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Title: INCORPORATING ENVIRONMENTAL AND AESTHETICAL ASPECTS IN DESIGN: AN OVERVIEW

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Summary:
Elegancy and environmentally friendly- these two criteria have now got prominence in the sphere of designing a product. But honestly speaking, aesthetics consideration being rather subjective while environmental judgment based on so many factors- both have been sweating designers much to date. In the present paper, the scenario of already done research and findings are briefly paraphrased. Further, an expert system designed to give a hand to designer on the above-mentioned aspects is also outlined.
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INCORPORATING ENVIRONMENTAL AND AESTHETICAL ASPECTS IN DESIGN: AN OVERVIEW

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ABSTRACT

Elegancy and environmentally friendly- these two criteria have now got prominence in the sphere of designing a product. But honestly speaking, aesthetics consideration being rather subjective while environmental judgment based on so many factors- both have been sweating designers much to date. In the present paper, the scenario of already done research and findings are briefly paraphrased. Further, an expert system designed to give a hand to designer on the above-mentioned aspects is also outlined.

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1. INTRODUCTION

In the competitive world of market, aesthetically pleasant and environmentally friendly products have become the pressing need of the day. With the advent of computer technology in 1941 followed by subsequent development has already incorporated many segments of design to be done with the help of this boon. However, amalgamation of aesthetics has to go a long way to the conventional design procedure, let alone in computer-aided design process. On the other hand, environmental aspect analysis has past some landmark achievements albeit remains a bit expensive and not to be mentioned lengthy. This paper would focus on the present development and research on these two fields with specific emphasize on the integration of these two factors with computer-aided design and manufacturing.

2. DESIGN FOR AESTHETICS

2.1 Definition of Aesthetics

According to Britannica [1], Aesthetics the study of beauty. The term 'Aesthetics' was coined by Alexander Baurmgarten [2] in his book 'Reflection of Poetry(1735)'. Further, He pointed that sensations and perceptions, the sources of aesthetic experiences, are neglected as subjects of study in the rationalistic school of Philosophy. As encored in the rationalistic domain, he embarked on a mathematical study of aesthetics. Towing the line, some two thousands year ago, the roman architect and artist Vitruvius claimed that, for human products, 'firmitas', 'utilitas'

and ‘venustas’ are the key ingredients, as well as their harmony. Another illustrious Belgian architect and designer- Henry van de Velde voiced, “Beauty is the result of clarity and system, and not an optical illusion”(De Wolff, 1992) [3]. Following this criteria Mijksenaar(1997) [4]developed a scheme to measure the relative strength of these qualities for industrial design products.

Talking to philosophy of aesthetics, in last three centuries great contributions have been made in this field by many philosophers including Kant, Tolstoy, Bearsdley and so forth. Mainly two theory were envisaged as follows: firstly theory of taste—originated in Eighteenth century sees aesthetics as reactions in an observer, that are triggered by specific kind of object. So faculty of perception, faculty of reaction, and object to be perceived, a mental state resulted from reaction to the object and a judgment of taste---all these five components are required. The other theory—namely attitude theory—paraphrased as that the appreciation of aesthetics is more subjective and requires certain modes of perception or consciousness from the observer (Dickie, 1974) [5]. In addition, two more prominent view points [6] have been dominating the thinking sphere on aesthetics- namely:
a] Rationalistic view: aesthetics is nothing but the science of beauty.
b] Romanticist view: the perception of beauty lies in the heart of human being and so could not be fully phrased under certain law.

2.2 Evaluation of Aesthetics Terms and Interaction with Product Design
As aesthetics is rather subjective and relative to the myriad of human taste, it is quite difficult to have a unanimous analysis of it. However, various dimensions have been suggested as Goldman [7] did with the following eight criteria:
• Broadly evaluative, e.g. beautiful, ugly, sublime, dreary.
• Formal, e.g. balanced, graceful, concise.
• Emotional, e.g. sad, angry, joyful, serene.
• Evocative, e.g. powerful, stirring, amusing, hilarious, boring.
• Behavioral, e.g. sluggish, bouncy, jaunty.
• Representational, e.g. realistic, distorted, artificial.
• Perceptual, e.g. vivid, dull, flashy.
• Historical, e.g. derivative, original, conservative

Besides, according to the most researchers in philosophy the following three have prime importance as –

- Expression
- Representation
- Form

And on the sphere of physical characteristics, the terms used are as follows: Geometry, form, Shape, Composition and Physical Attributes.

To relate design characteristics with aesthetics, Pham[8] has propounded the following nine categories that should be addressed during design.
Balance: According to Ruskin, a balanced composition puts several things together so as to make one thing of them. Liken balance that keep our body straight from falling apart, in design does so in different prospective. It could be also paraphrased as achieving equilibrium. There are two ways of doing so—symmetry[mirror image] and asymmetry. Symmetry is the mirror image organisation, that is grouping objects with characteristics of complimentary order so to appeal much to human, and to say

looking around the nature, most things are symmetric, e.g. two eyes, two ears, etc. On the other hand, not all the symmetry would have soothing affect, might cause monotony and for that asymmetry in the perceived area.

Proportion: Proportion is a design principle that has to do with the relationship between size and scale, that is of spatial balance. Three types of balance are usually envisaged as- Linear, Areal and Volumetric. In brief, linear proportion deals with the relation between the dimensions (e.g. length, width) of a single object (or feature) or between linear dimension of one object or feature to that of another, areal and volumetric do so with the respective area and volume and vice versa.

Dominance / Principality: Following the literal meaning, dominance describes an object or something that dominates in a situation or presentation. In principle, unity of design could be achieved by focusing only one thing in focus, not jumbling a lot with equal importance.

Contrast / Interchange / Alteration: The thesaurus explains contrast as the opposition or dissimilarity of things that are compared. Truly in this way, maximum visibility could be attained. For instance, light against dark, positive against negative shapes, smooth against sharp curvature and vice versa. To achieve contrast, size, value, color, shape and so on should be used judiciously.

Continuity/ Gradation: Looking at a composition, viewer's attention could be directed or continued to the other one when primary object do so by some sort of pointing techniques. For instance, eye direction, paths, perspective and many other subtle ways. Apart from having attention transfer, continuity or change in gradual fashion creates or imparts soothing and calm feeling whereas the opposite might produce striking effects or unsettling feeling. The latter one is not normally wanted but some cases may become usable.

Solidity / Structural Coherence: Intrinsically human beings are accustomed to solid or full structures and so this sensation creation is quite important to excel in aesthetics quality. Generally speaking, double curved surfaces give and impression of more fullness than a single curved surface. Intriguingly, abrupt transitions between the parts convey the message of fragility to brain and so such should be avoided. On the contrary, combination of small parts focusing somewhere generates the notion of stability and strength.

Simplicity: Sometimes simple is the best rather than jumble of things placed haphazardly as it causes fuzzy and untidy feeling.

Dynamics: The world is moving round the sun and human life also prefers dynamic pattern rather than rigid and stiff one. So incorporating sort of dynamic effect in design would be appreciated by almost every genre of people. The techniques for that might be definite orientation or path like spiral composition around an axis, smooth transition from one color to another and shape, etc.

Rhythm: The prime receptor of aesthetics is eye and it finds catchy the repetition of form, color, intensity or tone. This is called rhythm and compounds a major element

in elegant design. However, a caveat be kept on mind- too much use of the same pattern without variation might cause monotony.

2.3 Past Research and Development on Design For Aesthetics

A plethora of research works has been done in past on the field of aesthetics but mainly those are focused on art, philosophy, music, painting and so on. Presumably only a few attempts on design (Pye, 1995)[9], and have to be sifted to find works specifically on computer-aided design for aesthetics. Still all these works have been helping a lot to formulate the design for aesthetics with computer aid.

As the whole horizon research turns around emotion, consumer or specifically people taste and else, so a short glimpse could be highlighted on these kind of research. In psychology many studies have been focused on emotion and feelings as mentioned by Frijda (1986)[10]. To have the idea of consumer attitude, the arena of marketing research has developed different models of customer judgments based on survey (Snelders,1995)[11]. The first and foremost attraction of an urban landscape is skyscrapers or elegant bridge. And may be for that reason, quite substantial attempts have been made in Civil engineering regarding the building aesthetically pleasant bridge, together with dam (Furuta, et al., 1993[12],1995[13], Reich, 1993[6], Miles et al., 1993[14]).

On the domain of Industrial Engineering that much more related in findings methods and criteria for making aesthetically pleasant products. Some researchers have worked in the last two decades. Claesen (1996)[15] has explored the relationship between color and shape. Fresdam, a computer model produced from sketches or mock-up 3D models, has been developed by Kurango (1992)[16] and used also by Sony Corp for their design of video cameras. And finally, computer-oriented methods to assist product design have been made by Takala and Woodward (1998)[17], Hisao and Chen (1997)[18]. And the two names must be mentioned with special highlight—Wallace and Pham. To speak with veracity, they have been gearing through the major research on this specific field of incorporating aesthetical and in some cases environmental aspect to design with computer aid. Pham [8,19 & 20] enumerated the interactions between design variables and aesthetic properties and then proposed a methodology of analysis that would facilitate building computer tool for aesthetic design. On the other hand, As Wallace had done his masters in " A Computer Model of Aesthetics Industrial Design", continued to work on aesthetically pleasant and environmentally friendly design. He and Jakiela [21]proposed a computer-aided industrial design to integrate industrial design and engineering concerns into the initial concept stage of the product design and depicting the process specifically to consumer electronic gadgets those being injection molded. Besides, along with aesthetics incorporation, his works [21-28] have also encompassed environmental aspect to design.

3. DESIGN FOR ENVIRONMENT

Man is the custodian of the environment—this statement has been tucked to the conscious segment of the world also gladly among the common people. As a result, tremendous pressure has been put on the Manufacturer, even in the form of stringent

legislation, and forced them to whittle from conventional design to concurrent engineering. In simpler words, Design for 'X' includes Design for environment, the soubriquet – DFE among others.

At the overture, better go through some of the pedantic definition of the term DFE. Overly plainly speaking, DFE is the design philosophy, which has its goal as the minimization of harm caused to the environment during the product's entire life cycle. Again, Fiskel and Wapman (1994)[29] defined design for environment as "the systematic consideration, during new production and process development, of design associated with environmental safety and health over the full-product life-cycle."

3.1 Goal of DFE

According to Horvath, Hendrickson, Lave and McMichael (1995)[30], the goals of DFE are:

- ?? Minimize the use of non-renewable resources
- ?? Effectively manage renewable resources, and
- ?? Minimize toxic release to environment
- ??

3.2 Methods for studying DFE

To study design for environment is not just a matter of serendipity or heuristic judgment rather systematic scientific process developed to analyze the whole gamut. Among those procedures, Life-cycle assessment, cognomen as LCA, and Recycling methodology, are the most prominent ones. The others are Environmental Impact metric, Environmental Accounting Method, and so on.

3.2.1 Life Cycle Assessment

According to Society of Environmental Toxicology and Chemistry (SETAC, 1991)[31], Product life-cycle assessment is an objective process to evaluate the environmental burdens associated with a product or activity by identifying and quantifying energy and materials used and wastes released to the environment, to access the impact of those energy and material uses and release to the environment. So in simpler words, it is based on the life-cycle costs of a product, that is, product-specific costs that occur within the life-cycle framework. In other words, from extraction and processing of raw materials, to manufacturing, transportation and distribution, and eventually reuse, maintenance, recycling, and final disposal (Bras 1997[32],Ritzen et al. 1997[33]). It may be segmented into two sections as:

a] Cost of product development and manufacturing
b] Cost of operation, maintenance and/or service

3.2.2 Recycling for Environment

Wrapping all the consideration for design for environment comes to Design for Recycling [DFR]. Elaborately, having parts disassembled, if not be able to reuse, the later option is to recycle, and the last one left on the bow to dump, still have to look up the degradability at that stage too. On the overture, better be on mind that not everything would be possible or economically viable to recycle completely. The plus side of the statement, lots of research opportunities have been left to do so!

As first principle, the following aims for recycling could be put forwarded:

- ?? Maximizing the recycling resource
- ?? To utter importance, minimize the mass and pollution potential of the remaining product.

3.3 PAST RESEARCH AND DEVELOPMENT ON DFE:

Henstock (1988)[34] mentioned some principles of DFR with respect to recycling practices of various metal based items with specific focus on steel scrap in automobiles. Those criteria are:
a] Simplify mechanical assembly
b] Avoid self-contaminating combinations of materials
c] Standardize materials used
d] Separate high copper content items from steel items

On the alley of Plastic manufacturing, Ishii et al [35] conducted research and ultimately created a training tool based on design compatibility analysis. An extensive environmental impact analysis, also encompassing disposal together with the cost associated in overall product and material recycling loop, has been carried out by Navinchandra (1991)[36].

Rose and Evans(1993)[37] have carried out research in CIM institute of Georgia Tech on assembly oriented life-cycle analysis, where recyclability of a product is evaluated under possible future trends in the development of recycling technology and economy, and that somewhat complimentary works as problem mentioned by Simon. Another prominent research work has been done by Zust and Wagner (1992)[38] on Swiss Federal Institute of Technology on propounding an evaluation procedure to support product design based on conflicting DFD criteria. On the proposed scheme, each criterion is weighted and the final decision could be made after analyzing or considering all these weight age and other factors.

Concept of clumping for disassembly and recycle as proposed by Ihsii, Lee and Eubanks (1995)[39], clumping heralded a new dimension to disassembly and recycle analysis. The viewpoints could be described as follows:

- ?? Clumping for recycle: If anyway the product materials are not compatible, then mechanical connection among the components should be easily broken. i.e. using snap fit, press- fits, screws, and screw insert.
- ?? Clumping for disposal: in that case, neither the material nor the fastening method is important, only looking should be degradability.

Material recognition or selection for recycling is another important facet of study for disassembly and recycling. Material selection done on the earlier stage should be compatible to be recognized easily at later recycling process. On the success of this kind research is Shergold (1994)[40] who has indicated that the Fourier Transform Infra-Red (FTIR)-based equipment developed by Rover and Bird is good at identifying plastics and some other filler materials.

A potentially economic viable recycling could be done on automotive parts and significant progress has been made in this direction. According the data provided by Shergold (1994)[40], 75% of the weight of each vehicle disposed of can be recovered for recycling. And his assessments, the parts removed by a dismantler are determined

by market demand and now a day includes items such as the engine, gearbox and other mechanical parts as well as electronic components.

Somewhat patented notion of BMW is the concept of recycling path of components and materials. Wittenburg (1992)[41] worked on the same concept and proposed a 'cascade model' of decreasing values, in elaboration that means attention should be first be given to the dismantled parts suitable for reuse which have the highest value. And looking to BMW achievement as mentioned by Burke, Belter and Ishii (1992) [42], Z1 model's all plastic skin could be removed from the metal chassis in 20 minutes, that's a pretty short time in case of dismantalation. Further, the doors, bumpers, and the front, rear, and side panels are made of recyclable thermoplastics produced by GE[General Electrics]. BMW3251 is also for environmentally conscious customer as special feature includes recyclable plastic parts. However, many a company are now using this reusable materials. are made entirely of recycled bumpers from the former 3 Series and current 5 and 7 Series. Turning around, the three objectives mentioned by Zussman, Kriwet and Seliger (1994)[43] could be significant in design evaluation

Not ending to this end, for disposal purpose the destination should be identified and Simon (1991)[44] has done sort of research on it.

3.4 EXISTING TOOLS OR SYSTEMS IN DFE

Team- The acronym for Tools for Environmental Analysis and Management- a widely used Life Cycle Inventory modeller as it provides databases of life cycle inventories for various processes, along with means for modeling the flows between the processes (Ecobilan 1996[45]; Menke and David, 1996[46]).

Life-cycle-analysis is the founding block or stepping stone for design for environment[DFE]. Several methods or tools have been developed to pursue LCA. Simplified LCA is the need of the day as average company could not afford LCA to develop their product that has very short time frame, mentioned by Bras (1997)[32]. The possible way out could be the use of simplified methods that product designers can apply themselves (Nissen et al. 1997[47]; Graedel and Allenby 1995[48]).

To rescue comes several concurrent-modelling approaches. For enumeration, IPPD-the Integrated Product and Process Development method proposed by Schott (1997)[49]. The juicy feature of this is that it allows the designer to model the life cycle along with the design of the product.

A comprehensive list of LCA tools provided below on courtesy of Menke and David (1996) [46]that includes Clean, Ecopack2000, GABI, KCL-ECO, and many more.

Spicer and Wang(1995)[50], the prototype software tool namely Environmental Design Industrial Template[EDIT] focuses on inventory assessment of the retirement phase of life cycle analysis

In the latest development, a distributed modeling environment for product design developed by the MIT CADLAB, namely DOME- Distributed Object based Modeling and Evaluation[22].

On the avenue of ecological consideration aspect, NORDLIST-LCA project has gone a long way (Storen et al.1997)[51]. It developed already a prototype version of an LCA program for ecological consequence of a product through its life span.

5. PROPOSED SYSTEM

Having said all these, the proposed system to be researched is introduced by the flow chart. In plain words, firstly a group of designer makes the rough sketch according to his creativity, knowledge and experience. In this sate, if communication could be made among different designers dealing with various aspects of design, that would be very much beneficial and in the proposed system that is encouraged. Anyway, if not satisfied with the rough design, modification would be advised and designer group reassess the design. After passing through these checkout phases, comes prototyping and manufacturing stage. Prototyping is a vital stage of assessing the product design in low cost and the feedback got from here is very important. Then CAM compatibility would be checked because in most cases production phase run by CAM in today's industry. Furthermore, Feedback is given to both designer and database on

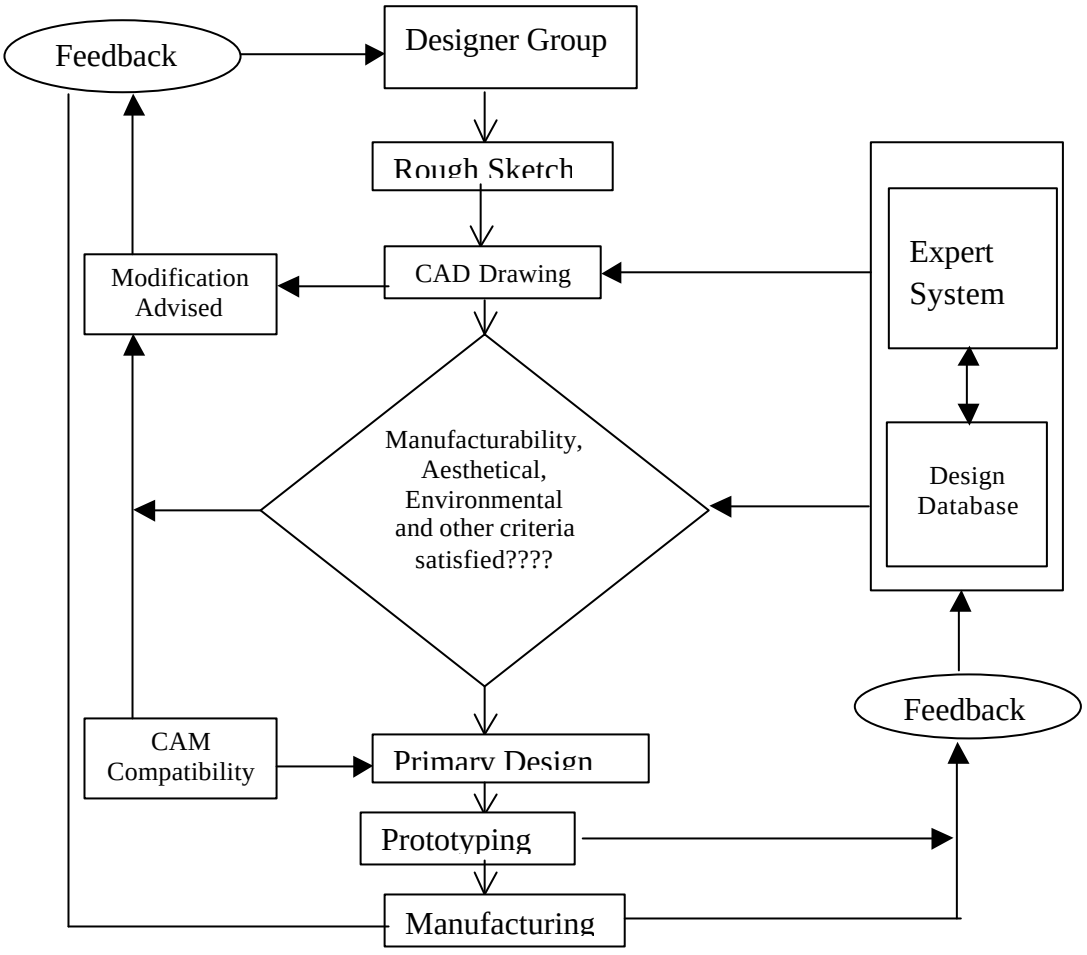

Fig: Expert System based Intelligent CAD/CAM

all these stages. The system would be designed as such it could learn from the feedback and so increase the accuracy of design considering different aspects. But as always, human beings would be there for coordinating and detecting glitches, if there

is any. And it must be mentioned expert system would guide the designer in every step.

6. CONCLUSION

Under the present world market trend, it could be foretold that an expert system that would give hand to design; specifically to CAD/CAM has a tremendous promise. Further, if an integrated expert system could be built that would encompass all main aspects of design consideration, that would be a major breakthrough in design arena.

7. REFERENCES

[1] http:// www.britannica.com/

[2] Y. Reich, A Model of Aesthetic Judgement in Design, *Artificial Intelligence in Engineering*, Vol 8(1993), issue no 2, 141-153.

[3] M. de Wolff , Over Henry van de Velde (in Dutch), *Volkskrant*, Issue on September 11, (1992).

[4] P. Mijksenaar, *Visual Function: An Introduction to Information Design*, OIO Publishers, Rotterdam, (1997).

[5] G. Dickie, *Art and Aesthetics: An Institutional Analysis*, Cornell University Press, Ithaca and London, (1974).

[6] Reich, Y.: "A Model of Aesthetic Judgement in Design", *Artificial Intelligence in Engineering*, Vol 8, issue no 2, (1993), 141-153, 1993.

[7] Goldman, *Aesthetic Value*, Westview Press, Colorado, (1995).

[8] B. Pham, Design for Aesthetics: Interaction of Design Variables and Aesthetic Properties, Proceedings of IS&T/SPIE Conference on *Human Vision and Electronic Imaging*, San Jose, California, January, 1999.

[9] D. Pye, *The Nature and Aesthetics of Design*, The Herbert Press, UK, (1995).

[10] N.H. Frijda, *The Emotions, Studies in Emotion and Social Interaction*, Cambridge University Press, Cambridge, UK, (1986).

[11] H. Snelders, *Subjectivity in the Consumer's Judgement of Products*, Ph.D. Thesis, Delft University of Technology, Delft University Press, Delft, (1995).

[12] H. Furuta, H. Hase, E. Watanabe, T. Tonegawa and H.Morimoto, Applications of Genetic Algorithm to Aesthetic Design of Dam Structures, *Advances in Engineering Software*, Vol. 25(1993), no.2-3, 185-195.

[13] H. Furuta, K. Maeda and E. Watanabe, Application of Genetic Algorithm to Aesthetic Design of Bridge Structures, *Microcomputers in Civil Engineering*, Vol. 10(1995), no.6, 415-421.

[14] J. Miles, C. Moore and S. Evans, Deriving Rules for Bridge Aesthetics, *Knowledge Based Systems for Civil and Structural Engineering*, (1993), p.vi and p.325.

[15] J. Claessen, *Shaped by Colour: a Study on the Effect of Colour on the Perceived Shape of Objects*, Ph.D. Thesis, Delft University of Technology, DelftUniversity Press, Delft, (1996).

[16] T. Kurango, FRESDAM System for Design of Aesthetically Pleasing Free-form Objects and Generation of Collision-free Tool Paths, *Computer-Aided Design*, Vol. 24(1992), no.11, 573-581.

[17] T. Takala and C. Woodward, Industrial Design based on Geometric Intentions,

Theoretical Foundations of Computer Graphics and CAD, Ed. B.A.Earnshaw, *NATO ASI Series*, Vol. F40(1988), pp.953-963.

[18] S. Hsiao and C. Chen, A Semantic and Shape Grammar based Approach for Product Design, *Design Studies*, Vol. 18(1997), nr.3.

[19] B. Pham, W. Knoop, E. Breemen, I. Horvath and J. Vergeest, Towards Computer Supported Design for Aesthetics, 31st ASATA- International Symposium on *Automotive Technology and Automation*, Dusseldorf, Germany, 2-5 June, 1998.

[20] B. Pham, W. Knoop, E. Breemen, I. Horvath and J. Vergeest, Developing a Methodology for Design for Aesthetic Based on Analogy of Communication, Proceedings of *1998 ASME DTM* Conference, Atlanta, Georgia, USA, 1998.

[21] D.Wallace, M. Jakiela, Automated Product Concept Design: Unifying Aesthetics and Engineering, *IEEE Computer Graphics and Applications*, Volume 13(1993), number 4, 66-75.

[22] D. Wallace,N. Borland and H. Kaufmann, Environmentally-conscious Product Design: a collaborative Internet-based modelling approach, *Journal of Industrial Ecology*, Volume 3(2000), number 2.

[23] D. Wallace and S. Smyth, Towards the synthesis of aesthetic product form, Proceedings of the *ASME DT* Conferences, *DETC/DTM-14554*, Baltimore, MD, 2000.

[24] D. Wallace, J. Eisenhard, I. Sousa, M. Schepper and J. Rombouts, Approximate life-cycle assessment in conceptual product design, Proceedings of the *ASME DT* Conferences, *DETC/DFM-14026*, Baltimore, MD, 2000.

[25] D. Wallace, S. Abrahamson, N. Senin and P. Sferro, Integrated Design in a Service Marketplace, *Computer-aided Design*, volume 32(2000), number 2, 97-107.

[26] D. Wallace, N. Borland and H. Kauffman, Integrating Environmental Impact Assessment into Product Design: A collaborative modeling approach, Proceedings of the *ASME DT* Conferences, *DETC/DFM-5730*, Atlanta, GA, 1998.

[27] D. Wallace and P. Jackson, A Modular Method for Representing Product Life-Cycles, Proceedings of the *ASME DT* Conferences, *97-DETC/DFM-4344*, Sacramento, CA, 1997.

[28] D.Wallace, T. Tomiyama and Y. Umeda, A Holistic Approach to Life-cycle Design, Proceedings of the 4th International Seminar on *Life Cycle Engineering*, CIRP, Berlin, June, 1997, 92-103.

[29] J. Fiskel and K. Wapman, How to Design for environment and minimize Life cycle cost, IEEE symposium on *Electronics and the Environment*, San Francisco, CA, May, 1994.

[30] A. Horvath, C. Hendrickson, L. Lave, and F. McMichael, Performance measurement for environmentally conscious manufacturing, *Manufacturing Science and Engineering*, MED2-2/MH3-2 (1995), 855-860.

[31] SETAC, *A Technical Framework for Life-cycle Assessment*, Washington DC: Society for Environmental Toxicology and Chemistry, (1991).

[32] B. Bras, Incorporating environmental issues in product design and realization, *UNEP Industry and Environment*, 20(1–2)(1997), 7–13.

[33] S. Ritzen, J. Baeckmar and M. Norell, Product development—integration of environmental aspects, Fourth International Seminar on *Life Cycle Engineering*, Berlin, Germany, 1997, 383–394.

[34] M. Henstock, *Design for recyclability*, Institute of Metal on behalf of Material Forum, (1988).
[35] K. Ishii, L. Hornberger and M. Liou, Compatibility-based design for injection molding, Proceeding of 1989 ASME Winter Annual Meeting on *Concurrent Product and Process Design*, December 1989, Sanf Frannsisco, 153-160.
[36] D. Navinchandra, Design for environmentability, *Design Theory and Methodology*, 31(1991), 119-124.
[37] E. Rose, and S. Evans, A robust design for recyclability methodology, Proceeding of *CIM-Europe* Annual Conference, 1993, 201-211.
[38] R. Zust and R. Wagner, Approach to the identification and quantification of environmental effect during product life, *Annals of CIRP*, 41(1)(1992), 473-476.
[39] K. Ishii, B. Lee, and C. Eubanks, Design for product retirement and modularity based on technology life-cycle, *Manufacturing Science and Engineering*, MED 2-2/MH 3-2, (1995), 921-933.
[40] M. Shergold, Automotive material recycling for the future, *Proceedings of Institution of Mechanical Engineering*, Vol. 208(2)(1994), 75-82.
[41] G. Wittenburg, Life after death for consumer product: design for disassembly, *Assembly Automation*, 12(2)(1992), 21-25.
[42] D. Burke, K. Belter and K. Ishii, Life cycle design for recyclability, Fourth International Conference on *Design Theory and Methodology*, 1992, 325-332.
[43] Zussman, E., Kriwet, G., & Seliger, G.,Disassembly-oriented assessment, methodology to support design for recycling, *Annals of the CIRP*, 43(1)(1994)
[44] M. Simon, Design for dismantling, *Professional Engineering*, November, 20-22, (1991)
[45] Ecobilan, *Team 2.0, Users Manual*, (1996).
[46] M. Menke and G. A. David, Evaluation of life cycle assessment tools, 1996, URL: http://www.ec.gc.ca/ecocycle/english/software.doc.
[47] N. Nissen, H. Griese, A. Middendorf, J. Mueller, and H. Poetter, Comparison of simplified environmental assessments versus full life cycle assessment (LCA) for the electronics designer, Fourth International Seminar on *Life Cycle Engineering*, Berlin, Germany, 1997, 435–444.
[48] T. Graedel and B. Allenby, *Industrial Ecology*, Prentice Hall, Englewood Cliffs, NJ, (1995).
[49] H. Schott, C. Gruener, K. Buettner, F. Dannheim, and H. Birkhofer, Design for environment-computer based product and process development, Fourth International Seminar on *Life Cycle Engineering*, Berlin, Germany, 1997, 407-420.
[50] A. Spicer and M. Wang, A Software Tool for End-of-Life-Cycle Consideration within A DSS Approach to Environmentally Conscious Design and Manufacturing, *Computers & Industrial Engineering*, Volume 29, Issues 1-4, (1995), 501-505.
[51] S. Storen, O. Myklebust and T. Lamvik, NORDLIST LCA: life cycle assessment in product development, Fourth International Seminar on *Life Cycle Engineering*, Berlin, Germany, 1997, 185-196.