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Research Article
To Research the Assessment and Sustainable Design of Office Furniture from a Design Perspective

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Abstract
This study presents a method for determining the importance of assessment criteria for sustainable design in office furniture using the so-called a sustainable design index. In the theoretical part of this study on the basis of literature there are identified sustainability criteria related to sustainable design and office furniture industry. Moreover, there is described a simplified procedure for determining the importance of assessment criteria for sustainable design using the preference analysis Analytical Hierarchy Process (AHP). In the empirical part there are present the result of study, which were conduct among expert. In this study researchers present a set of indicators which are used as criteria for sustainable design assessment. The aim for this study is to provide a new tool for decision making based on sustainable design index. This tools help in classifying the sustainable office furniture which is to fulfill the needs of customer toward sustainability. The researchers present the numerical example in order to explain the decision making process and indicate how the application of sustainable design index can contribute toward more sustainable office furniture.

Key words: Sustainable design, OPS, SDI, AHP

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The 21st century will be a new age for furniture design and furniture design and innovation will be the wing of furniture business[1]. At the moment industrial design is integrated interested in the design process of best new products and in world of comprehensive competitions, it creates good business sense to do so. In short technical and industrial designs are the essential, complementary part of design of anything. A person always has been involved with fashioning artifacts to improve life and to ensure its continued progressions. Significant as they were, these initial works normally required an analytical aspect because to the original, design was essentially a matter of trial and error.

Interestingly enough, some of the most important furniture construction techniques were develops to meet serious material shortages. The revolution in the form of up-to-date products and architecture was stimulus the team with a new ideas, techniques, material and forms. Designer should think about how to use all kind of advances science and technology, material to reduce the environmental impact during the early decision making in the design process[2].

The dynamic of innovation for furniture industry is with regard the role player by the immediate business environment such as a suppliers, customers, competitors and retailer paramount importance[3]. Some of the important decisions with respect to environmental properties of a new product are taken during the product development[4] as shown in Fig. 1.

At some further period in history, human began to nonstop this process of designing as they observed and experienced the requirements of a tool. In the act of designing, primary consideration must be given to the needs of the user, involving the special functional, material and visual requirements of the problem. Human factor is the study of the interactions between people and the products they use and the environments in which they works and live. Designer should emphasis on finding efficient ways to manufacture goods to meets the demands of the customers. Since design is an extremely interactive development, with a constant rotation of description, conceptualization, choice and embodiment, the assessment and assortment part of the development will be continual through the new product development method.

MATERIALS AND METHODS

Assessment of sustainable design of office furniture: The responsibility of designer and manufacturers regarding this intolerable situation is to plan and make environmentally benign products. These series of problems make people have to re-examining the living environment of them. The problem how can human maintain survival environment while making development and progress in science and technology to achieve human social, environment and economic sustainability[5]. The theoretical goal of practice to achieve it is through the assessment of industrial sustainability and one of the category of sustainability assessment tools is indicators[6]. If in that sense, sustainability is incorporate within a company's strategy, it thus aims for improvement in all the three areas, economic, socio-economic and ethic dimensions[7].

Design is a method able to change the human activities, daily life and social interaction. In recent year, the sustainability become a popular subject either industries or educations sectors, which is continuously seeking the sustainable design and green design. Sustainable design is required a less environmental impact, less consumption of energy and material during the process of the manufacturer and using. A triple bottom line approach to design for sustainability is describe by McDonough and Braungart[8], in which firms balance traditional economic objectives with environmental, economic and social concerns as show in Fig. 2.

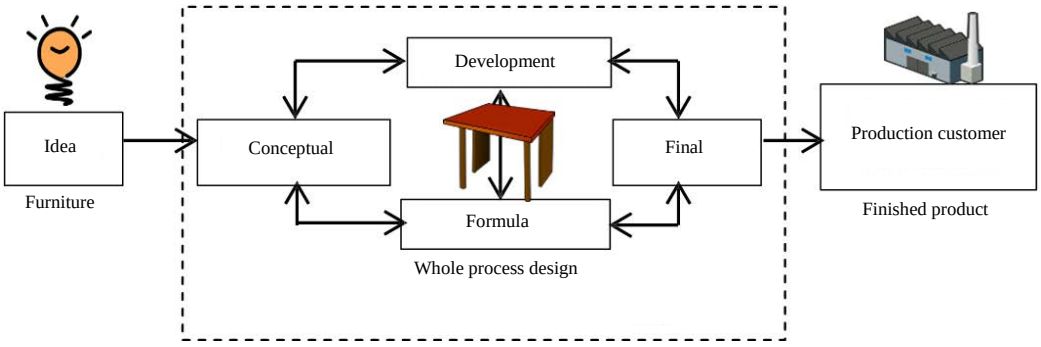


Fig. 1: Design process

Commonly use of office furniture include: Work surface, wood leg, metal leg, pedestal, mobile pedestal and panel, drawers, hanging shelve, etc. They need various material as wood, metal, plastic, aluminum and additive during the production process. They will affect H_2O, air contamination and soil pollution late in the manner of damages. Inappropriate on the social concern, designer set advancing the thought green design and sustainable development. The green design objective is to practice the resources and approaches of design to synchronizing the correlation between social product environments and to achieve the goal of sustainable design.

The sustainable design idea of office furniture aims to meeting the necessities of individual and the development of the society, efficiently keeping the environment and natural resource, wisely making use of the natural resources, sustaining and stabling the sustainable economic growth in the process of growth and design of office furniture industry example as shown in Fig. 3 is a cluster of three of Open Plan System (OPS).

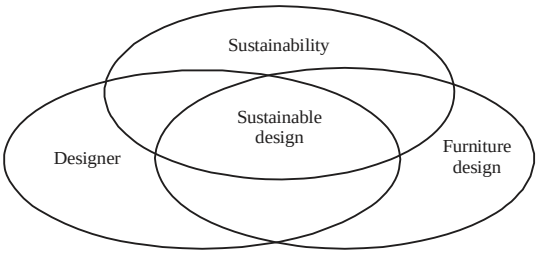


Fig. 2: Sustainable design spanned out from the triple bottom lines

Proper life cycle assessment has a vital role in the design phase to control office furniture toward sustainability. The keys of product development are how to distinguish the optimal designs form the bad designs at the early stage and how to reduce the interactive error rate[9].

Evaluation index system of sustainable design of furniture: The purpose of assessment for sustainable design of office furniture is to evaluate the impact on sustainable design of it and to achieve the purpose of environmental protection through various means. The main assessment of the principle can be summed up in four aspects. We analyses the sustainable design of the office furniture and choose the evaluation index system, the following factors should be considered: (1) Make use of life cycle assessment to grasp the process of office furniture early decision making in design process, (2) Sustainable design assessment should understanding the sustainable economic, environment and social, (3) Sustainable design criteria should be able to evaluate several aspect in every stage of the early decision making in design process and (4) Sustainable design index should be able to provide an appropriate the product consumption of office furniture namely open plan system. To formulate the assessment of office furniture toward sustainable design in this study the four factor were applied which is modularity and reconfigutrability, design structure matrix, axiomatic design and CAD environment were consider as shown in Fig. 4.

Sustainable furniture sustainable design: The knowledge of sustainability could help resolve the problem by determining the best choice of any design performance. The designer first

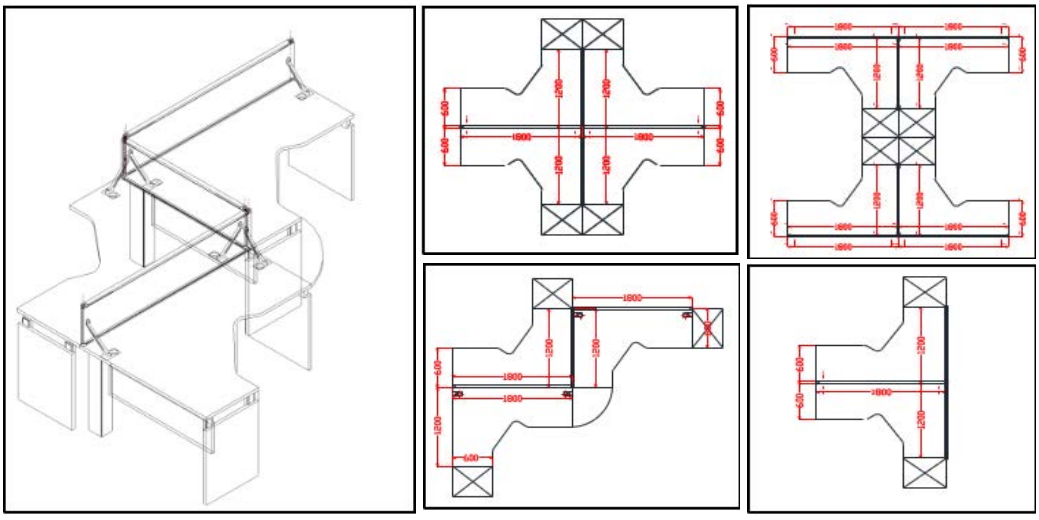


Fig. 3: OPS cluster of three and cluster of two

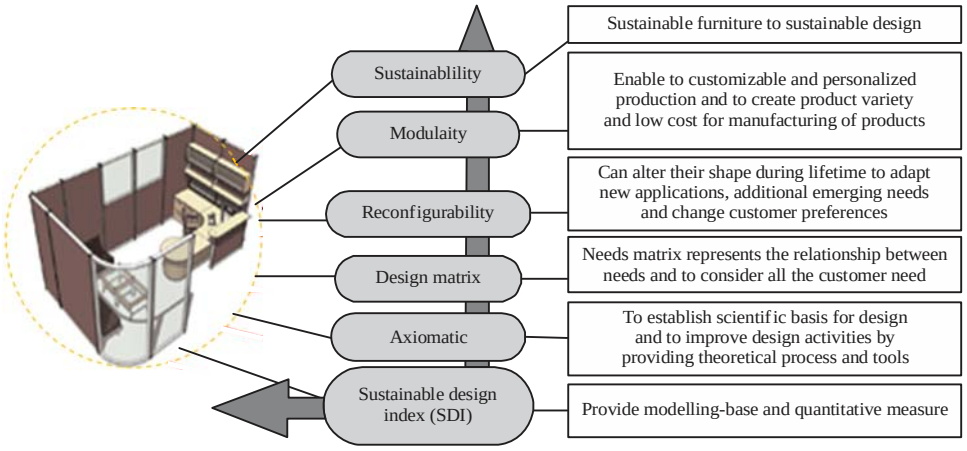


Fig. 4: Interrelation for a cooperative design tool

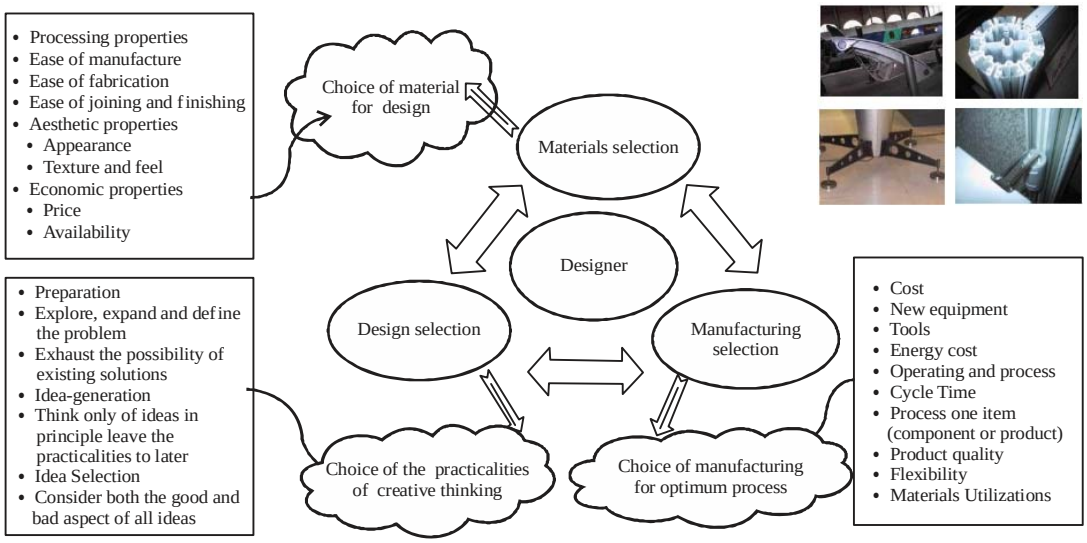


Fig. 5: Design selection

should be aware and understand the complex and wide ranging issues when designing and developing a new product. This is prompting to produce a tool for designers to present the sustainable issues related to their products in a more manageable form[10].

In practice, environmental, social and economic concept should take account of the sustainable design aspect, due to that designers need to consider the whole life cycle approach and the awareness of stakeholders and a useful cooperative design tool in design selection, material selection[11] and manufacturing selection as shown in Fig. 5. It is clear that the designer has a vital role in leading the world towards sustainable future particularly in terms of efficient and effective resources consumption and utilization[1].

Sustainable design office furniture: The traditional office furniture design mainly consider basic attributes of product (function, quality, ergonomic, material and aesthetic) it pay more attention to how to produce efficiently at the best design toward sustainable design with low impact on the environment during the manufacturing, assembly and disposable. The sustainable design required designer to consider environment protection maximum from concept design phase, to manufacturing process. Handfield *et al.*[10] suggested that, the manager should integrate the environmental thinking into purchasing decisions, better supplier and might consider reducing the hazardous waste production and reducing the environmental negative impact.

The process of furniture design means the whole technology preparation for the product design, i.e., from planning to mass production. As an example, the success of the wood furniture in Malaysia is due to collective effort of all innovation actors in the industry also support from supplier to equip the manufacture needed[3]. The scientific product design and development process includes material selection, functionality design and analysis, economic costing and aesthetics, plus the reasonable management, all together can ensure the design quality through the appropriate design cycle arrangement. The development of furniture design is complicated process of knowledge movement, which involves marketing analysis, suppliers, production and design techniques, etc. Designer should equip with multi-disciplinary knowledge. Generally the product design and development will undergo as shown in Fig. 6, including 4 main stages: Idea-formation, R and D, manufacturing and marketing adapted[12]. Furniture design is particularly dependent on trend and timeliness, in order to fulfil the changing customer demands it is necessary to develop new type of furniture with improved functionality[13].

Assessment method for office furniture sustainable design: The level of innovation is dependent on how to define a design problem. To solve this problem designer needs to broaden the way of thinking about furniture design. To design an innovative open plan system a designer needs to know the function and practicality to provide for people[14]. In previous years, innovation in the design process has existed essentially to decrease time required and the resources in the design, production and distribution of products. The new challenges require a systematic, integrated and simultaneous intervention on a product process, which requires a new method to address these design challenges[15]. The most efficient manner possibly for this is a design intervention oriented toward sustainable design.

Many models and techniques have been applied to concept selection in different field. Pugh[16] developed a simple graphic and fast method utilizes a matrix with column and rows. Concept selection is one of early stages in product development in which proposed concept evaluated to select the best concept that best fulfill the decision making criteria. The sustainable design alternative generated through the extended methodology are evaluated through a set of sustainability metric[17] as shown in Fig. 7. The important in matrix contains a list of all constitute members and the corresponding information are required and generate must effectiveness and efficiency. Once the information flow are documented in a design structure matrix DSM, some analytical can be operate for all kind of goals.

As a part of the process of generating alternative office furniture towards sustainable design, the engineering implications of control positioning, weight distribution, material choice and manufacturing method were taken into account. As and aid to evaluating the sustainable criteria, the designer set about producing an evaluation matrix. One of the primary purposes of the matrix is to force the designer to evaluate each concept against all the requirements and to work toward a consensus decision on which concept or concept to develop further. The most difficult task that the designer of the design team face is to compare each of the concept design with the datum product for each of the assessment criteria and then to decide whether it meets each criteria equally, more effectively or less effectively than the

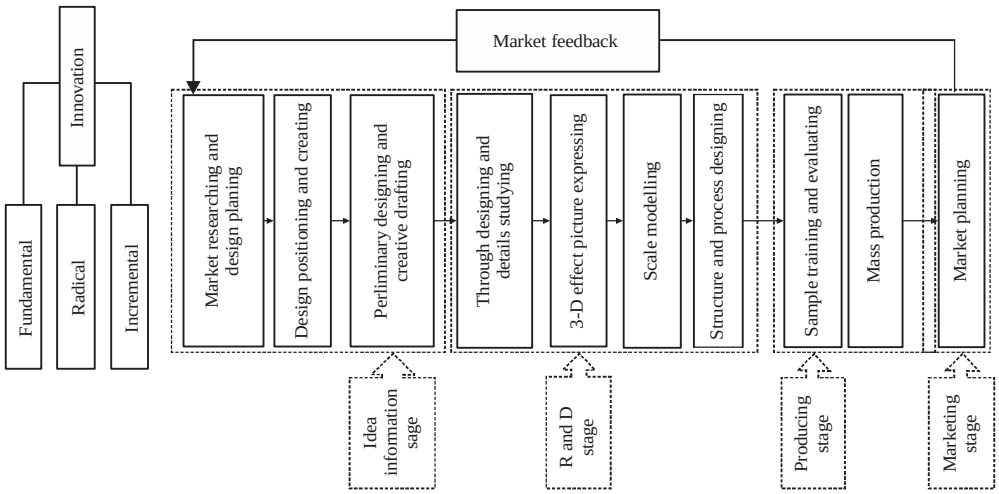
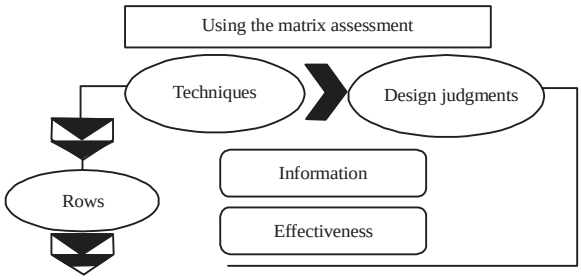
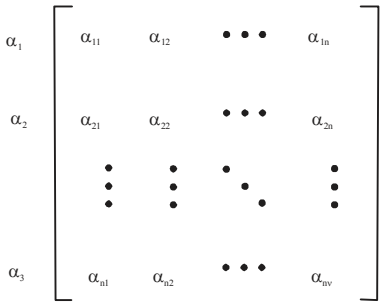


Fig. 6: Development process of furniture design adapted[12]



Sustainability matrix	Sustainability	Design selection	Materials selection	Manufacturing selection	User
Marketing		x			x
Design	x	x	x	x	x
Manufacturing	x		x	x	
Purchasing			x		

Fig. 7: Flow of matrix for OPS



Components of (OPs)										
	x		0	0	1	0	0	0	0	0
	0	x	0	0	1	0	0	0	0	0
	1	1	X	0	0	0	0	0	0	0
	1	1		X	0	0	0	0	0	1
	1	1	1	1	X	0	0	0	0	1
	0	0	0	0	1	X	1	0	0	0
	0	0	0	0	1	1	X	0	0	0
	0	0	0	0	1	0	0	X	0	0
	0	0	0	0	1	0	0	0	X	0
	0	1	0	0	1	0	0	0	0	X

Fig. 8: Component part design structure matrix of furniture open plan system

datum product. A DSM associated with a directed graph is a binary square matrix with m rows and columns and n non-zero elements, where m is the number of nodes and n is the number of directed lines connecting these nodes in the direction graph. If there exists a directed line from node j to node i, then the value of element aij (column j, row i) is unity (or mark with and X). Otherwise, the value of the element is zero (or left empty) as shown in Fig. 8.

Weighted evaluation: A matrix comprising the value of interaction among products in hierarchical clustering methods is required. Thus, value includes it the matrices are used to calculate weight matrixes that balance the requirements. This is a multi-criteria decision making problem solved using weighting techniques. The purpose of weighting methods is to assign values to set of criteria to indicate their relative importance[18]. The AHP is a method that relies exclusively on the judgement of expert to arrive at a decision. The expert judgement enters on the whole during determination of technology impact and weighting scenarios.

The most important impact on the design process and activities of designers has come from computer-based data processing. The CAD is influencing design methods example between conceptual and detail as well the creativity and thought process of individual designer[19]. Furthermore, the ability to create macros can be very helpful to enabling automatic sequences of features and actions. AutoCAD advance package software offer programming language or editors which is VBA, VB.NET, the integration of these programming into the CAD software enable other CAD files supports the generation of efficient tools for specific problem in the development process. An automated handling of problem oriented mathematical connection, formulas, rules and algorithms can be integrated into the corresponded product model to provide significant support for the SDI in the design phase as shown in Fig. 9.

Figure 10 show a schematic view of a hierarchy of office furniture design option within sustainability criteria, which can prioritized and subsequently narrowed down, on a situational basis.

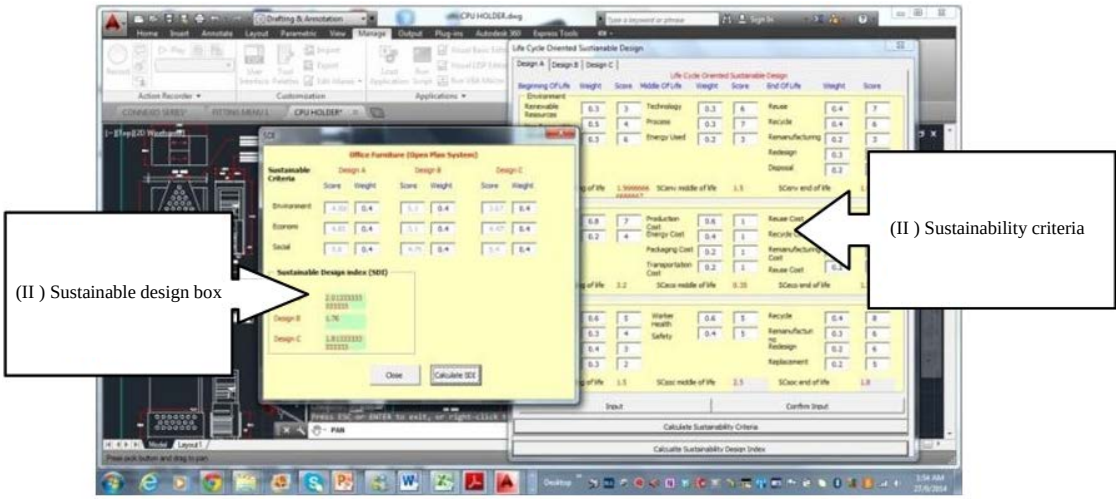


Fig. 9: CAD-based environment

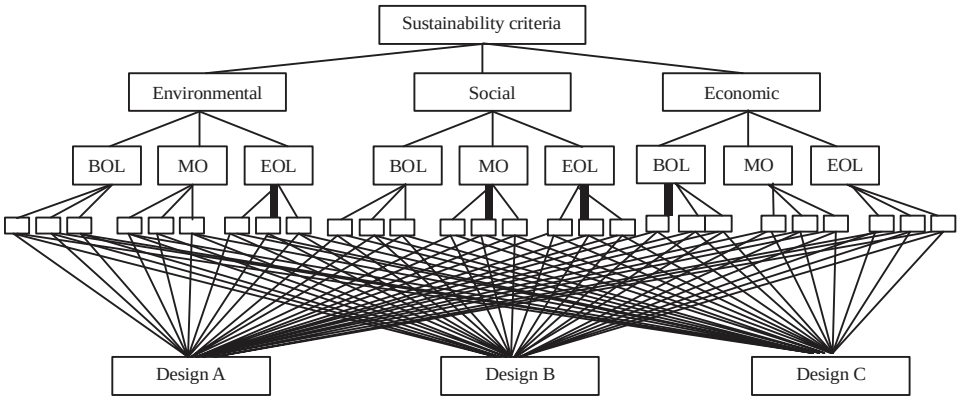


Fig. 10: Schematic view of sustainable criteria

Equation: The equation is derive form SMART is the simplest from the MAUT methods. The different knowledge and priority of the group designer and expert are expresses by voting power both for weighting the criteria and qualifying (scoring) the alternative against the criteria. The method of calculating the Sustainability Criteria (SC) of alternative is as following Eq. 1-3:

$$F_{env} \in SC_{env} = \frac{\sum_{i=1}^{n} (\omega_i S_i)}{\sum_{i=1}^{n} \omega_i} \quad (1)$$

$$F_{eco} \in SC_{eco} = \frac{\sum_{i=1}^{n} (\omega_i S_i)}{\sum_{i=1}^{n} \omega_i} \quad (2)$$

$$F_{soc} \in SC_{soc} = \frac{\sum_{i=1}^{n} (\omega_i S_i)}{\sum_{i=1}^{n} \omega_i} \quad (3)$$

where, SC_{env} is sustainability criteria of environment SC_{eco} is a sustainability criteria of economic and SC_{soc} is a sustainability criteria of social. The F is a factor and ω is a weight for each of the factor given respectively.

The Analytical Hierarchy Process (AHP) established by S_{aaty}, is a structure techniques for organizing and analyzing complex decision. A nine-point scale is utilized to rate pair-wise comparisons and their reciprocals, of hierarchy components between levels as an eigenvalue approach. The pair-wise comparisons are judgement. Within an AHP decision-maker preferences are represented by a pairwise comparison procedure of criteria and alternative based on scale and within

a hierarchical structure[20]. The AHP has been used to determine the weights at various levels[21]. The objective of this study is to introduce sustainability and to present a conceptual decision model, using Analytical Hierarchy Process (AHP) to assist in evaluating the impact of sustainable design index to office furniture open plan system.

Weight (W) can be express as:

$$W = [w_1, w_2, ...w_n],\ w_i \geq 0, \sum_{i=1}^{n} w_i = 1 \quad (4)$$

The three criteria of environmental, social and economic has been collected and calculated the example result as shown in Table 1. The three criteria were combined in the Sustainable Design Index (SDI). The weights for the three criteria were derived from the pairwise evaluation matrix as assessed by the design team member. It is calculate for each option by multiply each value by the weight, follow by summing the weights score for all criteria using the weight summation method:

$$SDI = \frac{1}{3}\sum_{q=1}^{3} F_q W_q = \frac{1}{3}\sum_{q=1}^{3} F_q + \frac{1}{3}\sum_{q=1}^{3} W_q \quad (5)$$

Table 1: Scale of pair-wise comparisons on sustainability criteria

Type of relation	Interaction	Description
No	0	No relation at all
Weak	1	Loose connection and medium relation
Medium strong	3	Medium connection and medium relation
Strong	5	Medium connection and high relation
Very strong	7	Firm connection and high relation
Excellent	9	Strong connection and high relation
Intermediate	2, 4, 6, 8	Intermediate Values

$$SDI = F_{env} \times W_{env} \times F_{soc} \times W_{soc} \times F_{eco} \times W_{eco} \quad (6)$$

where, the symbol SDI denotes as Sustainable Design Index (SDI) and F_{env} is an environmental F_{soc} is social and F_{eco} is an economic each of these factors will multiply by the weight.

RESULTS AND DISCUSSION

In particular the research originated the following as a result, there are many decisions that need to be taken, resulting in many types of selection problem. Whatever, the problem the aim is usually similar, to select the best way to fulfilling a set of requirements from the option available. Sometimes the selection criteria may be objective, for instance when they can written down mathematically[22].

The decision made by a customer to purchase products, it based on many factors including prices, quality and functionality, etc. Sometime, it is subject to the value of the product, to ensure this, the designer and end user must systematically understand the common language often through indexing[23]. In this study the researchers used semi-structured interview with designers and experts in furniture product design and development. To overcome the problem of communications, this study makes an interview face to face with the experts working more than 10 years with office Furniture Company on Open Plan System (OPS). The investigation on the criteria will be found from the experts through open-ended questionnaire, then it will be applied to forming the Sustainable Design Index (SDI).

Concerning the describe example, the coefficient between pair product are calculate using the expression of sustainable criteria as shown in Table 2. Equation 1-3 and sustainable design index in Table 4 (Eq. 5 and 6).

Table 2: Sustainability criteria

Sustainability criteria	Life cycle oriented sustainable design								
	Beginning of life (BOL)	Weight	Score	Middle of life (MOL)	Weight	Score	End-of life (EOL)	Weight	Score
Environment	Renewable resources	0.5	3	Technology	0.4	6	Reuse	0.4	7
	Non-renewable (durable)	0.4	4	Process	0.3	7	Recycle	0.3	6
	Non-renewable (non-durable)	0.3	6	Energy used	0.2	3	Remanufacturing	0.2	3
		-	-	-	-	-	Redesign	0.9	4
		-	-	-	-	-	Disposal	0.8	1
	SC_{env} beginning of life	1.6		SC_{env} middle of life	1.7		SC_{env} end of life	1.92	
Economic	Raw material cost	0.8	7	Production cost	0.6	7	Reuse cost	0.4	7
	Procurement	0.2	4	Energy cost	0.4	5	Recycle cost	0.2	6
		-	-	Packaging cost	0.2	3	Remanufacturing cost	0.2	3
		-	-	Transportation cost	0.2	2	Redesign cost	0.2	3
	SC_{eco} beginning of life	3.2		SC_{eco} middle of life	1.8		SC_{eco} end of life	1.3	
Society	Detail design	0.6	5	Worker Health	0.6	5	Recycle	0.4	8
	Safety	0.3	4	Safety	0.4	5	Remanufacturing	0.3	6
	Conceptual design	0.4	3	-	-	-	Redesign	0.2	6
	Part manufacturing	0.3	2	-	-	-	Replacement	0.2	5
	SC_{soc} beginning of life	1.5		SC_{soc} middle of life	2.5		SC_{soc} end of life	1.8	

Table 3: Weight justification

	Environmental	Economic	Social	Weight	Ranking
Environmental	1.000	2.000	5.000	0.545	1
Economic	0.500	1.000	6.000	0.370	2
Social	0.200	0.167	1.000	0.085	3

Table 4: Sustainable design Index comparisons of option design A, B and C

	Office furniture designs (open plan system)					
	A		B		C	
Sustainable criteria	Score	Weight	Score	Weight	Score	Weight
Environment	5.22	0.545	7.5	0.545	6.0	0.545
Economic	6.30	0.369	8.0	0.369	5.55	0.369
Social	5.8	0.084	5.55	0.084	4.55	0.084
Sustainable design index (SDI)	1.885		2.501		1.900	

$$SC_{env} = (BOL)\ 0.5\times3+0.4\times4+0.3\times6 = 1.6+$$
$$(MOL)\ 0.4\times6+0.3\times7+0.2\times3 = 1.7+$$
$$(EOL)\ 0.4\times7+0.3\times6+0.2\times3+0.9\times9+0.8\times1 = 1.92$$

$$SC_{eco} = (BOL)\ 0.8\times7+0.2\times4 = 3.2+$$
$$(MOL)\ 0.6\times7+0.4\times5+0.2\times3+0.2\times2 = 1.8+$$
$$(EOL)\ 0.4\times7+0.2\times6+0.2\times3+0.2\times3 = 1.3$$

$$SC_{soc} = (BOL)\ 0.6\times5+0.3\times4+0.4\times3+0.3\times2 = 1.5+(MOL)$$
$$0.6\times5+0.4\times5 = 2.5+(EOL)\ 0.4\times8+0.3\times6+0.2\times0.2\times5 = 1.8$$

$$SDI\ (Design\ A) = 5.22\times0.545+6.30\times0.368+5.8\times0.084 = 1.885$$

$$SDI\ (Design\ B) = 7.5\times0.545+8\times0.369+5.55\times0.084 = 2.501$$

$$SDI\ (Design\ C) = 6\times0.545+5.55\times0.369+4.55\times0.084 = 1.900$$

With these values, the unique matrix is shown in Table 1 and 4.

By incorporating these into the decision matrix, for each alternative, the results are multiplied by the weights of the indices, which lead to results being calculated in order to determine the score against each part[23]. Score and ratings will be calculated for each part, showing the significance of their influence with the corresponding index. For example, Table 3 shows the method of calculating the SDI value. The value of 2.501 indicates the Sustainable Design Index (SDI) of that furniture product.

The main reason for using rating and weight factor method is that it allows expert of the chosen suitable criteria to be allocated values to come non-quantifiable parameter and thus provides a base to which the various types of criteria can be deduced as shown in Table 3. The three criteria of environmental, social and economic has been collected and calculated the example result as shown in Table 4 the three criteria were combined in the Sustainable Design Index (SDI). The weights for the three criteria were derived from the pairwise evaluation matrix as assessed by the design team member. It is calculate for each option by multiply each value by the weight, follow by summing the weights score for all criteria using the weight summation method. The best design option has the highest score in the sustainability design index. The higher sustainability index the better the option. Once the criteria are standardized, they can be incorporated into a decision-making model. The Sustainable Design Index (SDI) model can be expressed. The higher sustainability index the better the option. Once the criteria are standardized, they can be incorporated into a decision-making model.

CONCLUSION

Innovation is essential in industry strategies today. Selection of a proper concept is one of the most important and planned tasks that should have been taken in early stages of new product development. In the design perspective, it is very important to consider the environmental impact due to the requirement form the end user. Taking into account the entire sustainable design index is needed to calculate the environmental impact to the office furniture design namely open plan system in the early decision making toward sustainable. Designer must escape their comfort zone and begin looking at the big picture. For sustainable design determinants were identified and sustainable design index for project appraisal was developed.

The sustainable design index can determine the sustainability of OPS by considering the key variable of economic, environmental and social criteria to select the best design option among other. The design of Sustainable Design Index (SDI) tool and its application in adaptive smart CAD environment will interpret the unique role of sustainable aspect in realizing sustainable furniture. In the conventional design process, the design result mainly depends on the designer's experience, knowledge and creativity. Sustainable design reflect the new idea of human being and new aesthetics and value, to be friendly and cooperate with nature.

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