A FUZZY QFD TO RECOGNIZE THE FUNDAMENTALS OF SUSTAINABILITY EDUCATION

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ABSTRACT

Enhancement of sustainability education requires probing through multiple foci that pertain to the economic, social, and the environmental aspects of sustainability. Many approaches are considered to enhance the education of sustainability, but most emphasize on one aspect leaving the rest for other disciplines to tackle. Such inconsistency of sustainability teaching may lead to breaches in the overall comprehension of such important topic. In order to achieve such robust and comprehensive teaching, a correlation study is needed to connect the required objectives of sustainability to the teaching techniques. Quality Function Deployment (QFD) is a proper tool that permits such connection and provides the suitable metric to enhance and assess the progress of the sustainability learning. All aspects of sustainability are studied and fragmented into its important factors to be treated in QFD as the objectives then a combination of solutions are compared and contrasted to fit and satisfy such objectives. Nonetheless, QFD depends on subjective analysis that makes its outcomes debatable among scholars. A Fuzzy logic technique is therefore embedded in QFD for sustainability learning to minimize the ambiguity occurred from the subjective assessment and draw clear objectives and functions that leads to the proper means needed to achieve sustainability education. Fuzzy Quality Function Deployment (FQFD) provides multi-tier evaluations that further observe the teaching techniques and examines them in relation with the specific means that satisfy and prioritize such educational methodologies. The study provides a systematic approach that evaluates and recommends educational programs for undergraduate studies to establish and maintain sustainability knowledge that ensures the health, safety and wellbeing for all.

Keywords: Sustainability, QFD, Fuzzy Logic, Sustainability Education Requirement, Curricular Design Parameters.

INTRODUCTION

Earth is the center of attention when defining sustainability which aims to uphold the life support systems by delivering today's needs without compromising the needs of the future generations (Kates et al, 2001). Sustainability is a balanced distribution of the environmental responsibility of economic development between and within nations; hence it's very important for future professionals to learn and adhere to the sustainability guidelines for economic, environmental, and social development. Involving different types of values, achieving a balance among these three aspects of sustainability requires early and systematic measures. Therefore, the study of sustainability raises concerns to the educational institutes. Built on three pillars (environment, social and economic,) sustainability education become discombobulated and difficult to trace mainly because it addresses transnational issues characterized by non-linear behavior and long-term implications running across environmental, economic and social domains (Kates et al, 2001). It is conventional to start finding the answers for the sustainability development in the schools where competence building is inaugurated. Education is occasionally held responsible for failing to inculcate enough trained professionals who recognize and adhere to sustainability; additionally, it is debated that education is part of the sustainability challenge. However, education is accountable for sculpting the behaviors and philosophies that cater for sustainable future (Meadows *et al*, 1972). Being intertwined across multiple disciplines makes sustainability hard to be approached by one profession; therefore, sustainability education seeks a system that integrates the environmental allegiance, economic feasibility, and social impartiality. This study proposes Fuzzy Quality Function Deployment (FQFD) to found a structure that helps students perform as individuals or in communities in a matter that upholds the sustainability culture. FQFD facilitates the integration process of the three interdisciplinary aspects of sustainability and provides a roadmap to the faculty to comprehend the pedagogical steps needed to enhance planning for sustainability education. Conjointly, FQFD helps moving towards more proactive outcomes encouraging communication in the pedagogical process and ensuring educational success. The proposed system focuses on the students' requirements and uses the competitive information effectively to prioritize resources and identify outcomes to be aligned with the existing learning outcomes (Meadows *et al*, 1972). The selected outcomes from the FQFD which align with the requirements of the curriculum will then be embedded in a relevant education component. The attested outcomes will be considered as a guide for developing a new interdisciplinary program focusing on sustainability to enhance engagement in different curricular contexts. FQFD outcomes are set to enhance the knowledge of the attributes of sustainability and acquire skills for sustainability development. The new study employs the three levels sustainability education approach suggested by Sterling et al. The first level is Education about Sustainability aiming to increase knowledge about human interactions with the environment. The second level is Education for Sustainability which connects the knowledge and behaviors to create necessary changes to achieve sustainability. The third level is called Education as Sustainability which integrates knowledge and action into a mental state that drives the applicable transformations (Sterling, 2004).

QUALITY FUNCTION DEPLOYMENT (QFD):

Quality Function Deployment (QFD) is a system's engineering approach that employs steps to capture the needs or intentions of the client and implements them into a design process that leads to a satisfactory solution (Gonzalez, 2001). QFD consists of several stages starting with gathering the requirements of the clients, planning product, concept development, and then subsystem and parts deployment (Blanchard et al, 1998). In other words, Quality Function Deployment converts the customer's needs into system parameters, then allocates, and integrates those parameters into the various disciplines and finds the appropriate processes and products. The customer's requirements, QFD, are collected via surveys, interviews or benchmarking. These requirements are usually referred to as the WHATs and are treated as initial goals to be achieved by the new design parameters.

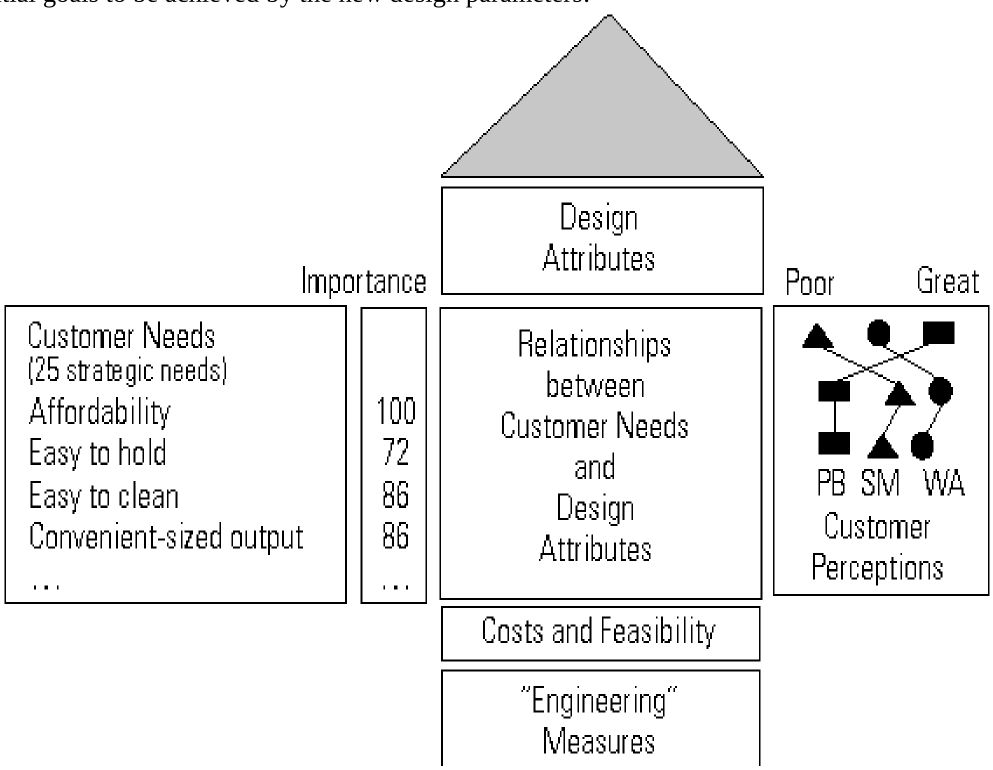

Figure 1: House of Quality Compartments and Relationships (Martin, 1997)

QFD employs matrices to evaluate the relationship between what the customer needs (the WHATs) and how the needs are met (the HOWs). These relationships may conflict or support each other when meeting the customer's need which lays a roadmap for the designers to decide which design parameters or features will optimally meet the goals. The designer has the opportunity to make management decision regarding such conflict or accordance by considering the importance of the affected needs to the consumer. The roof of the HoQ gives an indication of how such solutions will influence the final design of the products by studying the relationship among the design parameters (the HOW to HOW relationship). This is important to the designer to anticipate and avoid conflicts that may occur when altering or redesigning the new strategy. Figure 1 illustrates the various compartments of HoQ and the relationships among each other (Martin, 1997). In order to completely meet the system engineering guidelines of lifecycle management, higher levels of QFD could be considered where the HOWs in the proceeding stage of QFD become the WHATs in the next stage and new HOWs are generated to fulfill the old HOWs and so on.

FUZZY LOGIC

Complex problems are usually handled with ease thanks to the advancement of the computers, yet the complexity of the problem can rise to a level where its uncertainty becomes difficult to solve using conventional computational methods. In 1965, Lotfi Zadeh introduced Fuzzy Logic as a computation tool employing mathematical methodologies to control uncertainty (Zadeh, 1965). Fuzzy logic allows the machine to reason like humans using mechanism that expands the use of the traditional binary set mechanisms into using relatively graded membership that describe outcomes in verbal expressions such as “low,” “medium,” “many,” “few” or “often.” The traditional binary set theory describes crisp events, too precise for problems with complexity reaches fuzziness. Fuzzy logic uses probability theory to measure the chance with which a given event is expected and achieves satisfactions compromise between the information at hand and the accepted amount of uncertainty.

Fuzzy logic in QFD addresses the uncertainty by employing the fuzzy sets theory which uses triangular fuzzy numbers that represent various degree of membership donated on the real continuous interval (0-1) to represent the subjective requirements of the customers (Zadeh, 1965).

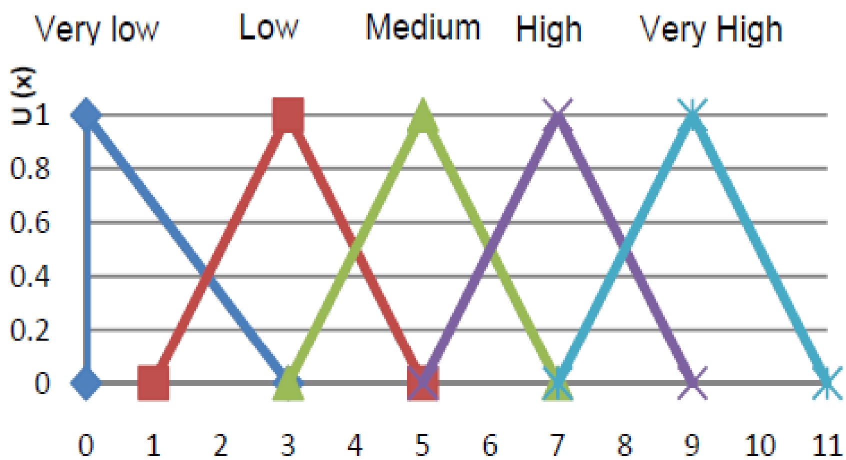

Figure 2: Triangular membership function for fuzzy sets (Kauffman, 1988)

EDUCATION FOR SUSTAINABILITY STANDARDS & PERFORMANCE INDICATORS

The roadmap toward a sustainability education can be achieved by connecting the students to the mechanisms of the society then clarifying and identifying interconnection among articles that leads to sustainability. An understanding of these three aspects should be among the learning goals of sustainability education and developing a sustainability curriculum that helps students understand the interaction among the coupled natural and human systems. In this study, FQFD is developed to allow educators to assess the learning progress as the three pillars of sustainability are established and maintained in the students’ intellect. Following the guidelines from the Cloud Institutions of Sustainability, ten sustainability education requirements (SER) are considered aiming to demonstrate the outcomes of the proposed technique and hoping to cultivate the sense of relation, path, and place with sustainability education (Cloud, 2014). The curricular design parameters (CDP) deployed to achieve such requirements came close to 150 parameters, each was driven to meet one SER and supports the other SERs to different degrees. In this study, 20 design components were considered as showing in the second column of Table 1.

Table 1: Sustainability Education Requirement and the Curricular Design Parameters

Sustainability Education Requirement (SER)	Curricular Design Parameters (CDP)
SER1. Understand and maintain cultural histories and heritages	**CDP1.** Connecting the Biosphere and the Ethnosphere
SER2. Establish proper transformation of cultural identities and practices that contribute to sustainable communities.	**CDP2.** Reconciling Tradition and Change
SER3. Learn the rights, responsibilities and actions associated with leadership and participation toward healthy and sustainable communities.	**CDP3.** Uncovering and Catalyzing through Arts and Culture
SER4. Understand the dynamic nature of complex systems as an organization of components that are interconnected and effect of change over time.	**CDP4.** Understanding Citizenship
SER5. Establish novel theories and practices of economics to support and maintain life on the planet and the shift towards integrating the economic, natural and social systems	**CDP5.** Activating Participation
SER6. Recognize and value the vital importance of the Commons of today and the future (i.e., air, trust, biodiversity, climate regulation, our collective future, water, libraries, public health, heritage sites, top soil, etc.).	**CDP6.** Leading Change
SER7. Understand and adhere to the natural laws & ecological principles	**CDP7.** Recognizing Systems as the Context
SER8. Design, implement and assess actions that lead to inventing & affecting the future	**CDP8.** Taking the Long View
SER9. Know, understand, value and draw from multiple perspectives to co-create healthy and sustainable future locally and globally.	**CDP9.** Taking Responsibility for the Difference We Make
SER10. Recognize and value the interrelationships between the social, economic, ecological and architectural history of that place and contribute to its continuous health.	**CDP10.** Paying Attention to Driving Forces
	CDP11. Being Strategic
	CDP12. Shifting Mental Models
	CDP13. Framing the Commons
	CDP14. Protecting the Commons
	CDP15. Understand the Natural Laws and Ecological Principles
	CDP16. Advocating for Living by the Natural Laws and Principles
	CDP17. Envisioning, Creating, and Thinking Out of the Box
	CDP18. Tapping Our Passion
	CDP19. Persevering
	CDP20. Accepting and Taking Risks

Weights of importance for the SER are determined by a high level management team in the position to decide curriculum development using decision-making techniques to rank these requirements at different levels. The relationship matrix in QFD is the component where the evaluation of the correlations between the HOWs and WHATs takes place. In FQFD, the evaluation results will be translated into fuzzy numbers with respect to an alpha cut value to address the vagueness of traditional QFD. The alpha value will be chosen between zero and one where one represents the lowest level confidence of the evaluators. However, if the evaluators seem to have average confidence, alpha cut value will be given 0.5. The weights used to rank the importance of the SER are also translated into fuzzy numbers in a similar manner using equation (1) with the same value for α. The linguistic values with their corresponding fuzzy numbers are given in the following equations (Kauffman, 1988):

Very low:	$1^\alpha = [\,1\,,\,3-2\alpha]$
Low:	$3^\alpha = [\,1+2\alpha,\,5-2\alpha]$
Medium:	$5^\alpha = [\,3+2\alpha\,,\,7-2\alpha]$
High:	$7^\alpha = [\,5+2\alpha,\,9-2\alpha]$
Very high:	$9^\alpha = [\,7+2\alpha,\,11-2\alpha]$

The crisp judgment can be obtained by defuzzificating the fuzzy preference by the following equation:

$$X_{ij}^{\alpha} = \omega X_{iju}^{\alpha} + (1-\omega)X_{ijl}^{\alpha}, \omega \in [0,1]$$

ω is the index of optimism, which reflects the degree of optimism of decision makers towards their judgment (Khoo, 1996). When ω approaches one, it reflects that the designers' attitude is inclined towards more extreme values, whereas when ω is approaching zero, it reflects that the designers' attitude is inclined towards more moderate values. Showing in Table 2, the relationship matrix between the WHATs and the HOWs in the first stage of QFD.

Table 2: The relationship matrix for the first stage of QFD

	Importance	CDP1.	CDP2.	CDP3.	CDP4.	CDP5.	CDP6.	CDP7.	CDP8.	CDP9.	CDP10.
SER1.	(2,4)	(8,10)	(8,10)	(8,10)	(4,6)	(8,10)	(1,2)	(0,0)	(2,4)	(0,0)	(4,6)
SER2.	(2,4)	(8,10)	(2,4)	(1,2)	(8,10)	(6,8)	(1,2)	(8,10)	(1,2)	(0,0)	(0,0)
SER3.	(2,4)	(6,8)	(4,6)	(2,4)	(0,0)	(6,8)	(0,0)	(6,8)	(1,2)	(0,0)	(0,0)
SER4.	(1,3)	(6,8)	(4,6)	(2,4)	(4,6)	(0,0)	(2,4)	(6,8)	(1,2)	(8,10)	(8,10)
SER5.	(1,2)	(0,0)	(0,0)	(2,4)	(0,0)	(8,10)	(0,0)	(0,0)	(0,0)	(0,0)	(6,8)
SER6.	(1,2)	(8,10)	(0,0)	(4,6)	(1,2)	(0,0)	(4,6)	(8,10)	(0,0)	(1,2)	(6,8)
SER7.	(1,2)	(0,0)	(1,2)	(1,2)	(2,4)	(8,10)	(6,8)	(0,0)	(4,6)	(0,0)	(0,0)
SER8.	(1,2)	(8,10)	(8,10)	(1,2)	(0,0)	(0,0)	(2,4)	(8,10)	(2,4)	(0,0)	(8,10)
SER9.	(1,2)	(0,0)	(4,6)	(8,10)	(2,4)	(0,0)	(2,4)	(4,6)	(0,0)	(4,6)	(0,0)
SER10.	(1,3)	(8,10)	(4,6)	(1,2)	(2,4)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(8,10)
Raw score		**(74,206)**	**(49,152)**	**(41,130)**	**(35,114)**	**(56,144)**	**(20,72)**	**(54,148)**	**(15,58)**	**(13,46)**	**(44,136)**
Defuzzied crispy value		**140**	**100.5**	**85.5**	**74.5**	**100**	**46**	**101**	**36.5**	**29.5**	**90**

	Importance	CDP11.	CDP12.	CDP13.	CDP14.	CDP15.	CDP16.	CDP17.	CDP18.	CDP19.	CDP20.
SER1.	(2,4)	(0,0)	(6,8)	(0,0)	(8,10)	(8,10)	(0,0)	(0,0)	(2,4)	(4,6)	(0,0)
SER2.	(2,4)	(2,4)	(8,10)	(4,6)	(1,2)	(6,8)	(1,2)	(2,4)	(1,2)	(0,0)	(4,6)
SER3.	(2,4)	(8,10)	(1,2)	(4,6)	(2,4)	(6,8)	(6,8)	(8,10)	(1,2)	(8,10)	(0,0)
SER4.	(1,3)	(4,6)	(4,6)	(2,4)	(2,4)	(0,0)	(6,8)	(0,0)	(1,2)	(6,8)	(0,0)
SER5.	(1,2)	(2,4)	(0,0)	(4,6)	(2,4)	(8,10)	(1,2)	(4,6)	(0,0)	(6,8)	(2,4)
SER6.	(1,2)	(6,8)	(0,0)	(6,8)	(4,6)	(0,0)	(8,10)	(0,0)	(0,0)	(0,0)	(2,4)
SER7.	(1,2)	(1,2)	(1,2)	(4,6)	(1,2)	(8,10)	(1,2)	(1,2)	(4,6)	(8,10)	(0,0)
SER8.	(1,2)	(1,2)	(1,2)	(8,10)	(1,2)	(4,6)	(2,4)	(2,4)	(2,4)	(0,0)	(2,4)
SER9.	(1,2)	(2,4)	(0,0)	(2,4)	(8,10)	(4,6)	(0,0)	(0,0)	(0,0)	(8,10)	(2,4)
SER10.	(1,3)	(2,4)	(0,0)	(8,10)	(1,2)	(4,6)	(1,2)	(1,2)	(0,0)	(0,0)	(0,0)
Raw score		**(38,126)**	**(36,106)**	**(50,158)**	**(41,130)**	**(68,186)**	**(33,106)**	**(28,86)**	**(15,58)**	**(52,144)**	**(16,56)**
Defuzzied crispy value		**82**	**53**	**104**	**85.5**	**127**	**69.5**	**57**	**36.5**	**98**	**36**

DISCUSSION AND CONCLUSION

By altering the value of the level of uncertainty α and the index of optimism ω, the designer can determine the proper weights of the weights of the curricular design parameters. Results show that the general trends of ranking importance remain the same regardless of the values of α and ω. However, depending on different values of α and ω, there is a slight variation in the ranking between these closely ranked attributes. Figure.2 shows the resulted attribute weights for ω = 0, 0.25, 0.50 and 0.75 when α equals 0.5. These variations provide possibility for making more informed decision through a scientific approach by taking various options from different participants.

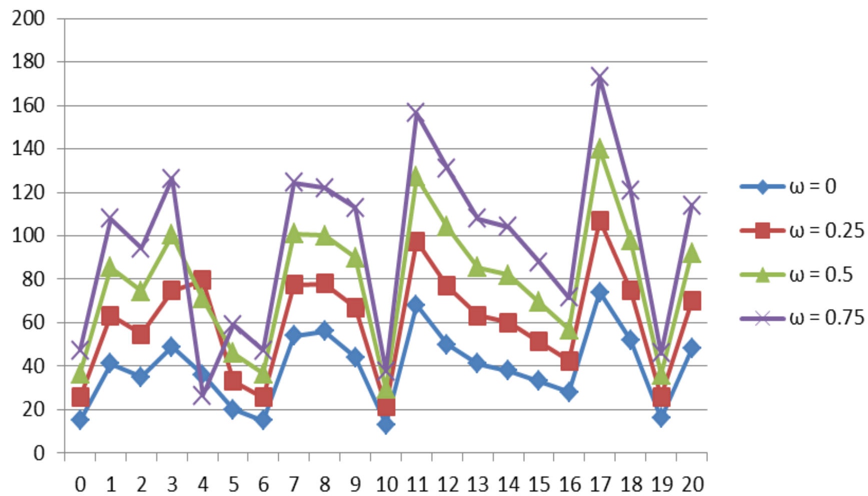

Figure 3: Attributes scoring with different ω value.

A systematic educational solution is proposed in this paper by enhancing the traditional QFD with integrated methodology for translating various curricular design parameters into sustainability education requirements, the results show that fuzzy logic can be a helpful tool to promote decision making and lessen the subjective outcomes coming from the traditional QFD. To further enhance the proposed methodology, other artificial intelligence techniques, such as artificial neural network, K-means, etc. can be adopted to improve the reliability of the proposed methodology. Also, multiple phases of QFD can be implemented to further investigate specific parameters that can facilitate the sustainability education.

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