INTEGRATION OF CUSTOMER, COST AND ENVIRONMENTAL REQUIREMENTS IN PRODUCT DESIGN: AN APPLICATION OF GREEN QFD

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ABSTRACT

Growing concerns regarding the environmental impact of industrial activities, coupled with consumer demands for environmentally sound products, have forced manufacturers to consider the environmental impact of their products during the design process. To produce a more environmental friendly product, environmental requirements must be considered during the conceptual design phase, where the cost of incorporating changes is relatively low. To select the best conceptual design, the customers, costs and environmental criteria must be taken into account during the decision making process, and the Green Quality Function Deployment (G-QFD) provides a very useful methodology to fulfill this objective.

The starting point of the G-QFD methodology is establishing the alternative designs that verify the product's initial objectives. The methodology has two main phases: Phase I: *Product concept analysis* consists of evaluating each alternative design from the customer, cost and environmental perspective. In order to obtain the best conceptual design that integrates all these criteria simultaneously, a multi-criteria decision making technique is applied in Phase II: *Selection of the best conceptual design*.

In this communication, the G-QFD methodology is presented and applied to the furniture industrial sector to help a design team concurrently to design products according to the consumer demands and with a reduced cost and environmental impact.

RESUMEN

La preocupación sobre el impacto ambiental de las actividades industriales, junto a la mayor demanda de productos *ecológicos* por parte de los consumidores, han forzado a los fabricantes a considerar el impacto ambiental de sus productos durante su desarrollo. Para fabricar un producto ambientalmente correcto, el requerimiento ambiental debe considerarse durante la etapa de diseño conceptual, donde es posible incorporar más cambios a un bajo coste. Para seleccionar la mejor alternativa a un diseño, la opinión del consumidor y criterios tales como el coste o el medio ambiente deben considerarse durante el proceso de toma de decisión, y para ello, la metodología Green Quality Function Deployment (G-QFD) es una herramienta útil para integrar todos estos requerimientos.

El punto inicial de la metodología G-QFD es la obtención de los diseños conceptuales alternativos que cumplen los objetivos iniciales del producto. La aplicación de la metodología consta de dos pasos. El primero de ellos consiste en la evaluación de cada alternativa desde diferentes perspectivas: consumidor, coste y medio ambiente (Fase I: Análisis de los diseños conceptuales). La segunda etapa de la metodología consiste en la obtención del mejor diseño conceptual que integra simultáneamente estos tres requerimientos, mediante la aplicación de una técnica de análisis multicriterio.

En este trabajo se presenta la metodología G-QFD y se aplica a productos del sector del mueble, con el objeto de dotar al equipo de diseño de una herramienta que permita diseñar productos aceptados por el consumidor, a bajo coste y que produzcan un impacto ambiental reducido.

1. INTRODUCTION

The main objective of the eco-design is to create products for a sustainable society that will not only reduce the impact on the environment, but also, take into account the expectations of the customer and the economic reality of the company. The most effective way to produce an environmental friendly product is to consider the environmental requirements with the rest of the customer demands during the conceptual design phase, where more changes are possible. From this perspective, the Green-QFD methodology is a useful technique for helping designers select the best conceptual design, not only from traditional viewpoints regarding costs or customers, but also from the environmental perspectives.

Different versions of the *Green-QFD* help to select the best alternative design taking into account the environmental, customer and cost requirements. Cristofari *et al.* (1996) combines Quality Function Deployment (QFD) and Life Cycle Assessment (LCA) in *Green-QFD I*; Zhang *et al.* (1999) further incorporates the Life Cycle Cost (LCC) with LCA and QFD in *Green-QFD II*; Mehta and Wang (2001) utilizes the Eco-Indicator'99 method (Goedkoop and Spriensma, 1999) for quantifying the environmental impact of the product in *Green-QFD III*. Finally, Dong *et al.* (2002) includes fuzzy multi-attribute utility theory to estimate the life cycle cost in *Green-QFD IV*.

This communication focuses on improving the G-QFD III, which is presented in Section 2. Section 3 presents the application case to office furniture products, and finally, Section 4 presents the main conclusions obtained from this study.

2. GREEN QUALITY FUNCTION DEPLOYMENT METHODOLOGY

Green Quality Function Deployment (G-QFD) is an innovative design tool for developing environmentally friendly products. This tool is applicable during the conceptual design stage of product development. The starting point of the methodology is to set the alternative designs that verify the product's initial objectives. The methodology has two main phases, as shown in figure 1. Phase I: *Product concept analysis* consists of evaluating each alternative design from the customer, cost and environmental perspective. From each independent viewpoint, each alternative receives a punctuation. In order to obtain the best conceptual design that integrates all these criteria simultaneously, a multi-criteria decision making technique is applied in Phase II: *Selection of the best conceptual design*.

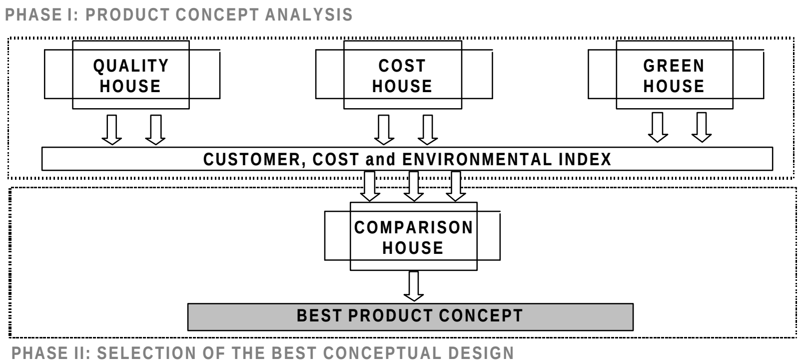

Figure 1: The Green Quality Function Deployment methodology.

2.1. Phase I: Product Concept Analysis

In Phase I, the design alternatives are evaluated from the customer, cost and environmental perspective by applying the Quality House (QH), Cost House (CH) and Green House (GH) structures.

Quality House

The quality of a product concept is measured by the Quality Index (QI). This index quantifies how well the customer demands are achieved by the product concept. This index is obtained from the Quality House (Akao, 1993), whose structure is illustrated in figure 2.

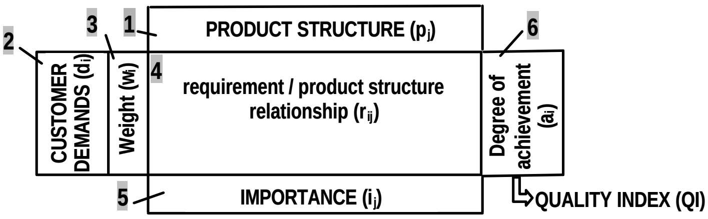

Figure 2: Quality House (QH) structure.

Room 1 represents the product structure (p_j), organised along its different life cycle stages. The next step in QH includes all activities focused on gathering the customer demands (d_i) and their importance level (w_i), ranged qualitatively from 1 (not important) to 5 (very important), which are included in room 2 and 3 of the QH, respectively. Room 4 analyses the interaction between the customer requirements and the life cycle stages (r_{ij}), that takes value 0 (, non relationship), 1 (?, weak), 3 (**O**, middle) or 5 (◎, strong) depending on the strength relationship between the demand and the product structure. Room 5 reports the importance that customers assign to each product area, calculated following the same procedure as in the House of Quality of the QFD methodology: $i_j = \sum_j \sum_i w_i \, r_{i,j}$. The last step in the QH is to measure how well the product concept fits to the customer demands. This is done in room 6 by assigning a score from 1 to 10, measuring the achievement level (a_i) of the product concept to each customer requirement. A higher score indicates a better degree of achievement or adequacy. Finally, the Quality Index is calculated by using $QI_j = \sum_{i=1}^{r} w_i \, . a_i$, where w_i is the importance of each r-requirements identified by the consumers and a_i is the achievement level.

Cost House

The cost of each product concept is evaluated in the Cost House (CH), as shown in figure 3. CH consists of four rooms. Room 1 includes the product structure along its life cycle stages (as in QH). Room 2 and 3 includes the internal and external cost, respectively, for each component of the product along its life cycle. Room 4 includes the summation of life cycle costs for each component of the product structure. The sum of the partial costs is the Cost Index (CI), which represents the life cycle cost of each product concept.

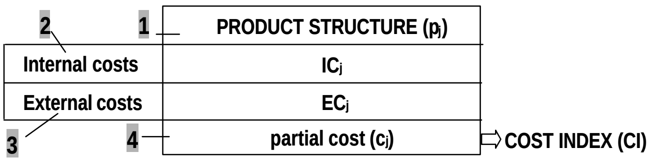

Figure 3: Cost House (CH) structure.

Internal costs (or company costs) include the costs for which the firm directly bears. These costs can be divided in two major subcategories: (1) conventional costs that include operational costs such as labor, material, transportation, equipment, etc. and (2) hidden and less tangible costs that consider environmental licensing, disposal waste, waste clean-up, worker productivity, employee health insurance, etc.

External costs (or societal costs) are those for which a company, at a specific time, is not responsible in the sense that neither the marketplace nor regulations assign such costs to the firm. Examples of external costs are human health impacts, ecological impacts, climate change, natural resource depletion, etc. Although external costs are real costs, they are difficult to quantify because placing a monetary value on goods without a market is difficult. The economic parameter values applied to estimate the external costs are shown in table 1.

Table 1: Economic parameter values for external costs.
Source: [1)] Craighill and Powell (1996), [2)] Quinet (1996).

Emission[1)]	**€/kg**	**Road congestion**[1)]	**€/km**	**Noise**[2)]	**€/100Tmkm**
CO_2	0.006	Motorway	0.004	Train	0.12-0.13
CO	0.009	Non central	0.189	Road	0.11-0.19
CH_4	0.111	Rural	0.001	Airplane	2.3
SO_2	3.972				
NO_x	1.952				
N_2O	0.944				
Particulate	13.804				

Green House

To evaluate the environmental performance of each product concept, the LCA methodology (Consoli *et al.*, 1993) is applied and reported in the Green House (GH), as figure 4 shows. Room 1 documents the product structure organised along its different life cycle stages, as in the Quality House. Room 2 documents the three types of environmental damage considered in the Eco-Indicator'99 methodology: human health, ecosystem quality and resource depletion. The environmental impact in each of the environmental damage categories is reported in Room 3 for each product component along its life cycle stages. Finally, the partial environmental impact (*ej*) that each product area produces is calculated in Room 4. The summation of all the partial eco-indicators represents the environmental impact (*EI*) of the product concept.

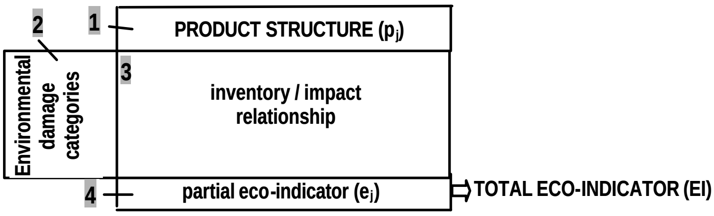

Figure 4: Green House (GH) structure.

2.2. Phase II: Selection of the best product concept

Once the quality (QI), environmental (EI) and cost (CI) index have been calculated for each product concept, the next step is to select the best solution that simultaneously accomplishes the three requirements. The values of these indexes indicate the potential of a product to satisfy quality, environmental and cost requirements, respectively. Table 2 shows the results for each product concept in the Comparison House.

Table 2: Comparison House structure.

	Quality Index (QI)	Cost Index (CI)	Environmental Index (EI)
Product concept 1	QI_1	CI_1	EI_1
Product concept 2	QI_2	CI_2	EI_2
Product concept i	QI_i	CI_i	EI_i

To select the best product concept, a multi-criteria selection method can be applied. In our case, the multi-criteria ranking method ELECTRE III (1994) was used. The method uses an outranking relation for modeling the decision maker's preferences. Its final result provides a partial preorder of the alternatives of the product concepts.

3. APPLICATION CASE TO FURNITURE INDUSTRY: OFFICE TABLE

The G-QFD methodology was applied to three conceptual designs of an office table. These tables are assumed to differ mainly in materials in order to maintain similar aesthetic properties. The most differentiating characteristics are reported in Table 3.

Table 3: Differentiating characteristics of the three conceptual designs.

	Product_Concept_1	**Product_Concept_2**	**Product_Concept_3**
Board	Standard particleboard 30 mm	Ecological particleboard[1] 19 mm	Standard particleboard 19 mm
Coating	Low density laminated	Low density laminated	High density laminated
Edge	PVC 2mm	PVC 2mm	High density postformated
Legs	Carbon steel(solvent coating)	Carbon steel(powder coating)	Anodising aluminium
Structure	Carbon steel (based solvent coating)	Carbon steel (powder coating)	Carbon steel (powder coating)
Packing	Corrugated cardboard	Retractile film with reinforcements	Corrugated cardboard

Applying the proposed methodology described in section 2 to the Product_Concept_1, Figure 5, 6 and 7 show the results of the Green House, Quality House and Cost House, respectively.

	PRODUCT STRUCTURE								
Damage Category	Particleboard	Coating	Edge	Leg	Levelling	Structure	Iron fitting	Packing	
Human health	0.40	0.11	0.13	2.19	0.02	0.83	0.01	0.14	3.83
Ecosystem quality	0.05	0.01	0.02	0.35	0.00	0.12	0.00	0.02	0.57
Resource depletion	0.45	0.09	0.16	1.17	0.06	0.47	0.01	0.30	2.71
PARTIAL ECO-INDICATOR	2.23	0.42	0.64	7.41	0.17	2.86	0.05	0.92	**7.11**

⟹ **GI_1=7.11**

Figure 5: Green House (GH) applied to Product_Concept_1 (Eco-Indicator'99 (€)).

[1] Particleboard with low content in formaldehyde.

Demands	weight	Particleboard	Coating	Edge	Legs	Levelling	Structure	Iron fitting	Packing	
		PRODUCT STRUCTURE								
Strong working surface	3	◎	◎	O						7
stability	4	?			O	◎		?		7
no damage during transport	4								◎	7
light weight	1	◎	?	?	O	?	◎	?		4
visually attractive	4		◎	O	◎					6
wood touch/sense surface	3		◎	O						5
non visible fittings	3							◎		6
low cost	3	?	?	?	O	?	O	?	?	6
easy to disassembly	3							◎		3
ABSOLUTE IMPORTANCE		27	54	34	44	24	14	38	23	**QI_1=165**
RELATIVE IMPORTANCE (I%)		10.5	20.9	13.2	17.1	9.3	5.4	14.7	8.9	

Figure 6: Quality House (QH) applied to Product_Concept_1.

Type of costs	Particleboard	Coating	Edge	Legs	Levelling	Structure	Iron fitting	Packing		
	PRODUCT STRUCTURE									
Internal Costs	16.79	2.25	4.40	69.92	4.61	12.77	1.20	11.36	123.27	
External Costs	10.05	0.84	0.23	5.23	0.08	2.07	0.10	3.17	21.77	
PARTIAL COSTS	26.84	3.09	4.63	75.15	4.69	14.84	1.30	14.53	145.07	**CI_1= 145.07**

Figure 7:Cost House (CH) applied to Product_Concept_1 (€).

Analogously, applying the same methodology to the remaining two product concepts, the summary of the quality, cost and environmental indexes are shown in Table 4.

Table 4: Application of the Comparison House to the application case.

	Quality Index (QI)	Cost Index (CI)	Environmental Index (EI)
Product_Concept_1	165	145.33	7.11
Product_Concept_2	144	142.06	6.79
Product_Concept_3	181	154.74	7.34

Finally, as a result of the application of the multi-criteria ranking method ELECTRE III and assuming the same importance level for each requirement, the best conceptual design, taking into account the quality, the cost and the environmental requirements, is the Product_Concept_2, followed by Product_Concept_1 and 3.

4. CONCLUSIONS

G-QFD is a structured approach that can help a design team prioritise product concept alternatives to simultaneously satisfied quality, cost and environmental requirements. An index that quantifies the achievement level of each product concept in each requirement is calculated by applying a simplified House of Quality of the QFD methodology to evaluate the Quality Index, by estimating the internal and external costs to evaluate the Cost Index, and by applying the LCA methodology and the Eco-Indicator'99 impact assessment method to evaluate the Environmental Index. Finally, by applying a multi-criteria decision method, the best product concept can be selected.

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