsequent sections, and concluding remarks in the last section.

LITERATURE REVIEW

The literature has been reviewed from the perspectives of environmental considerations in design platform using traditional design tools.

Quality Function Deployment (QFD) is a method to transform user needs into design quality, to deploy the functions forming quality, and to deploy methods for achieving the design quality into subsystems and components, and ultimately to specific elements of the manufacturing process (Wang *et al*., 2010). Vinodh and Rathod (2010) have collected and summarized an application of QFD for enabling eco-design from several researchers all over the world. Some of them are highlighted in this paper. Bevilacqua *et al*. (2007) developed a methodology for integrating Design for Environment (DfE) and Life Cycle Assessment (LCA) approach into new product development and into the process of redesigning a set of existing products. Sakao (2007) developed quality function deployment for environment (QFDE) by modifying and extending QFD to be employed in an eco-design methodology. Besides, LCA and Theory of Inventive Problem Solving (TRIZ) have been employed in the methodology to effectively

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support eco-design of products. Qian and Zhang (2009) used fuzzy analytic hierarchy process (FAHP) to rank eight environmental criteria that capable to capture most of potential environmental impacts of modular products through a semi-quantitative environmentally conscious modular analysis model in order to reduce pollution. Vinodh and Rathod (2010) constructed four phases of ECQFD where phases I and II are concerned with the identification of components for product design that considers both customer needs and environmental requirements. Meanwhile, ECQFD phases III and IV are focused on examination of the possibility of design improvements for components and to determine the improvement rate and effect of design changes. Wang *et al*. (2010) integrated ECQFD and LCA in a single methodology for sustainable product design. The methodology includes environmental voice of customer, environmental engineering metrics, product life cycle cost and product effectiveness.

METHODOLOGY

Environmentally Conscious Quality Function Deployment (ECQFD)

Vinodh and Rathod (2010) have constructed the ECQFD methodology based on the literature review on QFD, and its application on environmentally friendly aspects, as shown in Figure-1.

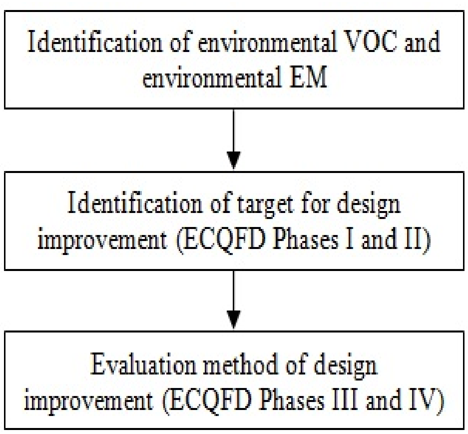

Figure-1. ECQFD methodology.

The ECQFD consists of four phases. Phase I is concerned with the application of ECQFD for product design considering Voice of Customer (VOC) from an environmental perspective. Phase II is concerned with the deployment of Engineering Metrics (EM) items to product components. In phase III, the options of a set of design changes on EM items are discussed. The goal of phase IV is to translate the effect of design changes on EM into environmental quality requirements.

Approach for Enabling Eco-Design of a Product using ECQFD in Conceptual Design Activities

The proposed approach for enabling eco-design of a product based on ECQFD in conceptual design activities is outlined in Figure-2. ECQFD methodology is performed at the beginning of conceptual design activities. Decisions from the ECQFD phase IV are discussed and finalize the possible design improvement of a target product. Then, a Morphological analysis is performed to systematically structure the alternative concepts for identified design element into complete product combinations which is referred to as a complete product design. Next, these product combinations are evaluated using Weighted Decision Matrix with regards to environmental aspects based on selected EM items in ECQFD phase III. In this section, a decision for the most environmentally conscious design of product combination concepts is made. Finally, the selected product design with eco-design concept is achieved. Otherwise, if the proposed product combinations are not satisfied by designers, the process is going back to ECQFD for improvement of VOC or EM, or the process only return to Morphological analysis for redesigning the product concepts.

CASE STUDY

In this section, a case study is conducted to illustrate the proposed approach. A portable vacuum cleaner was identified as the product. All calculations by ECQFD approach are not fully presented in this study, yet it is only shows the results. The specific calculations of ECQFD can be referred in Vinodh and Rathod (2010).

Identification of Environmental Voice-of-Customer (VOC) and Environmental Engineering Metrics (EM)

In creating a product design, the VOC is very important. This is because consumer using these products for their specific purpose everyday. Besides, in this study, the VOC must considers from the environmental perspective over the product life cycle, and translates into a set of feasible EM. The list of identified environmental VOC and EM are shown in Table-1.

Identifying the Target for Design Improvement

Identification of the target for design improvement through ECQFD consists of 4 phases.

ECQFD Phase I

Phase 1 is the first stage of ECQFD application to the design of portable vacuum cleaner to deploy VOC against EM as shown in Table-1. There are 11 criteria of VOC that have been collected from a market survey. All identified VOC are associated with the 15 items of EM. Each criteria from the VOC are weighed based on the market survey. EM consist of characteristics of portable vacuum cleaner that may be associated with conditions by the consumer.

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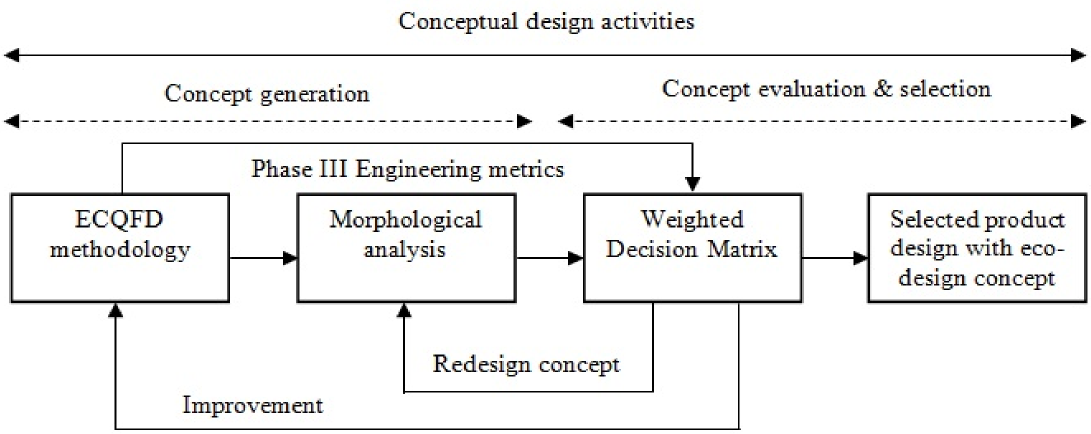

Figure-2. Proposed approach for integrating ECQFD methodology in conceptual design activities.

The important relation of VOC and EM has been indicated and determined by the designer using a scale, “9” indicates strong, “3” indicates moderate, and “1” indicates low. It can be interpreted as an attribute that must be met from the findings of consumer need, such as performance, availability and diversity of portable vacuum cleaner that will be designed.

Table-1. ECQFD phase I of portable vacuum cleaner.

Voice of customer	Customer weights	Engineering metrics														
		Price (RM)	Motor (watt)	Voltage (v)	Weight (kg)	Size / Dimensions [mXmXm]	Capacity dust container (m)	Suction speed [RPM]	Type of filter	Noise levels (dB)	Physical lifetime (Years)	Type of material	Toxicity of material	Total Cleaning tool	Number of Part (part)	Recyclability of package material
Low Prices	3	9	3	3					3							3
Easily Operated	9				3		9							9	3	
Easy to open and install	9				1		9		3					9	9	
Easy to carry	9				9	9									3	
Lightweight	3				9										3	
Durables	9						3		3		9	9				
Long Lifespans	9						3				9	9				1
High Safety	9			3									9			
Comfortable holders	9				1							9				
Less noise	3		9				9	9		9						
Various types of Cleaning tools	3	3												9	3	
Raw score		36	36	36	153	81	216	27	63	27	162	243	81	189	153	18
Relative weight		0.024	0.024	0.024	0.101	0.053	0.142	0.018	0.041	0.018	0.107	0.160	0.053	0.124	0.101	0.012

ECQFD Phase II

Phase II is the second stage of ECQFD where 15 items of EM in this study are correlated to components of portable vacuum cleaner. Each item of EM used the weights that are obtained from Phase I. The important relation between EM and components of portable vacuum cleaner is performed in the same way as phase I. As shown in Table-2, components of portable vacuum cleaner are consists of dust container, vacuum head, starter switch, dust filter, vacuum motor and holder. After calculation, components that have the highest weighted value are selected, where it is found that “Vacuum Head”, “Dust Container”, and “Holder” are the important components.

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Table-2. ECQFD phase II of portable vacuum cleaner.

Engineering metrics	Phase 1 relative weight	Component characteristics of portable vacuum cleaner					
		Vacuum head	Starter Swich	Dust Container	Dust Filter	Vacuum Motor	Holder
Price (RM)	0.024				3	9	
Motor (Watt)	0.024					9	
Voltage (V)	0.024					9	
Weight (kg)	0.101			3			9
Size/Dimension (m x m x m)	0.053	9		9			3
Capacity of dust container (ml)	0.142			9	3		
Suction Speed (RPM)	0.018					9	
Type of Filter	0.041			9	9		
Noise levels (dB)	0.018			3		9	
Physical lifetime (Years)	0.107	3	1	1	3	3	3
Type of material	0.160	3	1	3	3		9
Toxicity of material	0.053	9	3	9	3	1	9
Total Cleaning tool	0.124	9					
Number of Parts	0.101	9	1	1	1	1	1
Recyclability of part material	0.012	3		9			9
Raw score		3.816	0.847	3.754	1.856	1.447	3.515
Relative weight		0.250	0.056	0.246	0.122	0.095	0.231

ECQFD phase III

Phase III in ECQFD discussed the effect of design improvement of components of portable vacuum cleaner on EM items, as shown in Table-3. There are two options have been discussed, the first option relates to the requirement by the customer that based on VOC. Another option is based on the most important components identified in Phase II. In this study, environmental aspects are playing an important role in the design improvement for components of portable vacuum cleaner. The two proposed options as follows:

Option I

- Improve the life expectancy of portable vacuum cleaner.
- Machine that high durability and powerful and can be used repeatedly in good condition in any situation.
- Comfortable and ergonomic handle and to be able to hold a good and stable while in cleaning situations and different angles.
- Dust container must be opened easily without the need for a lot of movement to open.

Table-3. ECQFD phase III of portable vacuum cleaner.

Engineering metrics	Phase I relative weight	Characteristics of the components						Score	Improvement rate of engineering metrics
		Vacuum head	Starter Swich	Dust Container	Dust Filter	Vacuum Motor	Holder		
Price (RM)	0.024								
Motor (Watt)	0.024								
Voltage (V)	0.024								
Weight (kg)	0.101						9 (9)	9 (9)	0.75 (0.75)
Size/Dimension (m x m x m)	0.053			9 (9)			3 (3)	12 (12)	0.571 (0.571)
Capacity dust container (ml)	0.142			9 (9)				9	0.75 (0.75)
Suction Speed (RPM)	0.018								
Type of Filter	0.041								
Noise levels (dB)	0.018								
Physical Lifespan (Year)	0.107	3		1			3	7	0.237
Type of Materials	0.160	3 (3)		3 (3)			9 (9)	15 (15)	0.79 (0.79)
Toxicity of material	0.053	(9)		(9)			(9)	(27)	(0.79)
Total head cleaner tool	0.124	(9)						(9)	(1.00)
Number of Part	0.101								
Recyclability of part material	0.012	(3)		(9)			(9)	(21)	(1.00)

* the number in brackets is the score for option II

Option II

- Reduced the use of PVC should reduce the environmental impact of the package.
- The multifunction vacuum head should easy to use where it is suitable for areas to be cleaned and the place has a different angle.
- Comfortable and ergonomic handle and to be able to hold a good and stable while in cleaning situations and different angles.
- Dust container must be opened easily without the need for a lot of movement to open.
- Improve the materials that can be recycled.

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ECQFD Phase IV

Phase IV for portable vacuum cleaner as shown in Table-4 is to convert the effect of design improvement on EM into environmental considerations. Based on the calculation, it is found that the amount of (improvement effect of customer requirement) option II of phase IV is higher than option I, where option II is 4.812. Meanwhile, option I is 2.958. The requirement from option I cannot be accepted because, the production of portable vacuum cleaner which has high strength and durability are difficult, yet less environmentally friendly features. It is very important to know what are the best to produce some product by taking the various aspects that can serve as a useful guide to consumers.

Table-4. ECQFD phase IV of portable vacuum cleaner.

Voice of customer	Customer weights	Engineering metrics: Price (RM)	Motor (watt)	Voltage (v)	Weight (kg)	Size / Dimensions [m X m X m]	Capacity dust container (ml)	Suction speed [RPM]	Type of filter	Noise levels (dB)	Physical lifetime (Years)	Type of material	Toxicity of material	Total Cleaning tool	Number of Part (part)	Recyclability of package material	Improvement rate of customer requirement	Improvement effect of customer requirement
Low Prices	3	9 (9)	3 (3)	3 (3)					3 (3)							3 (3)	0.036 (0.083)	0.108 (0.249)
Easily Operated	9				3 (3)		9 (9)							9 (9)	3 (3)		0.008 (0.05)	0.072 (0.45)
Easy to open and install	9				1 (1)		9 (9)		3 (3)					9 (9)	9 (9)		0.002 (0.034)	0.018 (0.306)
Easy to carry	9				9 (9)	9 (9)									3 (3)		0.063 (0.063)	0.567 (0.567)
Lightweight	3				9 (9)										3 (3)		0.143 (0.143)	0.429 (0.429)
Durables	9						3 (3)		3 (3)		9 (9)	9 (9)					0.043 (0.033)	0.387 (0.297)
Long Lifespans	9						3 (3)				9 (9)	9 (9)				1 (1)	0.047 (0.041)	0.423 (0.369)
High Safety	3			3 (3)									9 (9)				0.063 (0.26)	0.189 (0.78)
Comfortable holders	9				1 (1)							9 (9)					0.085 (0.085)	0.765 (0.765)
Less noise	3		9 (9)				9 (9)	9 (9)		9 (9)							0 (0)	0 (0)
Types of cleaning tools	3	3 (3)												9 (9)	3 (3)		0 (0.2)	0 (0.6)
Improvement rate of design parameters				0.75 (0.75)	0.571 (0.57)	0.75 (0.75)					0.237	0.79 (0.79)	(0.79)	(1.0)		(1.0)		2.958 (4.812)

* the number in brackets is the score for option II

Weighted Decision Matrix

Weighted Decision Matrix is used to make a selection between the concepts that have been listed for narrowing elections to get the concepts selected according to several criteria. Evaluation citeria are based on EM in phase III for option II where the highest improvement rate of EM are selected. Table-5 shows the application of Weighted Decision Matrix on three generated concepts of portable vacuum cleaner using selected EM. Calculations are made to select the best concept with respect to environmental considerations. This selection process is based on evaluation using rating. The highest value means the best concept, meanwhile the lowest value means poor concept.

From the Weighted Decision Matrix analysis, a concept which meets the EM items is the winner. Hence, Table-5 concluded that concept C is selected to be forwarded to embodiment design. Concept C is selected due to the highest rating compared to the other concepts that obtained from the aggregation of the engineering metrics. The detail design of portable vacuum cleaner with the consideration of eco-design concept is illustrated in Figure-3.

Concluding Remarks

In this paper, an integration of ECQFD in conceptual design activities for enabling environmentally conscious design is presented with a simple case study of a portable vacuum cleaner. ECQFD methodology which consists of four phases is applied before new alternative concepts are generated. In the conceptual design activities, morphological chart is used to generate several possible concepts, then the selected concept is evaluated using weighted decision matrix based on criteria in the phase III of ECQFD. This methodology provides a new and much more meaningful basis for developing eco-products in the design platform for designers.

Table-5. Weighted decision matrix of portable vacuum cleaner concepts.

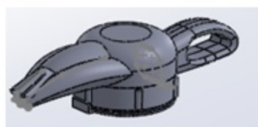
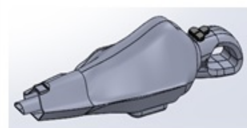
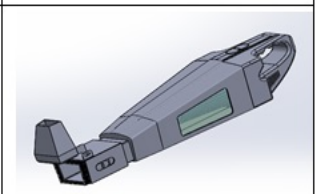
Phase III option II engineering metrics	Phase I relative weights	Units	Concept A			Concept B			Concept C		
											
			Magnitude	Score	Rating	Magnitude	Score	Rating	Magnitude	Score	Rating
Weight	0.101	kg	0.481	7	0.707	0.503	6	0.606	0.429	8	0.808
Size/Dimension	0.053	m x m x m	0.33 x 0.12 x 0.12	7	0.371	0.41 x 0.13 x 0.14	6	0.318	0.4 x 0.13 x 0.13	6	0.318
Type of Materials	0.160	Experience	Good	7	1.12	Good	7	1.12	High	7	1.12
Toxicity of material	0.053	Experience	Good	6	0.318	Good	6	0.318	High	6	0.318
Total Cleaning tool	0.124	Experience	Good	7	0.868	Good	7	0.868	Excellent	9	1.116
Recyclability of part material	0.012	Experience	High	8	0.096	High	8	0.096	High	8	0.096
Total					3.480			3.326			3.776

Figure-3. Selected eco-design concept of portable vacuum cleaner.

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