



Title:

**An Investigation on Sustainable Design Index and its Implementation within the CAD Environment**

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Introduction:

In recent years, sustainability development has become a timely but major challenge in many countries. As a consequence, engineering production systems are increasingly complex, which is well reflected in their design, for their multi-disciplinary nature, complexity and sustainability in particular [10][11]. Therefore, sustainable design is an essential and much needed approach for the 21<sup>st</sup> century engineering design [14], particularly with the aid of CAD tools in a design automation process [4].

According to Wallace [16] if new knowledge is required, the methods and tools must be easily understood and applied by engineering designers. Hence, the research presented aims to investigate and understand the nature of sustainable design and analysis, through the development of a sustainable design index (SDI) with the associated analysis, for its industrially feasible implementation within the computer aided design (CAD) environment. In this paper, an innovative sustainable design index concept is presented particularly its implementation and application within computer aided design (CAD) environment. The application case study is carried out on furniture design, where the industry is pressured to take the responsible sustainability of economic, social, and environmental which need to be incorporated effectively at the early design stage.

Integrated design process and SDI:

Designers have the opportunity to implement sustainability in all stages especially within furniture industries. This intervention can be categorised as redesign, design, and product consumption and creation of new scenarios for sustainable lifestyle [8]. As one of the most important human necessities of life and consumer goods, furniture reflects the various elements of social phenomena [17]. A deeper knowledge, as well as awareness of the consumer enables companies to 'green' their products [1]. The furniture industry is defined as one of the major causes of environmental problems. As such, this research work focuses on developing a tool to enable designers to measure the sustainability in furniture designs, the main objective being to develop an SDI algorithm and implement it within a computer aided design (CAD) environment, to assist decision making throughout the design process. Many furniture companies have implemented CAD, but what is lacking is a source of information of how to improve or what other tools are available to enhance environmental impact in early decision making in the design process.

The environmental challenge is to design products that minimize these impacts [5]. The more quickly and accurately these predictions can be made, the shorter will be the product development time and the greater the chances of securing a competitive advantage. For this study the aim of the design method is to help designers improve their decision-making processes [6]. All decisions depend on forecasting and evaluating criteria, and the aim is to make the best possible decisions throughout the design process, which is very dynamic as there is continuous interaction between problem definition and solution generation. For this study, the movement and cycle from sustainable design

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toward sustainable design index (SDI) as a, generally accepted main phase of design process is show in Fig. 1. To deal with the problems of sustainability issues other indices such as human development index(HDI) ,City Development index (CDI),Environmental Performance Index(EPI), Environmental Vulnerability Index(EVI), Environmental sustainability index(ESI) [3], and for software is Guide to Sustainability Design-Solidwork [12] have been studied .

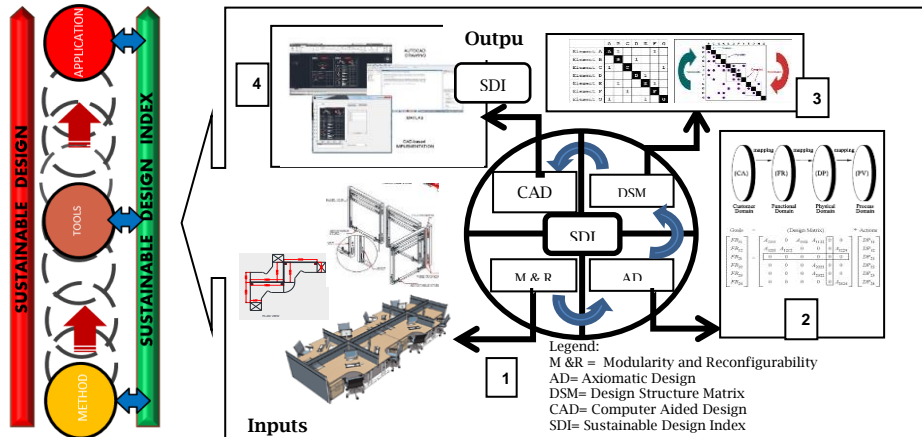


Fig. 1: The integrated design process and sustainable design index.

The uses of an appropriate CAD tool should be able to reduce the development cycle of new products [11]. Hence the selection of a suitable CAD system must be taken into consideration [9], and for a furniture designer, the software must be capable of producing any technical drawing [15]. The task of the design process is to find the solutions to meet the requirement of trends, the significant of their impact on customer perceptions and thus the purchasing decision. In this case the processes of sustainability decision for furniture concept of open plan system (OPS) are transferred into the CAD environment via sustainable design index (SDI) as implemented in this study. To enhance the application of SDI in a CAD environment new features have been developed, written in Visual Basic. In order to run this program the VBA macro is embedded in the CAD environment as shown in Fig. 2., and acts like a control panel by using the Manage Menu which the user needs in order to assess the functions of the system. Furthermore, the ability to create macros can be very helpful for enabling automatic sequences of features and actions. For this study AutoCAD 2014 enables programmers to integrate applications written in visual basic and load them into the AutoCAD main interface. In the Manage Menu of AutoCAD 2014, there are 3 buttons: Visual Basic Editor, Load Application, and Run VBA Macro buttons.

The following steps explain how the visual basic algorithm application is integrated into the AutoCAD 2014. Step 1 -Due to the ability of the CAD application link in the CAD environment, the SDI (from a template) - automatically picks form the Manage Menu. Step 2 -By clicking on the Visual Basic Editor Button, the applications is programmed after simulating the formulas as explained in equations 1 to 3 to calculate the result. Step 3 -the code is written in macro function inside visual basic editor. Step 4 -the user clicks on the Load Application button on the Manage Menu and defines the executable file of the visual basic application that has been developed. Step 5 - AutoCAD 2014 then loads the application into its allocated memory to be ready to run. Step 6 -The user then clicks on the Run VBA Macro button to select the name of the macro that will run from the visual basic application. Step 7 - The user reads the measurements from the design files in AutoCAD and then input parameters of three different designs as stated in graphic user interface. Step 8 -The Visual Basic application then calculates the formulas for SDI. Step 9 -In the future, the VB will be developed to read all the necessary parameters automatically from the design files.

For this study the graphic user interface make it easy to input data, in prescribed boxes call "Life Cycle Oriented Sustainable Design" as shown in Fig. 2., From the design 'A', design 'B', and design 'C'

options, users can fulfil the weight and score bases from their expertise to distinguish between the three design options - as equation 3.

In the case of defining the sustainable criteria for new furniture of an open plan system concept, designer knowledge and expertise has to be taken into account. At the end this process, a completely automated SDI calculates the design proposal for the series development of sustainable design generated as shown in Tab.2.

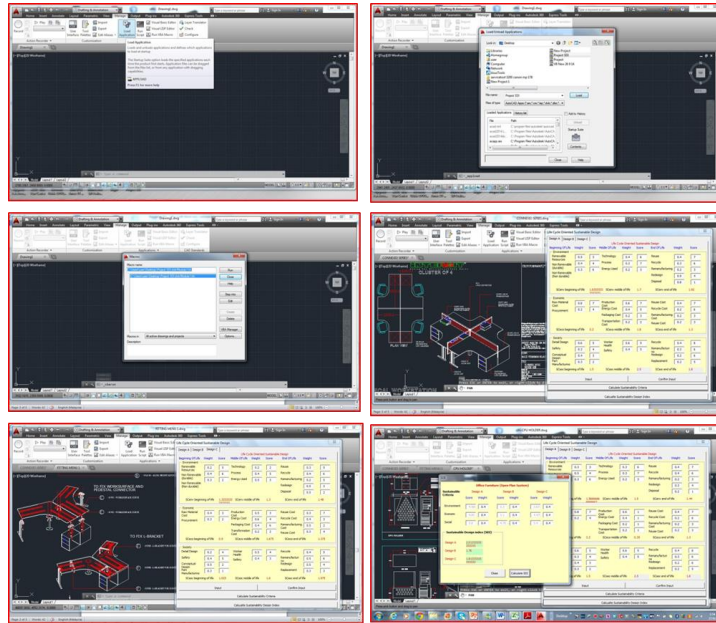


Fig. 2: The procedure of sustainable design index calculation.

Analytical representation of SDI:

Life cycle oriented sustainable design				
		Beginning of life (BOL)	Middle of life (MOL)	End-of life (EOL)
Sustainability Criteria	Environment	Renewable resources	Technology	Reuse
		Non-renewable (durable)	Process	Recycle
		Non-renewable (non-durable)	Energy Used	Remanufacturing
	Economic	Raw material cost	Production Cost	Redesign
		Procurement	Energy Cost	Disposal
	Society	Detail design	Transportation Cost	Reuse Cost
Safety		Worker Health	Recycle Cost	
Conceptual design		Safety	Remanufacturing Cost	
		Part manufacturing		Replacement

Tab. 1: Sustainability criteria for formulate SDI.

Proper product design planning in early stages of both product design and choice of sequence can give a products end-of-life more value, reduce time and increase cost effectiveness [2] [13]. The development of SDI is a tricky and complicated process. This study interviewed (faces-to -face) experts with more than 10 years' experience of office Furniture Company on Open Plan Systems (OPS). The investigation of the criteria found from the expert interviews, were then applied to the sustainable design index (SDI) criteria as show in Tab. 1., There are three important issues regarding product design namely: environmental, social and economic aspect [7]. The total sustainable design index (SDI) is achieved by computing a weighted average of overall mark from these environmental, social, and

economic elements. The influencing elements scores are recoded by the designer in each entity of matrix and evaluate the SDI in each matrix, for Sustainable criteria (SC) as in Tab. 1. Where the symbol ( $SC_{env}$ ) denotes the sustainability criteria,  $S_i$  is the impact factor based on a ranking 0-10 for the environmental elements of material,  $\omega_i$  is the weight of every factors of the material stage. The value of the social ( $SC_{soc}$ ) and economic ( $SC_{eco}$ ) elements of the materials can be calculated in a similar procedure as follows:

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

The main reason for using a rating and weighting factor method is that it allows expert of the chosen suitable criteria. The three criteria of environmental, social and economic have been collected and calculated, the example results as show in Tab. 2., were combined in the sustainable design index (SDI). The weights for the three criteria were derived from the pairwise evaluation matrix. It is calculated for each option by multiplying each value by the weighting, followed by summing the weights score for all criteria using the weight summation method. Therefore, the exercise may be regarded as approximations of weight, which provide a set of weight criteria and a representation of the relative importance of the criteria. Where  $n$  denotes the number required items of product design and the weight co-efficient  $w_i$  lies on the importance of the item in product design where the weight assigned to the criteria  $i$ . Weight ( $w$ ) can be expressed as:

$$w = [w_1, w_2, \dots, w_n], w_i \geq 0, \sum_{i=1}^n w_i = 1 \quad (2)$$

The best design option has the highest score in the sustainability design index. The higher the sustainability index the better the option. Once the criteria are standardised, they can be incorporated into a decision-making model. The sustainable design index (SDI) model can be expressed as follows:

$$SDI = \frac{F_{env} * W_{env} + F_{soc} * W_{soc} + F_{eco} * W_{eco}}{3} \quad (3)$$

Where the symbol SDI denotes Sustainable design index (SDI) and  $F_{env}$  is environmental  $F_{soc}$  is social and  $F_{eco}$  is economic each of these factors will be multiplied by the weighting. The total scores from the examples in Tab. 2., show that the design option b has the higher score of 2.80. This means design option b is the better option on the sustainable design index. Values of the SDI for each option of design vary between 0 (most unsustainable) and 10 (most sustainable). For SDI, a high value indicates that the design is sustainable, while a low value indicates not very sustainable, depending on the scale value used.

Sustainable criteria	Office Furniture (Open Plan System)					
	Design A		Design B		Design C	
	score	Weight	Score	Weight	Score	Weight
Environment	5.22	0.4	7.5	0.4	8	0.4
Economic	6.30	0.4	8	0.4	7.6	0.4
Social	5.8	0.4	5.55	0.4	4.55	0.4
<b>Sustainable design index (SDI)</b>	<b>2.31</b>		<b>2.80</b>		<b>2.68</b>	

Tab. 2: Calculating the alternative design option for SDI.

### Conclusion:

In this paper, a Sustainable Design Index (SDI) is presented in the CAD context, which can be used as a design “indicator” to analyze design sustainability within the design process. The SDI and the associated algorithms are investigated in light of a quantitative analysis approach particularly by taking account of its implementation within computer aided design environments. A case study on office furniture design is carried out because of its proneness to manufacturing, costs, life cycle, materials and societal aspect, although the approach developed aims to be applicable to wide range of design scenarios. The integrated CAD and SDI, provide for designers a dynamic transparency of the product sustainability throughout the design process.

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