Doctoral School on Engineering Sciences
Università Politecnica delle Marche

Extended summary

The EcoDesign Issue: Proposal for a new approach, methodology and tools

Curriculum: Ingegneria Meccanica e Gestionale

Author

Alessandro Morbidoni

Tutor

Prof. Ferruccio Mandorli

Date: 30 January 2012

Abstract. The design process in the past was focused mainly on cost-reduction, increasing product quality and time-reduction, several tools have been developed to assist designer in this activity. Nowadays the environmental aspects have become widely considered and represent an important and success market factor, in fact the consumers are developing an increasing environmental sensibility so they are attracted by "green" products. From this considerations come the needs for tools to assist the designers to consider both the environmental and the cost aspects into the design process, in recent years several tools were developed at this scope. IT systems are nowadays widely employed in the design process, they can be grouped under PLM (Product Lifecycle Management) system. PLM can be viewed as the integration of several tools as mentioned before, with methods, people and the processes through all stages of a product's life. On the other hand there are tools to assess and calculate the environmental impact of products by different methods. LCA (Life Cycle Assessment) is the most common and recognized method to determine the environmental burden of products and services. The research goals could be synthesized as the definition of a new approach, methodology and tools for the environmental and cost consideration in the design process. This research work is a step toward the development of an innovative EcoDesign approach and tool by linking IT systems and lifecycle methodologies: PLM software and LCA-LCC methods. This approach represent an EcoDesign method that take into consideration environmental and lifecycle cost aspects into the product

development process, the developed tool enable the designer to evaluate different design alternatives easily and rapidly during the early product development phase. By this way is possible to design green products taking into consideration the environmental lifecycle impact and also the lifecycle cost aspect of the product.

Keywords. Life Cycle Assessment, Life Cycle Costing, CAD, Life Cycle Design, Life Cycle Engineering.

1 Problem statement and objectives

There are several different ways to define ecodesign. Based on the existing definitions of ecodesign, we define ecodesign as an activity that identifies the environmental aspects of a product and then integrates them into product design process in the early stage of a product development process in parallel with other factors including function, cost, performance, quality, legal and technical aspects. The aforementioned challenge has been visualised by using the hierarchy of the Rathenau Institute (1), which takes an ecodesign viewpoint. The hierarchy illustrates that environmental improvements can be made in four stages, with each stage increasing both potential environmental benefit and the degree of innovation that is required in the design process (2). EcoDesign is based on the concept of Product Lifecycle. The main stages of Product Lifecycle are: extraction of raw materials, design and Production, packaging and distribution, use and maintenance and end-of-life treatment. Focusing on EcoDesign decision support model, there are a number of relevant studies such as Sherwin and Evans's work (3) who conclude that for industrial design, the 'best' place to integrate Ecodesign would be in the product development processes as they represent the earliest design stage. From the literature review on Design for Environment (DfE), different EcoDesign approaches have been studied. These tools were based on different techniques and characterized by different levels of difficulty related to their implementation (for a critical analysis of eco-design tools) (4). The increasing environmental sensibility that is growing nowadays, require the need to develop tools to assist the designers in the EcoDesign process, in recent years a large number of methods and techniques have been developed. These approaches vary from simple checklists and guidelines as presented in Wimmer et al. (5) and Stevels' (6) works, to complex methodologies, which require the designer to have a high level of personal knowledge in order to apply them correctly. From literature review analysis is possible to affirm that in spite of the great variety of Eco-design tools presented in the field, the large number of them, together with the need to comply with stricter and stricter environmental regulations, represents an obstacle for designers. The reason beside in the fact that many of these are not focused on design activities, but are aimed at management or at retrospective analyses of existing products, or they are too specific to be applied in different contexts from the ones where they were developed for. The different existing EcoDesign tools differ not only for the method which they are based on, but also in the difficulty of applying them in the design process and the tool features (such as requirements definition, generation of design alternatives, design alternatives comparison, best alternative selection). The comparative evaluation performed as starting point for this research work has been developed by analysing each tool, detecting the process design phase where it should be integrated and evaluating the time or difficulty that the integration could involve.

From the EcoDesign perspective is possible to make some considerations about the reviewed tools. The scope of this work is to develop an EcoDesign approach and tool to assist the engineers in the design process, to create and evaluate different design solution from environmental and cost point of view. From literature review is possible to state that each tool cover different set of design phases and have different difficulty usage level, from this can be affirm that each tool can be employed for a specific design objective.

Looking at the results coming from the comparative and critical analysis, is possible to affirm that only some of them can be employed as EcoDesign tool in the product development process, in particular allowing the possibility to integrate Sustainable Lifecycle Approaches in the product development process. Integrated CAD – LCA tools represent a valid and powerful method to integrate environmental considerations into the design process and more widely in the product development process. These tools are based on simplified Life Cycle Assessment method (SLCA), which allow to perform the environmental impact assessment analysis of products, considering their whole lifecycle from the raw material extraction to end of life treatments. The simplification of the LCA method allow to use this approach in the early design phase, where the complete product details are not available. Integration between SLCA method and CAD systems, which are the main tools used in the design process, allow to consider and make useful environmental considerations into the product development process. This integration is a tool to help engineers in designing sustainable and "green" products to challenge the increasing competitive market.

In this research work these integrated CAD – LCA tools have been taken as starting point for the development of new EcoDesign approach, methodology and tools to take into consideration Sustainable Lifecycle approaches (environmental and costs) into the product development process.

2 Research planning and activities

The research method followed in this work starts from Literature review on EcoDesign topic and developed tools in this filed and go through a comparison between an existing commercial integrated CAD-LCA tool and a complete LCA analysis in order to highlight the advantages and lacks of this method. From this comparative analysis a new approach has been developed considering environmental and costs aspects in the design process. The proposed approach leads to the development of an experimental tool which is validated though a case study, comparing the outgoing results with those obtained with complete LCA analysis and a commercial integrated CAD-LCA tool.

Considering the research goals and focusing them inside the state of the art on Ecodesign methods and tools, we can state that some interesting and innovative tasks come up from this work as listed below:

- New approach to consider environmental and costs aspects of products lifecycle in the design process;
- Extension of existing integrated CAD-LCA methods by considering the complete product lifecycle and distinguishing different component manufacturing families;
- Integration of cost aspect in the integrated CAD-LCA method by considering Life Cycle Costing (LCC);
- A new system architecture developed to implement above method in .NET framework;
- A case study implemented with the proposed approach and the developed tool, in order to show the advantages and possible limitation.

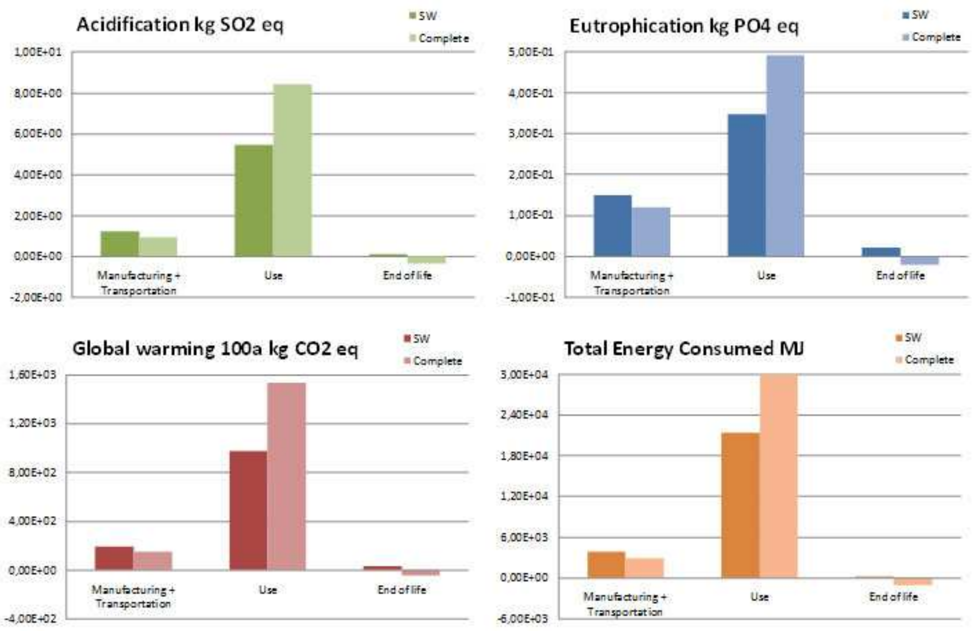

Figure 2-1 - Washing Machine LCA Graphs from comparison between SolidWorks Sustainable Vs Complete Analysis: Impact Categories Results.

2.1 Comparative evaluation of commercial integrated CAD-LCA tool

The comparative analysis performed in this work has the scope of highlighting the advantages and lacks of integrated CAD-LCA tools in order to improve them by the development of a new approach.

This analysis provide the evaluation of the complete product lifecycle, through the different phases composing it. The test case selected at this scope is a common washing machine, including manufacturing, transportations, use and end of life phases. The tool considered in this analysis is SolidWorks Sustainability, which is one of the few commercial available tools. In Figure 2.1 the results are grouped by lifecycle phases and impact category (Acidification, Eutrophication, Global Warming and Total Energy Consumed).

From the comparison analysis conducted is possible to summarize the lacks and deficiencies of SolidWorks Sustainable tool compared to a complete LCA study, the following list provide a clear view:

- Impossibility to select multiple processes to a single component (only the predominant one can be selected);
- Impossibility to assign Transport to single a component: is possible to select different continents for the manufacturing phase and the use phase, from these a value for the "transport and use" phase is assigned automatically from the tool;
- Impossibility to specify Transport data for an assembly products: only the predominant transport can be selected, but no specification can be assigned (distance, different transport, etc...);
- Impossibility to select a Use process for a component: only the country where it will be used can be specified;

- Impossibility to select multiple Use processes for an assembly products: only the predominant one can be assigned;
- Impossibility to select and End of Life process both for components than for assembly products: the tool assign proportional values for each impact category depending on the selected material and the component or assembly product weight.
- Impossibility to modify processes available in the database with customized flow quantities;
- Impossibility to add processes to the database.

2.2 Proposed approach: "CAST" tool

Considerations coming from the comparative analysis between commercial integrated CAD-LCA tool and complete LCA analysis, lead to the proposal of a new approach in Ecodesign topic. The integration proposed is focused on Life Cycle Assessment and Life Cycle Costing with PLM systems and it is aimed at the development of an Ecodesign tool to assist the designers in the early stage of product development.

By these lifecycle methods it is possible to evaluate the product under environmental and costs points of view, comparing different design solutions, receiving feedback to improve product performances. Nowadays Information Technology (IT) has become widely widespread and it is used by companies to control the product development process, by collecting and managing data of whole product lifecycle. The core of PLM is in the creations and central management of all product data and the technology used to access this information and knowledge. From these considerations is possible to state that PLM contains most of the required information needed to perform a Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) analyses.

The research carried out in this work led to the definition of different implementation methods based on the integration between PLM software and Sustainable Product Lifecycle methods (LCA and LCC). Principally this differentiation consists in the method used to calculate the environmental impact and costs of the product under investigation. Environmental impact can be calculated using LCA software, which are connected with database of materials and processes regarding all the lifecycle phases (manufacturing, transportation, use and end of life). Product costs can be calculated instead using LCC software, which assign a cost to each flow concerning the product lifecycle, from material to end of life treatments. LCA and LCC software are commercially available and is also possible to find some open-source tools, they allow to perform detailed and deep analysis referring to the whole product lifecycle. The two identified framework to integrate Sustainable Lifecycle methods with Product Lifecycle Management tool (PLM) differ in the LCA calculation method, in the first case a commercial or open-source LCA software has been selected and connected to the User interface, whereas the second framework provides the development of a dedicated Sustainable module which is able to calculate environmental impact and costs. As mentioned before only the LCA calculation method differ in the two approaches, in both cases the costs calculation is referred to a developed module connected with LCC database containing the costs for materials and processes. The reason to develop a dedicated LCC module is that in this approach a simplified Life Cycle Cost method is adopted, the available commercial tools are too complex and specific and are not well suited for our needs. Table 2.1 represent a summary of LCA Integration

Methods comparison from different perspectives: possibility to connect with external tools, connection implementation difficulty, need of implementation, possibility to reuse SLCA results (to develop complete LCA), database availability.

Table 2-1 – LCA integration Methods comparison.

LCA Integration Method	Connection with external tools	Connection Implementation difficulty	Need of implementation	Possibility to reuse SLCA results	Database availability
Commercial LCA tool	5/10	6/10 (if possible)	No	Yes	Proprietary - Generic (Commercial or Free)
Open-Source LCA tool	7/10	8/10	No	Yes	Generic (Commercial or Free) (converted)
Self developed LCA module	8/10	6/10	Yes	No / Partly	Generic (Commercial or Free) (to be converted) - Custom

Basing on the mentioned considerations, from this research work come out two different PLM – LCA/LCC Integration framework, the first one provides the integration with commercial or open-source LCA software, the core part of the tool is the user interface, connected from one side to the PLM software and PLM database and from the other side to the LCA software and LCC calculation module. The second framework provides the integration with self-developed Sustainable module, the main difference from the previous one is the presence of an integrated LCA – LCC module instead of the two separated.

The proposed approach is based on this last described integration frameworks, "CAST" name stands for Computer Aided Sustainable Tool, which indicate the integration of Sustainability tool with IT systems. This approach derives and represent an extension of a proposed CAD-integrated LCA tool, described in a previous research work (7). CAD tools constitutes the main core of PLM and they are used nowadays in all companies as support to the product development process, for this reason in this research work the attention has been focused on the development of a tool based on the integration between CAD systems and Sustainable Lifecycle methods. Figure 2.1 illustrates the framework of the mentioned tool. As is possible to see from the figure, the framework is the same as described in the previous paragraph, where the integration with PLM systems has been described. The only difference is the integration of CAD software as PLM module, this choice is dictated by the necessity to develop a prototype tool to demonstrate the validity of the proposed approach and by the fact that CAD tools are the core of PLM systems.

Furthermore, CAD software are largely widespread in companies nowadays and are used to manage the product development process. On the contrary, PLM systems are not so many common and diffused in small and medium companies (SMEs) due to the fact that its implementation and customization are complicated and onerous from time and cost perspectives. CAD software contain a lot of information about the designing product, according to Germani at al. work (8), which have classified the information stored within these models as local or global, implicit or explicit.

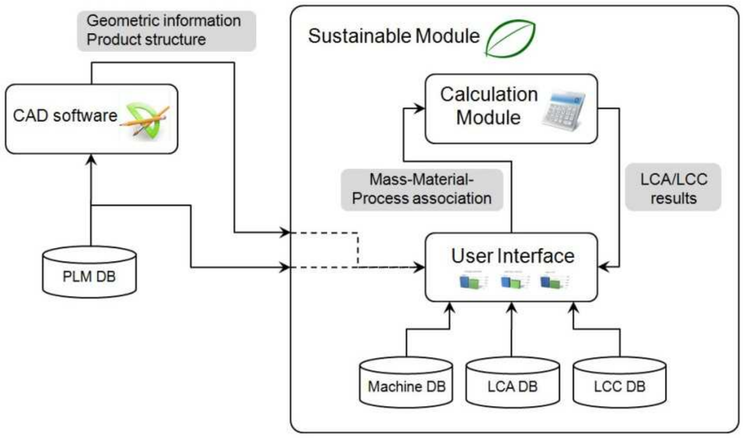

Figure 2-1 - CAD – LCA/LCC integration: "CAST" framework.

All the information contained in the CAD model are useful to perform environmental and cost analyses of the product, giving the possibility to evaluate it at the beginning of the design phase considering its complete lifecycle. The developed tool allow to evaluate the designing product under environmental and cost perspectives in the early product development process, considering its complete lifecycle from material extraction to end of life phase. Environmental impact is calculated by LCA method, which considers all the material and energy flows attributable to the product in its lifecycle, product lifecycle costs are instead evaluated by LCC method, which considers all the monetary flows occurring during the product lifecycle. LCA evaluation takes into consideration the environmental impact of all material and energy flows occurring during the product lifecycle, starting from row material extraction to end of life treatments and disposal. There are various evaluation methods that can be used to assess the environmental impact of a product in its lifecycle, developed by research groups and companies operating in this field. In this work Eco-costs has been taken as environmental evaluation method, due to the fact that in the developed tool was required an indicator that allow the user to have an immediate and easy method to evaluate the product under the environmental perspective and compare different design solutions.

In the proposed approach as already said LCA and LCC lifecycle methods were used to assess product under environmental and costs perspectives. In order to apply these methods to an Ecodesign tool is necessary to use simplified methods, maintaining the efficiency for the results calculation. The simplified methods adopted in the proposed approach distinguish Product as final element and Components ad single entities that constitute the product. Product and components lifecycles are composed by different phases: Manufacturing, Transport, Use and End of Life. Manufacturing phase transform the raw material into finished part, by several different processes; Transport phase regards all the transport that the part undergoes during its lifecycle, such as transports between the different companies involved in the manufacturing process or the transport to return the part to landfill at the end of its life. Use phase constitutes the real part life, in which is explicated the function for which the part was designed, for example in a washing machine the main use processes are the power and detergent consumptions; finally End of life phase regards the treatments that the part undergoes at the end of its life, such as landfill, incineration, recycling and other treatments.

LCA method allow to evaluate the environmental impact in the complete product lifecycle, from raw material to end of life treatments, though manufacturing and use phases, considering all the materials and processes occurring in product's life. According with the simplified LCA method employed in the proposed approach product environmental impact can be calculated by this expression:

$$LCA_{Product} = LCA_{Prod.manuf} + LCA_{Prod.transp} + LCA_{Prod.use} + LCA_{Prod.eol} + \sum_{1=1}^{n} LCA_{Comp.i}$$

Total environmental impact of a component can be expressed as:

$$LCA_{Component} = LCA_{Comp.manuf} + LCA_{Comp.transp} + LCA_{Comp.use} + LCA_{Comp.eol}$$

Where each member represent the impact of each lifecycle phase, it is important to report that the impact of the end of life phase depends on the selected treatment (reuse, recycle, remanufacturing or other treatments).

LCC method allow to evaluate the costs of the complete product lifecycle, from raw material to end of life treatments, though manufacturing and use phases, considering all the materials and processes occurring in product's life. Each above mentioned lifecycle phase is composed by different processes, involving energy and material consumptions that generate costs, which contribute to the total product cost.

Total product cost can be calculated by the proposed simplified approach as follow:

$$Cost_{Product} = Cost_{Prod.manuf} + Cost_{Prod.transp} + Cost_{Prod.use} + Cost_{Prod.eol} + \sum_{1=1}^{n} Cost_{Comp.i}$$

An important aspect to highlight is the fact that some classes of costs are incurred in a future time with respect to the design, for this reason these costs need to be actualized in order to be compared with the manufacturing ones, which are attributable to the design time.

As for the environmental impact assessment, even the costs calculation vary depending on the selected end of life treatment for each component, besides to material, manufacturing processes, transport and use processes selection.

The illustrated CAD – Sustainable tools integration approach is at the basis of the developed tool, which enable the integration of the Ecodesign perspective in commercial available CAD systems. Here below are illustrated the available features and functionalities of the tool through the user interface. First of all is necessary to make a distinction between Products and Components. Between Products and Components there is a degree of relatedness, in fact a product is composed by two or more components, which can be grouped in assemblies and sub-assemblies. Each single part is classified as component, assemblies and sub-assemblies are instead products. Taking a washing machine product, is possible to state that it is composed by sub-assemblies which in turn are composed by components, so for example the hydraulic group is a sub-assembly of washing machine, the hydraulic pump is a component of this sub-assembly. The user interface present different forms and functionalities for products and components, which are in turn subdivided in tabs which enable different functionalities.

<u>Components</u>

The form "Lifecycle information" allow to collect all the lifecycle data regarding environmental and costs aspects. According with the LCA and LCC calculation methods, the Component form presents different tabs corresponding with the different lifecycle phases (Manufacturing, Transport, Use and End of life).

The manufacturing tab is subdivided in LCA and LCC sub-tabs, the first one according with family parts classification, present different interfaces: Machined Part, Molding Part and Sheet Metal Part. Each component type form enable the possibility to select different data and parameter for LCA and LCC calculation, fundamentally material and manufacturing processes are the principal selected data, besides to amounts data calculated by different ways depending on the component family. Transport tab is also subdivided in LCA and LCC sub-tabs, and allow to select transport processes occurring during component lifecycle. Components does not have a proper use phase, which is instead allocated at product level, due to this consideration use tab allow the possibility to select component life time used for the calculation of maintenance aspects. Finally End of life tab is the most articulated for components, is possible in fact to select different end of life treatments and each one comport different environmental and consequently cost considerations. It gives the possibility to select the end of life treatment for the analyzed component, between Reuse, Recycle, Remanufacturing and Other treatments selectable from the database. Each treatment have a tab where is possible to specify the required data for the analysis, in case of other treatment selection is possible to assign a process from the database such as incineration, landfill and some others.

<u>Product</u>

The other class of user interface's form is the product one, it allows to complete products lifecycle already started by modeling components. Even this class of forms is composed by different tabs representing lifecycle phases. The manufacturing process consists mainly of processes related to the components, the product itself may undergo some manufacturing processes for assembly, packaging and other final processes, the dedicated tab allow to select processes for the database. The transport tab enables the possibility to add transport processes occurring during product lifecycle. Regarding use phase, the tool allow to include maintenance impact in the use phase, by the calculation of replaced components comparing their duration with product lifetime. The user can assign the product lifetime which enable the tool to calculate the components to be replaced and their number. In order to calculate use processes costs in necessary to specify the amounts for each lifecycle year. At this scope LCC use detail form allows to specify the different processes amounts for each lifecycle period (by year or month) and the discount rate used to actualize these costs. By this form is possible to calculate the costs of the product use phase processes, which are then reported in the main use LCC form. Ordinarily Product end of life is related to the correspondent components end of life treatments, except the case where the whole product undergoes the same treatments. The end of life LCA form allows to select processes from database and to visualize the different selected process for each component. The same consideration discussed above can be applied to costs calculation, in the case where the whole product undergoes the same end of life treatment the costs can be calculated considering costs and revenue of the product at its end of life. Obviously these costs and revenue have to be actualized at manufacturing period.

The tool framework is the core part of software, it has the function of manage, link and match all the data with the product and components. In order to create the product structure in the software a dedicated module has been implemented as Visual Studio project, it is called "Product Structure" and it is composed by several classes representing the structure of CAD product model. These classes reflect the product structure, each one allow to store the correspondent data, classes are inheritable in order to recreate the tree structure of assemblies and manage all the data retrieved from CAD model. Product Structure project has been implemented in order to be compatible with all CAD systems, in fact it has a general structure which can match with every CAD model. These classes are the base classes used to build Data structure module. This structure allows to store and manage all data needed to perform the environmental and costs analyses, coming from users input and retrieved from CAD system. Data structure is organized with different classes in order to link data related to the product lifecycle. The developed tool includes a database to store environmental and costs data, beside to the integrated CAD database which is part of the system itself. This database has been built as Microsoft Excel pages, the reason of this choice lies in its simple implementation and connection with the implemented user interface by the integrated API available for Excel in .NET environment. The tool includes also a machine database, which is a simple single Excel page, containing all the machine available in the company. Each machine have different columns representing machine data such as *carried out process, range unit, utilization range, cycle time, consumption unit* and *unitary consumption*. This database allow to select the best fitting machine for the selected process, though different machine properties.

The CAD connection module enable the connection with CAD system, allowing to retrieve the structure of the product and the several product and component model information, these data are used to populate Data structure classes. Product Structure has been implemented in a way to be compatible with all CAD systems, from this consideration can be state that developing specific modules the tool can communicate with different CAD software. The developed tool gives the possibility to connect two different CAD systems, SolidEdge and Inventor.

3 Analysis and discussion of main results

The proposed approach of CAD-LCA/LCC integration and the developed "CAST" tool has been validated through a case study, comparing the results with the ones obtained by complete LCA analysis and SolidWorks tool. In order to compare the results, the same washing machine has been taken as test case and the complete product lifecycle has been computed in the analysis, considering all lifecycle phases (manufacturing, transportation, use and end of life). Figure 3.1 shows the results coming from the comparative analysis performed, reporting four graphs which represent different impact categories of the CML 2001 impact assessment method: Acidification, Eutrophication, Global warming and Total Energy Consumed. The choice of the CML method was dictated by the fact that SolidWorks Sustainability uses these impact categories as environmental indexes.

From the figure is possible to see, taking as referring values those coming from the complete LCA analysis (Complete), that the different values of the impact category indexes obtained with the proposed method (CAST) are more close respect to those attributed to SolidWorks Sustainability analysis (SW).

From Table 3.1 is possible to see that the error values of CAST approach are sensibly lower than those previous described, with results close to those of complete LCA analysis.

Looking at the table divided by lifecycle phase, manufacturing errors are around 3% with a value of 11,8% for the acidification indicator, use phase shows errors less than 4% and finally end of life phase have values up to 15%, total lifecycle result errors are in general less than 5%. As just described the proposed approach reduces drastically the errors of all the environmental impact categories attributed to each product lifecycle phase. In particular, analyzing separately each phase, manufacturing cycle errors were reduced according to the possibility to select more than one process for each component, allowing to model the real complete manufacturing process. In the case of the washing machine taken as case study for this validation, most of the components undergo multiple manufacturing process, such as sheet metal parts where the main lamination and bending process is followed by galvanizing and painting processes. Use phase also shows an important errors reduction, obtained with the possibility to select multiple use process for the product, so in this case beside the main one which is electric power consumption, washing detergent and water usage were selected. Finally looking at the end of life, the errors attributed to this phase have values from 10 to 15%, describing a sensible reduction comparing to those obtained with commercial tool, the reasons of this improving precision resides in the possibility to select the real end of life treatment, considering component reuse, recycle and remanufacturing as described in the approach method paragraphs. In the end, another important feature of the proposed tool is the consideration of maintenance process, which enable the computation of replaced components. In this case some components such as the transmission belt, need to be replaced during product lifecycle, due to their life period.

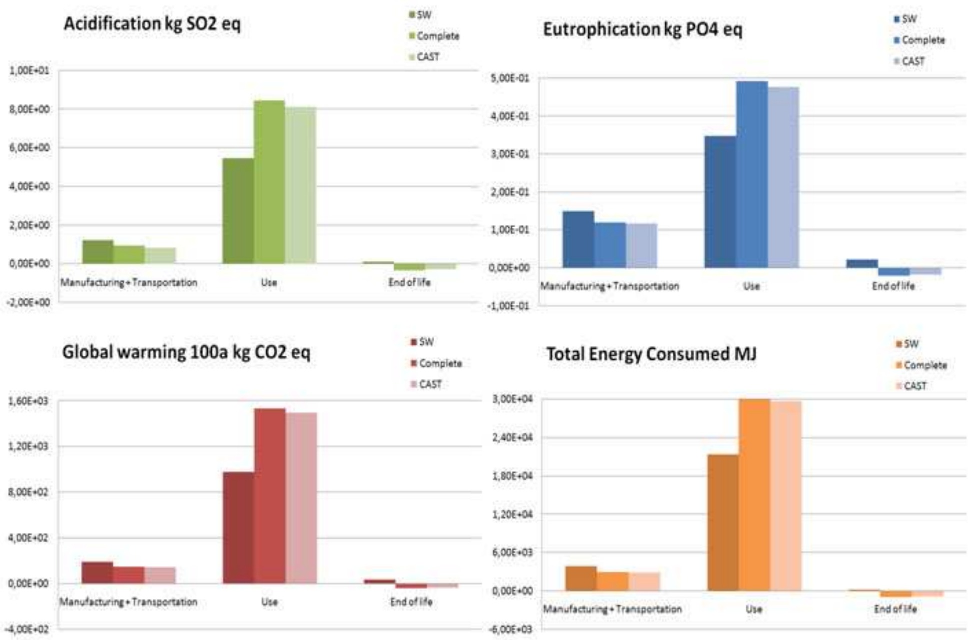

Figure 3-1 - Washing Machine LCA Graphs from comparison between SolidWorks Sustainable, Complete Analysis and CAST tool: Impact Categories Results.

Table 3-1 – Comparison result errors between SolidWorks Sustainability and CAST tool.

Impact category	Unit	Total		Manufacturing + Transportation		Use		End of life	
		SW Err. %	CAST Err. %	SW Err. %	CAST Err. %	SW Err. %	CAST Err. %	SW Err. %	CAST Err. %
Acidification	kg SO2 eq	24,8	4,2	-30,2	11,8	35,3	3,8	134,8	14,7
Eutrophication	kg PO4 eq	12,0	2,9	-25,6	2,7	29,4	3,3	208,1	12,2
Global warming 100a	kg CO2 eq	26,5	2,2	-28,4	2,3	36,1	2,4	180,3	10,3
Total Energy Consumed	MJ	21,9	2,9	-32,6	3,6	30,1	2,9	118,4	13,0

Figure 3.2 shows the CAST tool form for LCA results, as is possible to see the results are grouped into sub-forms representing the different lifecycle phases and the summary form visible from the figure. The results are shown in each phase tab (manufacturing, transport, use and end of life) graphically and in numerical format in a table, divided by lifecycle phase and impact category.

Regarding costs analysis a simple component has been taken as case study, in particular a sheet metal cover plate, and its complete lifecycle has been computed, due to the fact that performing a cost analysis for a complex assembly product require specific cost data for each component and companies are not inclined to give out these kind of data. Manufacturing process and end of life phase have been evaluated under cost perspective, the use phase was not considered because a simple component is not affected by use processes, but this phase regards in most of the cases assembly product.

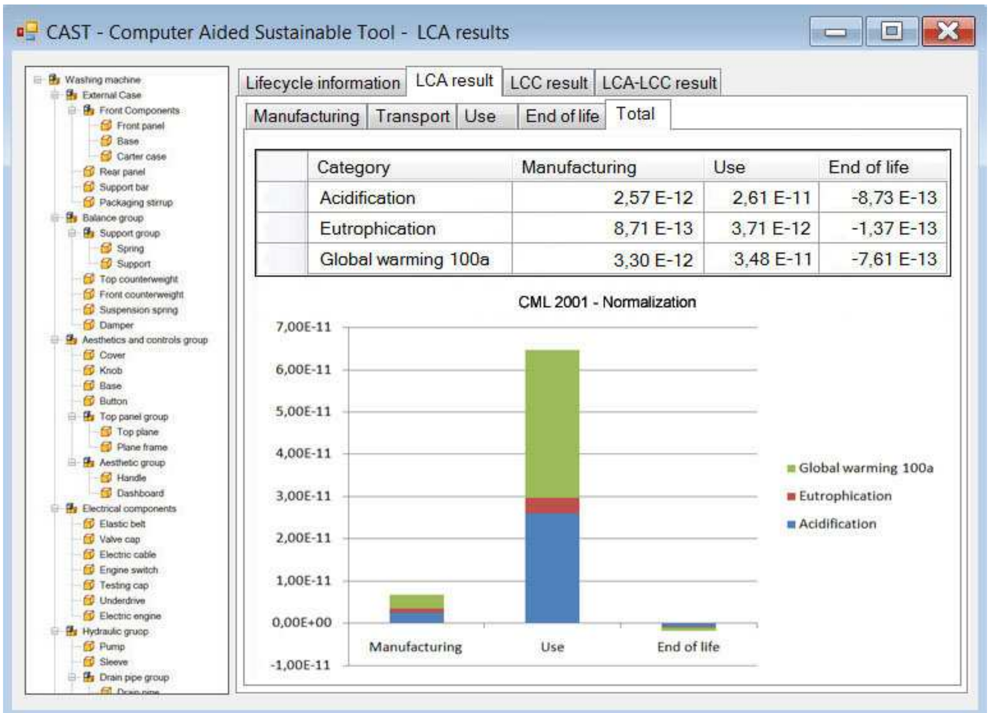

Figure 3-2 - LCA total results form.

The manufacturing cycle for this component starts with a sheet metal plate, then through laser cutting process the final shape is obtained and also the holes and slots; bending process is used to obtain the final bended shape of the four edges and finally through welding process these edges are joined together. The amounts for these processes have been retrieved automatically from the CAD model, such as bends number, laser cutting and welding path length. These quantities are calculated from the cad model, in the case of laser cutting process, path length is computed considering perimetric free edges for the external path and internal free edges for the holes and slots. The manufacturing processes costs are calculated considering the unit costs of machines adopted for the processes and the amounts of each one. The same method is adopted to calculate the material cost, in this case the amount of material computed is not the weight of the finished component, but the weight of the starting stock material used to obtain the final shape, considering the laser cutting waste. End of life phase for the component under analysis provides material recycle, the cost and revenue attributed to this end of life treatment are calculated considering a percentage of material cost. These data have been selected from the user depending on its experience and the information for the considered treatment.

In conclusion is possible to affirm that the proposed approach enable the possibility to evaluate product lifecycle under cost perspective with a good level of detail considering all lifecycle phases.

4 Conclusions

This thesis proposes a new Ecodesign approach for the consideration of sustainable lifecycle aspects in product development process. Environmental and costs perspectives have been included in product design phase through the development of an integrated CAD- LCA/LCC tool based on the proposed approach. The developed "CAST" tool integrate lifecycle aspects such as the environmental and costs issues in commercial CAD software, enabling the design of "sustainable" and "green" products. This thesis is a step forward the definition of new Ecodesign approach and development of a CAD integrated sustainable tool, improving and extending the commercial available ones.

The main results and contribution of this thesis can be summarized as follow:

- Classification of existent Ecodesign tool and approaches by application field and level of application difficulty;
- Comparative environmental assessment analysis between commercial integrated CAD – LCA tool and complete LCA analysis;
- Proposal of a new Ecodesign approach based on the integration between CAD and sustainable lifecycle methods: LCA and LCC;
- Consideration of environmental and costs perspectives in the product development process, allowing to design sustainable products;
- Validation of the proposed approach and developed tool through test case analysis and comparative evaluation with commercial tool and complete LCA analysis.

Test case evaluation of developed tool highlight several advantages deriving from the application of the proposed approach to CAD integrated sustainable tools:

- Consideration of environmental aspect beside to costs aspect in the design process;

- Possibility to compute in the analysis the complete real product lifecycle:
  - Considering machines adopted in the company with real consumptions;
  - Consideration of starting stock material depending on the component family (machined, moulded, sheet metal);
  - Customization of manufacturing processes;
  - Consideration of real end of life strategies for the components and assembly product;
  - Consideration of maintenance aspect in the product use phase.
- Possibility to compare different design solutions under environmental and costs perspectives;

Of course also some deficiencies emerged from the test case evaluation, in particular:

- Integration with other PLM tools, in order to retrieve additional product information;
- Integration of commercial LCA and costs database;
- Indication on product performance improving from the analysis results.

References

[1] Sustainable product innovation. J.C., Brezet. London, UK : s.n., 1998. Proc. of the Third International Conference Towards Sustainable Product Design.
[2] The Service Approach: Generate Added Value with less Environmental Impact. Van der Zwan, F.M. and Bhamra, T.A. Berlin : s.n., 2000. Proc. of Electronics Goes Green 2000 Conference.
[3] Ecodesign innovation: Is 'Early' Always 'Best'? Sherwin, C., Evans, S. 2000. International Symposium on Environmentally Conscious Design and Inverse Manufacturing.
[4] Handling Trade-Offs in Ecodesign Tools for sustainable Product Development and Procurement. Byggeth S., Hchschorner E. 2006, Journal of Cleaner Production, Vol. 14, p. 1420-1430.
[5] Wimmer W., Zust R. Ecodesign Pilot, Product investigation, Learning and Optimization Tool for sustainable Product Development. s.l. : Kluwer Academic Publisher, 2003.
[6] Moving Companies Towards Sustainability though Ecodesign: Conditions for success. A., Stevels. 1997, Journal of Sustainable Product Design, Vol. 3, p. 47-55.
[7] Environmental evaluation from cradle to grave with CAD-integrated LCA tools. Morbidoni A., Favi C., Mandorli F., Germani M. Bol, Croazia : s.n., 2011. Proceedings of MOTSP conference 2011.
[8] CAD-LCA Data migration supported by feature technology and Attributed Structures. al., Germani M. et. Berlin, Germany : s.n., 2004. Proceedings of Global Conference on Sustainable Product Development and Life Cycle Engineering. p. 379-384.