

Integration of LCA and EcoDesign guideline in a virtual cad framework

Federico Cappelli¹, Massimo Delogu¹, Marco Pierini¹

¹Università degli Studi di Firenze, Florence, Department of Mechanical Engineering and Industrial Technologies, Italy

Abstract

The necessity to create products and services qualified in terms of Environmental Sustainability is more and more growing in Europe, as in the other parts of the world. On this general assumption, it is important to develop an environmental methodology, matching the CAD/3D modelling tools, the Life Cycle Analysis (LCA) tools and the EcoDesign guidelines.

This paper intends to show how some defined environmental parameters, currently used within the Life Cycle Assessment procedures, can be transferred to the traditional design approach, adding another element of qualification to the design. In particular, the methodology will show how, at pilot scale, some defined environmental indicators, related to the design products, can be inserted into the traditional design processes and then can be used by the designer for improving some quality aspects of its activity. The selection of several defined indicators comes from the intention of not adding too many heavy procedures to the activity of the designer, otherwise there is the risk that the environmental information can be not appreciated and correctly used for improving the product in the design phase.

This methodology is addressed to develop a tool easily usable from the designers and, in the same time, able to give them some quality information for improving their current project.

Keywords

CAD, LCA, EcoDesign Guidelines, Design for Environment

1 INTRODUCTION

The necessity to create products and services qualified in terms of Environmental Sustainability is more and more growing in Europe, as in the other parts of the world. On this general assumption, it is important to develop an environmental methodology, matching the CAD/3D modelling tools, the Life Cycle Analysis (LCA) tools and the EcoDesign guidelines. Some defined environmental parameters, currently used within the Life Cycle Assessment procedures, can be transferred to the traditional design approach; at pilot scale the cad designer can simply use some defined environmental indicators for improving the overall quality of its project. To avoid the risk that the environmental information can be not appreciated and correctly used for improving the product in the design phase it is important that cad users can choose the more usefully environmental parameters.

This methodology is addressed to develop a tool easily usable from the designers and, in the same time, able to give them some quality information for improving their current project.

2 METHODOLOGY FOR INTEGRATION OF LCA AND GUIDELINES IN A CAD MODEL

2.1 The modern CAD

Modern Cad/3D tools are able to manage a high number of parameters and permit a considerable time reduction to realise a virtual prototype.

In order to make an early environmental analysis of the developing product it is necessary to know:

- volumes or geometries
- type of materials
- manufacture processes.

The information above are necessary to lead fast but accurate Abridged Life Cycle Assessment (aLCA), so that the designer can immediately know which components have a high environmental impact and immediately modify them. As shown in figure the changes made by the

designer are at the centre of the methodology and they act during the concept an production phase. The user is aided during the changes by the interaction of three databases Guidelines, LCA and CAD features.

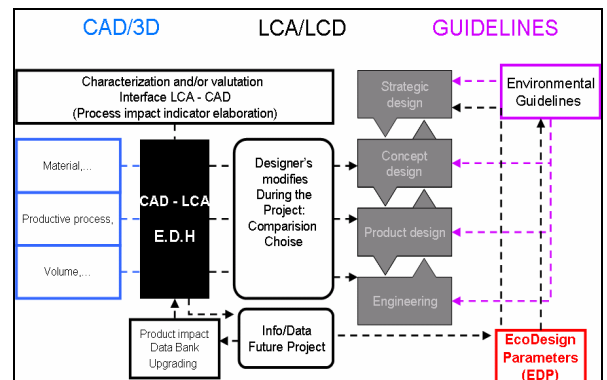


Figure 1 - Schematic view of LCA and Guidelines integration in 3D CAD Model.

2.2 LCA and CAD

Each virtual product is made of assembly which are recursively constituted of subassemblies, parts and processes. These data are always displayed with a tree structure. Analysing this tree and combining each leaves with the relative environmental impact data, coming from typical LCA database [1] [2], it is possible to calculate a mPt single score indicators (Eco Indicator 99) [3]. This index shows which parts or/and processes are highly pollutant; it is simple to understand and represents a right compromise between effort and time. Many authors disagree about the use of aggregate impact index, like EDIP, EI95 or EI99, because weights to assign at different impact categories are not commonly shared by the experts [4]. However, this index doesn't introduce significant errors, if it is used only and always for the same virtual product [5]. This analysis, despite of its rapidity, has some limits like:

- it isn't exhaustive because it can only predict the pollution of the productive phase (as a CAD process

features), without any external additional knowledge resource;

- it doesn't show how it's possible to improve the environmental product profile.

2.3 Environmental Guidelines and CAD

EcoDesign guidelines are a set of best design practise and represent a database of ecological questions and relative answers that the authors categorized using a set of well-known standard design parameters. Surveying the occurrences of these parameters, it is possible to determine which impact improvement has to be taken in account. EcoDesign guidelines allow guiding the designer in order to improve the environmental performance of the virtual product. This approach is very simple but the designer is forced to not ignore every ecological aspects of the initial project; the designer also leads himself to improve his environmental skills. Nowadays there is not CAD software that implement guidelines tools as an automated wizard that guide the designer to improvement process. Then, only by using software, it's very difficult to understand, without the designer contributes, which parts or features are relevant for the analysis. In the future it is desirable to detect the optimal improvement strategy by means of a correct study of the developing product assembly tree and a semantic examination of guidelines.

3 A NEW DFE INTEGRATED APPROACH

Modern tools for environmental impact assessment are often unfit to give fast and reliable information to designer [6]. Typically LCA is useful to characterize very well the ecological impacts of a product during its life cycle, but it isn't helpful to suggest the design solutions finalised to eliminate/reduce these impacts. EcoGuidelines, on the other hand, can give to designers the right direction of improvement (figure 2).

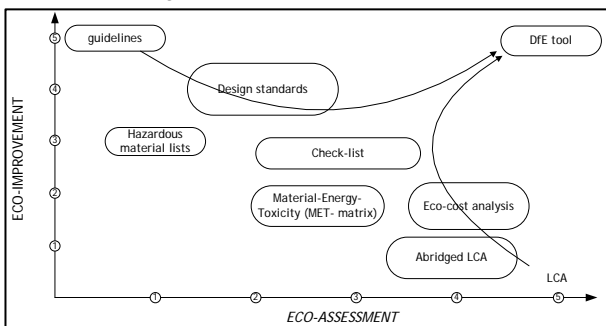


Figure 2 – EcoDesign tools: Ecological Assessment vs. Improvement.

Nowadays, the ecological redesign of a product occurs only after this has been placed on the market. The best solution is to optimise the environmental profile during the virtual design phase, although its time and costs rise [7].

In this paper, the authors propose an integrated Design for Environment (DfE) methodology useful to develop a new CAD tool add-on (or stand alone), EcoDesign Helper (EDH). EDH allows to the designer to assess the environmental implications of choices taken during the product design and to improve the product eco-profile by means of alternative solutions at the same time.

3.1 Architecture of EDH

The first task is to analyse the tree structure of CAD project. This is composed by assemblies, subassemblies, parts and features (typical data representation of commercial software, i.e. ProE, SolidWork...). Features,

like manufacturing and production processes or geometric data, represent data associated with assembly model that can be stored in CAD files or in a specific database, if they are inserted manually by the user (figure 3).

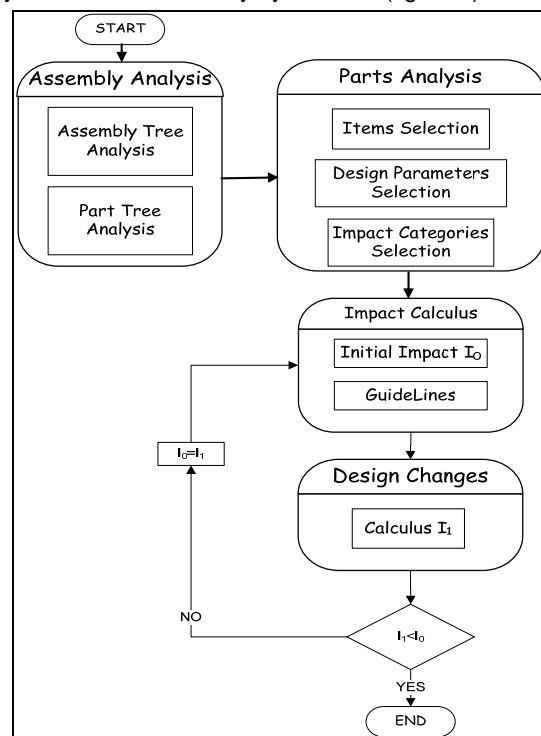


Figure 3 – Flowchart Diagram of the EDH architecture

Elementary parts and features are stored in a database table [8]. The base record is constituted by a unique identification filed key, represented by the part, and many other fields that are filled with data features, such as materials, processes or volume. This data table represents the fulcrum of the environmental analysis.

Tabella totale complessivo											
ID	cod. padre	cod. oggetto	nome	sub-assembly	massa[kg]	densita'	volume [dm3]	area superficiale mm²	materiale	processo	Ind 1 mPt materiale
1	1	scatolign			4,91E-04	1,78E-01	46,3		terzo dattilo	sviluppo	200
1	2	filettura			2,30E-04	3,72E-01	272		terzo dattilo	formatura	200
1	3	involucro			2,23E-02	2,23E+01			ABS	iniezione	400
1	4	scatoligno			5,29E-02	6,91E+00			ABS	iniezione	400
1	5	scatoligno			4,46E-02		44,85,00	7,22E+04	SONNAX		4,1
1	1,1	pietra									
1,1	1	integre			3,30E-02	5,30E+01		5,68E+04	terzo dattilo	costruzione	200
1,1	2	taglio			6,63E-02	6,63E+00		5,46E+05	ABS	iniezione	400
1,1	3	pedana			1,84E-01	1,84E+02		1,22E+06	ABS	iniezione	400

Figure 4 – Database record: the first key field is part id, the last filed is mPt impact index.

The user can select which parts he wants to analyse. This selection is fundamental to carry out a right assessment; in fact it isn't possible to study a complex product, made of a lot of parts, without hit on their contradictions: i.e., a car must be light as much as possible (use more plastic polymer instead of steel) to reduce the overall fuel consumption, but, on the other way, the recyclability may decrease. The purpose of this tool is not to study the overall impact of a complex project; it wants to help a designer to develop an environmental sound product; in fact is during the virtual design phase that it's possible to prevent most of the worse environmental errors.

After the selection of parts, it's necessary that the user chooses which impact category intends to revise. Using a typical subdivision, five impact categories related to each life cycle phase of the product are considered, such as: mineral extraction, production, transport, use and end of life. This selection is necessary to limit the action field of environmental design changes, but it can't inhibit the possibility that designer shift unconsciously the impact from a category to another.

The next step is to select the EcoDesign Parameters (EDP). These parameters, stored in a specific database, are:

- Reduction of material: applied loads and material, etc.
- Reduction of Energy: working temperature, working time and material, etc.
- Safety: toxicity, working temperature and part dimension, etc.
- Hostile environment: aggressive agents, atmospheric agents, etc.
- Product reuse: material, number and typology of fasteners, disassemblability;
- Product Processes: parts dimension, number of parts, consumption of energy.

EDP are fully customizable and can reflect the requirements and typical design parameters employed in a company.

For each selected part the designer must specify the impact category which it belongs and choose the EDP parameters. At this moment, it is calculated using an abridged LCA, based on materials, volume of parts and processes a first index of impact I_0 . It is also possible that useful information for the analysis may be provided by a commercial PLM. Taking into account the selection made by user, it is possible to select a very narrow subset of EcoGuidelines, able to guide the designer on an initial redesign. The choice of right guideline is obtained, at the moment, by a simple algorithm that calculates the number of occurrences of a selected design feature in the question; in the future it will be possible to improve the results implementing a semantic search engine on EcoGuidelines db.

After the user has made desired changes, another impact value I_1 is calculated. If $I_1 < I_0$ then it is possible to proceed; otherwise it is better to roll back changes [9].

<p>Program Main Tasks:</p> <ol style="list-style-type: none"> 1. 3d/CAD Assembly Analysis <ol style="list-style-type: none"> 1.1. Retrieve information about Material, Volume and Features of each parts 2. Selection of interested parts <ol style="list-style-type: none"> 2.1. Choose Impact Categories 2.2. Choose EcoDesign Parameters 3. Determination of first impact index I_0 4. Visualization of suitable EcoGuidelines 5. Redesign and calculus of new index I_1 <ol style="list-style-type: none"> 5.1. If $I_1 < I_0$ end 5.2. else go to 5, until user stops the task
--

Figure 5 - Synthetic description of the EDH architecture

The main characteristic of EDH tool is a fast assessment of environmental impacts within a set of a suggested and proper redesign guides. The user interaction is reduced at minimum (figure 4).

4 THE DATA STRUCTURE

The modern 3D/CAD can acquire, manipulate and manage an enormous quantity of information. Typically, a CAD part file can store intrinsic data like all geometry details (Volume, Area ...) and extrinsic data like all

information about material density and its production process, tensile strength, toxicity, recyclability, etc.

An essential data structure [10] can also store mechanical and environmental design parameters that user wants to appreciate such as: exercise temperature, hazardous material, tensile strength, fastener typology, etc.

These last parameters are typed in by the user or provide by a PLM, and they act like a filter on the choice of the right guideline subset. It's in mind of the authors that is always possible to customize the database data structure with field data that are particular important for the company.

In this manner the record of the data structure is composed by these fields (each record is referred to a part or subassembly considered as a part):

1. Position in the assembly tree (number, e.g. 121.3 represents the third son of first sub-assembly of the second sub-assembly of the tree root. Number zero is used for parts and features children of the root);
2. Geometric feature: Volume (m^3);
3. Material: Density (kg/m^3), Production Process (text e.g. cast, extrusion, welding, milling, ...), Ultimate Tensile Strength (MPa);
4. Environmental Impact: LCA mPt impact index of each parts and process involved in the project, when it's known. (EcoIndicator 99 v 2.0);
5. Fasteners (Boolean flag). It 's also possible to use, for the characterization, the SACS code [11];
6. Working tensile strength (MPa), temperature ($^{\circ}C$) and time (s);
7. Hazardous Material (Boolean flags);
8. Recycled Material (Boolean flags);
9. Hostile Environment (Boolean flag);
10. Impact Categories: Material Extraction Transport, Production Use, End of Life (Boolean flag);

The impact data are initially processed to calculate the overall Impact Index I_0 . This value is the reference for each change made on the project. After a part modification, the user must calculate a new Impact Index I_1 assuring himself that the value must be minor of I_0 . The information about the right modification of parts is provided by the EcoGuidelines. A typically and complete example of EcoGuidelines are the "EcoDesign Pilot" [12]. These guidelines are divided in the five Impact Categories, stated before; so it is possible extrapolate coherent subsets of fitting and environmental advices.

The add-on software user selects and assigns at the project one of the impact category. It is also may possible to calculate the predominant category, summing the recurrence and ranking of the field Impact Categories, if it is valorised.

The authors created an association between each question/answer of the EcoGuidelines and fields of the record belong to the data structure [13]. For example, a typical EcoGuidelines advice with a raw material intensive product is: "Reduce material input by design aiming at optimum strength". It's simple to associate this recommendation with parameters 2, 3 and 6.

For each part it's tacking in account its physical and mechanical properties and the Boolean flags recorded in the database. The set of valorised field of each part acts as a filter on EcoGuidelines questions [14]. Then calculating recursively the subset for each part and

intersecting them, it is possible to extrapolate the minimum subset of green advice.

The designer is free to apply the suggested adjustment or to skip the procedure and to go on with the project. In the first case, it is necessary to calculate the new impact index I_1 to validate the redesign.

5 CONCLUSION

Ecological product design requires deeper analyses in the early phase of the product design process. The introduction of new EcoDesign tools obliges the designer to see the product in a wider ecological view and the knowledge disparity between designers and environmental scientists can be covered through an interface between LCA, Guidelines and CAD systems.

In this paper it is presented a methodology that can be used to develop a new EcoDesign Tool. The aim of this approach is to conduct a fast and reliable environment impact assessment of the developing product: to do that it is necessary to have three databases, as EcoGuidelines db, LCA db and CAD parts/features. Combining together environmental and classic mechanical parameters, it is possible to suggest to the user the best subset environmental advices. The comparison of a synthetic impact index, associated with suggested design changes, can point out the direction of changes to do for the impact reduction.

The next step is to terminate the implementation and validation of the presented approach in a dedicated software tool.

ACKNOWLEDGMENTS

The systematic approach described in this paper resulted from research supported by Ing. Ivan Cini and EDIT group of DMTI. We extend our sincere thanks to all who contributed to preparing this work.

REFERENCES

- [1] P. A., Roche, T., Man, Camardiel, E., 1999, "Environmental advisor tool to support green design", CIMRU, National University of Ireland, Galway, Ireland.
- [2] Leibrecht, S., 2004, "Ecologicad: User Manual", www.leibrecht.org.
- [3] Goedkoop, M., Spriensma, R., Pré Consultants BV, Amersfoort, 2000, "The ecoindicator'99: a damage oriented method for life cycle impact assessment: methodology report", The Netherlands.
- [4] Bovea, M.D., Gallardo, A., 2006, "The influence of impact assessment methods on materials selection for eco-design", *Materials & Design*, Volume 27, Issue 3, pp 209-215.
- [5] Rebitzer, G., Ekvallb, T., Frischknecht, R., Hunkeler, D., Norriss, G., Rydberg, T., Schmidt, W. P., Suh, S., Weidemaier, B.P., Pennington, D.W., 2004, "Life cycle assessment Part 1: Framework, goal and scope definition, inventory analysis, and applications", *Environment International* 30, pp.701 – 720.
- [6] Jeswiet, J., Hauschild, M., 2005, "EcoDesign and future environmental impacts", *Materials and Design Journal* 26, pp. 629 – 634.
- [7] Nielsen, P.H., Wenzel, H., 2002, "Integration of environmental aspects in product development: a stepwise procedure based on quantitative life cycle assessment", *Journal of Cleaner Production*, 10, pp. 247–257
- [8] Yuan, G., Tseng, Y., 1999, "A modular modelling approach by integrating feature recognition and feature – based design", *Computers in Industry* 39, pp. 113 – 125.
- [9] Chen, R.W, Navin-Chandra, D., Nair, I.; Prinz, F., Wadehra, I.L., 1995, "An approach for Material Selection that Integrates Mechanical Design and Life Cycle Environmental Burdens" *IEEE* pp. 68 - 74.
- [10] Ishii, K., Eubanks, C.F., Di Marco, P., "Design for Product Retirement and Material Life – Cycle", *Material and Design Journal*, pp. 1 – 10.
- [11] Chi Haur Wu, Myoung Gi Kim, 1994; "Modelling of part-mating Strategies for Automating Assembly Operations for Robots" *IEEE Transaction on systems, man and cybernetics*; Vol.24; pp. 1065 – 1074.
- [12] Wolfgang, W., Züst, R., 2001, "Ecodesign Pilot", Kluwer academic Publisher.
- [13] Howard, L., Lewis, H., 2003, "The development of a database system to optimize manufacturing processes during design", *Journal of Materials Processing Technology* 134, pp.374 –382.
- [14] Hao, J.P., Yu, Y.L., Xue, Q., 2002, "A maintainability analysis visualization system and its development under the AutoCAD environment", *Journal of Material Processing Technology*, 129, pp.277 – 282.

CONTACT

Federico Cappelli

Università degli Studi di Firenze, Florence, Department of Mechanical Engineering and Industrial Technologies, Via di S.Marta 3, 50139 Firenze, Italy, federico.cappelli@unifi.it, website: www.pcm.unifi.it