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Development of the Sustainable Design Index and associated algorithm for furniture design based on the materials costing data and dynamics

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Abstract In order to illustrate the sustainability of a product and/or its materials, an algorithm of Sustainable design Index (SDI) is established based on the costing data and dynamics, which covers the dynamic costing of materials, processes, assemble/disassemble and transportation. The research of SDI is aim to evaluate or compare product's sustainability by number instead of feeling. When the SDI is implemented in the Computer Aided Design (CAD) software, such as windows and/or doors, the CAD program will be effective in guiding the sustainable designer, who tries to designing a product to meet the need of present and future generations.

Keywords Sustainable designing, Index, Dynamic costing, CAD software

1. Introduction

Brundtland Commission defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [1]. However, in product design and development practice, it is essential and much needed to have rapid quantitative assessment on the sustainability of the product designed, supported with the engineering design tools. The sustainable design index (SDI) and the associated algorithm embedded in the engineering design environment is likely ideal for fulfilling the purpose above particularly in the engineering design practice context.

Since the early 1990s significant effort has been put into the sustainable development and various methodologies for measuring sustainable development have been applied, which includes main these approaches, Pressure-State-Response (PSR) Model, Weak and strong sustainability model, and ESI, WI and EU sustainable development indicators [2, 3]. The PSR model has been initially developed by Canadian Statistics in 1970s, but only for environmental evaluation. Later it has been modified to include social and economic dimension as well [4]. Weak and strong models are strongly policy oriented. These two concepts reflect more their theoretical basis, especially the weak sustainability model. The third one

concentrated on using an extensive dataset covering rather equally environmental, economic, social and institutional aspects of sustainability.

Still, huge interest shown for the advancement in this area has not yet led to the consensus about the optimal sustainable development framework. Costing, one of the major factors influencing the diversity and inconsistency of sustainable development indicators, is enrolled at precise and complete definition and application in sustainability [5].

In this paper, formulation of the Sustainable Design Index (SDI) is presented based on the materials costing data and their dynamic fluctuation. The SDI computational implementation is explored within a CAD environment against the case study on the furniture design. The research aims to develop the SDI combining with the existing CAD tool, which will enable the designer to undertake sustainable products design and development in an industrial-feasible and effective manner.

2. Sustainable design index linking to materials costing

Many assessments have been undertaken in the recent years to identify which is better for the sustainability. Disposable nappies create 90 times more solid waste than reusable nappies (but this is only 2 per cent of total municipal waste), whereas reusable cloth nappies generate 10 times as much water pollution (including detergents) and consume 3 times as much energy as disposable nappies [6]. However, reusable nappies have a long lifetime and can be used for more than one child. This argument is currently unresolved, which illustrates how difficult it is to interpret the result of sustainability [7].

In furniture manufacturing, wood and WPC (Wood-plastic Composites) are commonly used materials. However, how to assess the sustainability of the materials selected in the product design and development is more experience driven on an individual case basis. Furthermore, it is based on the furniture designer or developer's 'sustainable' appreciation rather than on a quantitative analysis computerised within the design tool throughout the furniture design process. Woods look or feel like Green materials, which come from the natural trees and consume less energy in process. But, WPC is easily recycled and can absorb waste wood flour and plastic. So it is difficult to judge which one is sustainable by feeling.

To the materials used in designing and manufacturing, more attention should be paid on the balance between current resource and utilization. If the forestry can provide enough timber without threating environment, it is unnecessary to produce WPC and increase carbon emission. In most countries, the requirement of timber is

always more than the forestry's output. As a typical developing country, Chinese timber requirement is 371 million cubic meters in 2007, but the domestic forestry conversion only supplied 202 million cubic meters, so the gap was more than 100 million cubic meters. According to the prediction, the timber gap will climb to 100-150 million cubic meters in 2020, which definitely makes the timber costing increasing.

1.1 SDI of polar veneer

As one of popular materials in furniture manufacturing, poplar veneer, size 1270×840×2mm was selected to analyse the costing fluctuation and SDI, and the costing data from the website www.wood168.com (wood information in China) was listed in Tab.1.

Tab.1 Polar veneer (size 1270×840×2mm)

Year	2006	2007	2008	2009	2010	2011	2012	2013
Costing(CNY)	1.68	1.8	2.06	1.9	2.2	2.05	2.5	2.44

By Least Squares Regression analysis [8] and Mathematic software, the costing fluctuation is fitted in Fig.1. The red line is the result of line polynomial fitting, the green curve is square polynomial fitting and the blue one is cube polynomial fitting.

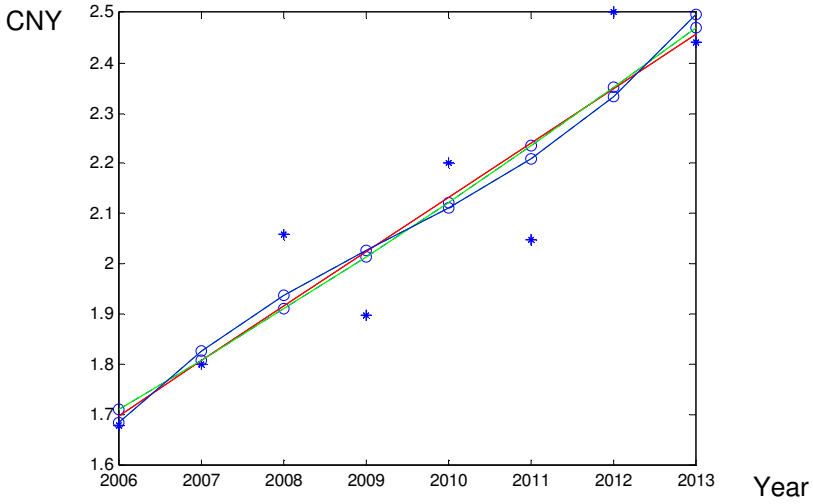

Fig.1 Polar veneer costing and its fluctuation fitting

The square and cube polynomial fitting can showed the costing fluctuation in short period, however the line polynomial fitting illustrates the general tendency in long term, both of them reflected the supply gap. In order to reflect the supply gap in a

long period, the slope of line polynomial fitting is selected as a stable parameter, the slope ratio divides the current costing as the SDI value of materials.

SDI of polar veneer is worked out by the following formula,

$$S=K/V \tag{1}$$

S means SDI,
K means slope of line polynomial fitting for costing fluctuation,
V means current costing.

According to the polar veneer costing fluctuation fitting, K=0.108214CNY per year, and V=2.44CNY in 2013, then S=0.108214/2.44=0.04435.

1.2 SDI of WPC

The WPC are also a typical material in furniture manufacturing. The costing of WPC floor in recent years was in tab.2, with Least Squares Regression analysis and Mathematic software, the K=-26CNY per year and V=140CNY in 2013, so the SDI of WPC floor, S=K/V=-0.1857.

Tab.2 WPC floor costing

Year	2009	2010	2011	2012	2013
Cost(CNY/ m^2)	240	210	180	150	140

If we are dependent on the timber too much, the supply gap will become bigger and bigger, which result the costing of polar veneer keeps increasing, so the SDI is positive and big value. In this case, the WPC is kind of alternative material to replace wood and made of waste wood flour and plastic, which property is recycled. To all the costing of WPC keeps decreasing and its SDI is negative. So in nowadays and in China, WPC is more sustainable than timber.

2. SDI algorithm for the products' sustainability

Most of products are composed by many parts, and the parts cover material and process. Furthermore, the whole products' transportation assembles and dissembles. All above factors should be considered in the Algorithm of product sustainability. For example, a product is divided into Part-1, Part-2,…, Part-i, …, Part-n, and the SDI of Part-i (shortened with S_i) is formulated by

$$S_i=K_{mi}/V_{mi}+K_{pi}/V_{pi} \tag{2}$$

K_{mi} and K_{pi} means the K value of Part-I's material and process
V_{mi} and V_{pi} means the V value in current year of Part-i material and process

So the SDI of whole product (shortened with S) is formulated by

$$S=\Sigma S_i+S_T+S_{A/D} \quad (3)$$

S_T means the S of transportation,
$S_{A/D}$ means the S of assemble and dissemble.

To the complex assemble and dissemble process, it may be divided into several sections, and in each section the relative parts are assemble together into a component [9]. In each section, the SDI algorithm is formed one by one, which is showed in the Tab.3.

Tab.3 Algorithm for product SDI

Part No.	**Materials**	**Process**	**Assemble/Dissemble**			**Trans-portation**
			Section 1	Section 2	…	
Part-1	$S_{m1}=K_{m1}/V_{m1}$	$S_{p1}=K_{p1}/V_{p1}$	$S_{A/D1-2}=K_{A/D1-2}/V_{A/D1-2}$	$S_{A/D1-5}=K_{A/D1-5}/V_{A/D1-5}$	…	K_T/V_T
Part-2	$S_{m2}=K_{m2}/V_{m2}$	$S_{p2}=K_{p2}/V_{p2}$				
Part-3	$S_{m3}=K_{m3}/V_{m3}$	$S_{p3}=K_{p3}/V_{p3}$	$S_{A/D3-5}=K_{A/D3-5}/V_{A/D3-5}$			
Part-4	$S_{m4}=K_{m4}/V_{m4}$	$S_{p4}=K_{p4}/V_{p4}$				
Part-5	$S_{m5}=K_{m5}/V_{m5}$	$S_{p5}=K_{p5}/V_{p5}$				
...	...	...	...	...	…	
Total	S_m	S_p	$S_{A/D1}$	$S_{A/D2}$	…	S_T
$S=S_m+S_p+\sum S_{A/D}+S_T$						

3. Discussions

To some products, such as luxury, military, tobacco products, the algorithm maybe fail. Even if their costing is decreasing and their SDIs are low, they are unsustainable to human for the characters of over resource consuming, violent destroy, unhealthy. So an assessment method should be taken to get rid of them from the sustainable product evaluation.

The algorithm of Dow Jones Sustainability World Index, developed by company RobecoSAM AG (www.robecosam.com), can be used to pre-evaluate the products (Fig.2). This model is designed to cover the economic, environment and social dimensions. Each of the three dimensions consists of several criterions, and each criterion contains 2-10 questions, totalling approximately 100 questions, depending on the product. For each product, a total sustainability score of up to 100 points is

calculated based on the pre-defined weights established for each question and criterion. This total score is used to rank the sustainability of products, the low score products are not eligible to the SDI algorithm.

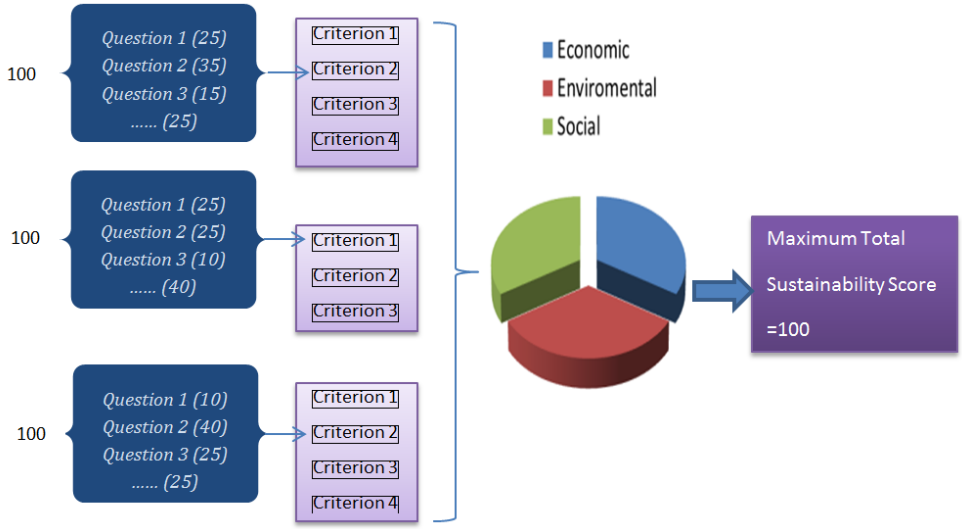

Fig.2 Pre-evalutate model for SDI algorithm

In addition, if one of parts SDI is negative and is abused with massive quantity to get the less value of whole product SDI, the formula will be unreasonable. To avoid this case, the whole product can be integrated instead divided into many parts. So the formula simplified into

$$S=S_I+S_{A/D}+S_T \tag{4}$$

S_I means the costing fluctuation of the integrated product.

This formula is suggested to be used in the case that the negative SDI parts are added viciously to get the less value of the whole product SDI. In fact, the previous formula (3) is common on guiding the sustainable product designing.

In some countries, the ruler about carbon footprint or environment protection is not very strict. Even though the product has great negative impacts on environment, ecology or society, the costing doesn't increase greatly and its SDI is low. So the government should enhance the criterion of production, force the company pay for the negative impacts, finally protect the needs of next generation, which will result in increased costing and high SDI.

4. SDI implementation within the CAD environment

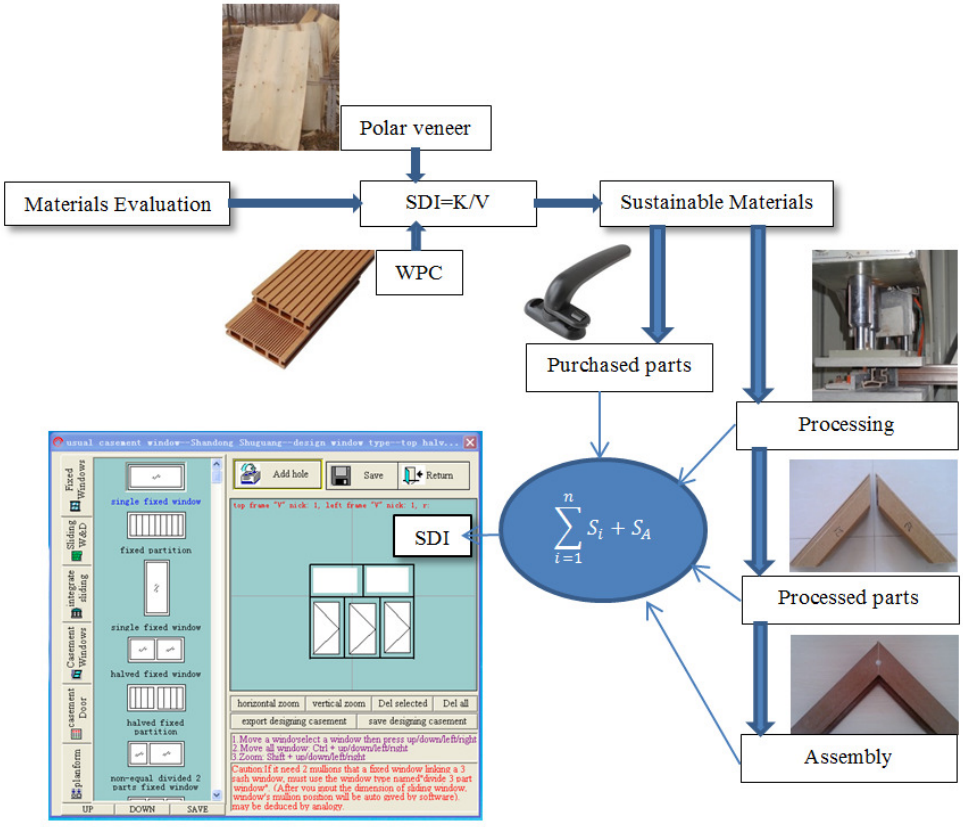

Fig.3 CAD software connected with SDI

In furniture manufacturing, some CAD software are used to design windows, doors etc. If the software is connected with SDI as illustrated in Fig.3, the sustainable designer will easily find his idea's sustainability and adjust it to be better.

Important part of Profiles implementation is the databases of materials and its costing, which are created by our customers, dealers and manufacturers of profiles. The CAD can develop the SDI by the database (Fig.4), which mainly focused on the sustainable design working with a number indicator. The algorithm of SDI maybe fails to some products, but the costing/price is an efficient method to connect the impacts on society, ecology and environment. With this foundation, the sustainable design indicator and algorithm will be adjusted to be better.

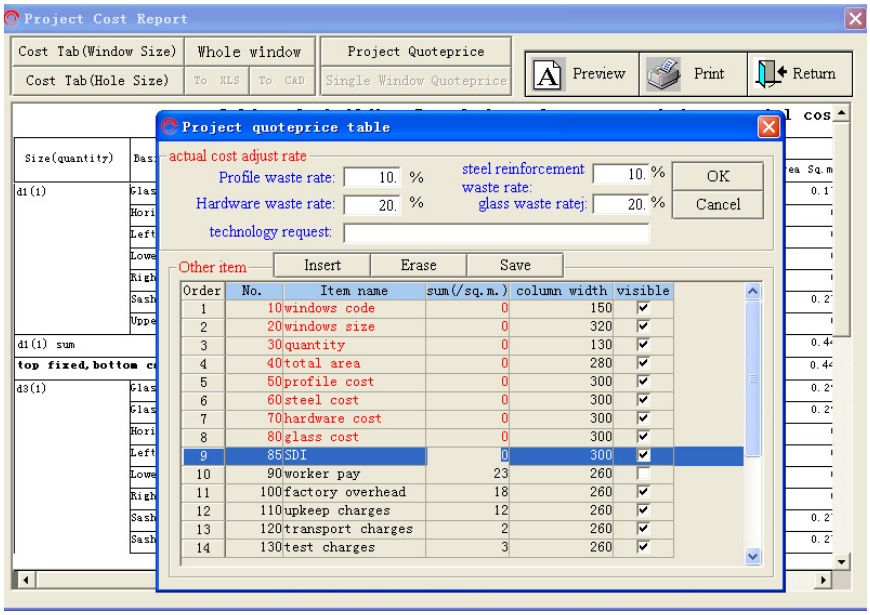

Fig.4 SDI in CAD software

5. Conclusions

There are many factors which have effect on costing, including government rulers, such as resource protection, carbon emission and energy consuming. They have also great effect on the fluctuation of furniture materials costing or thus the design and manufacturing process. With good supervising rulers, the costing can reflect a product's impact on carbon footprint, resource and needs of next generation. The other factors may have both effects on sustainable and unsustainable product, so it is unnecessary to consider them in judging sustainability of products. The SDI algorithm presented in this paper is also accordance with enterprise benefit, because a low SDI not only means a sustainable product but also a low cost in materials, process etc. This algorithm can be implemented in CAD software based on its costing database within recent years.

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