PRODUCT ENGINEERING

Product Engineering

Eco-Design, Technologies and Green Energy

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PREFACE

This book contains an edited version of the lectures and selected contributions presented during the Advanced Summer Institute on "Product Engineering: Eco-Design, Technologies and Green Energy" organized at the Transilvania University of Brasov (Romania) in the period 14-21st of July 2004. The Advanced Summer Institute (ASI) was organized in the framework of the European FP5 funded project "ADEPT – Advanced computer aided Design of Ecological Products and Technologies integrating green energy sources" and was devoted to the Product Engineering field, with particular attention to the aspects related to the environmentally conscious design and green energy sources.

The objective of the ASI was to create the framework for meeting of leading scientists with PhD holders and advanced PhD students carrying out research in the field of Eco-Design, CAD, Simulation technologies, Robotics, Manufacturing and green energy sources. The aim was to create conditions for high level training through a series of 15 invited lectures presented by world reputed scientists, as well as to give possibilities for young researchers to present their achievements and to establish professional contacts. The ASI was seen also as an opportunity for academics, practitioners and consultants from Europe and elsewhere who are involved in the study, management, development and implementation of product engineering principles in the learning and teaching sectors, as well as professionals to come together and share ideas on projects and examples of best practice.

Out of the invited lectures, the ASI programme included a number of contributions from the other participants. In total, the event was attended by about 70 participants from 12 countries.

The topics covered areas of Product Engineering including new aspects related to the environmental issues, i.e.:

– ECO-Design,
– Computer Aided Design (CAD),
– Simulation technologies,
– Robotics and Manufacturing,
– Green Energy

Although usually these topics are addressed within distinct approaches, it was the idea of this ASI to bring together scientists from different areas of Product Engineering, such as to catalyze cross-fertilization and enable new ideas in an interdisciplinary framework.

The lectures included in the book have been presented as tutorials as well as state of the art papers in the respective areas of Product Engineering, providing thus a good overview of the current work in the field. Therefore it addresses a wide range of readers, from students to professors, from industrial experts to the researchers.

The publication of this book has been possible thank to the kind support from the European Commission in the framework of GROWTH programme of the Fifth Framework Programme for research and scientific development. For this reason the ASI Directors express hereby their full gratitude. The support from the Transilvania University and all the other partners in the project ADEPT is also acknowledged.

Braşov and Galway,
July 2004.

Doru Talab and Thomas Roche

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INTRODUCTION

In the last decades Product Engineering became more and more a multidisciplinary field including aspects from a wide range of scientific areas, still treated distinctly within the research institutions. Aspects related to the environment, aesthetic style, human factors and ergonomics are now critical issues for the success of a product on the market. The Advanced Summer Institute on "Product Engineering: Eco-Design, Technologies and Green Energy" focused on some of these topics with a particular attention paid to the aspects relevant for the environmental protection.

In this context, this book is structured on five chapters, covering the topics of Eco-Design, Computer Aided Design, Simulation Technologies, Robotics and Manufacturing and Green Energy.

Eco-Design is the main topic of the book. This methodology penetrates all aspects of design following the stream of waste and resource consumption across the whole product life cycle. This is the reason for which this subject was privileged including five lectures and three selected contributions that treated the eco-aspects from various perspectives: from the management and integration of the environmental impact information into the product life cycle and business environment, to the human aspects in the man-machine relation and aesthetics style, as part of the human natural environment.

The *Computer Aided Design* (CAD) topic is included with two lectures and two selected contribution focusing mainly on conceptual design aspects which are of crucial importance for the next generation of CAD systems. In the same idea new ways of interaction between the user and the CAD environment, e.g. the use of haptic immersion technologies have been presented.

Simulation technologies are frequently included in the Product Engineering textbooks, which usually present Finite Element Methodologies for analysis in various applications. For the Adavanced Summer Institute (ASI) and this book, the editors chosen to focus on a simulation technology with potential for assembling a wide range of simulation methods, including Finite Element Method ones: Multi-Body Systems (MBS) simulation, represented in this book by four invited lectures and four selected contributions was another privileged topic of the ASI. From the systematic and tutorial presentation of the MBS formulations and models to complex applications in multi-physics and real time simulation, a wide area was covered, illustrating the potential of this simulation technology.

Robotics and Manufacturing is another important field of the Product Engineering and was included in the book with two invited lectures and four selected contributions. Recent advances in this area are covered e.g. parallel robots and high speed machining.

Green Energy comes into the Product Engineering area of research in the context of the eco-design and generally the quest for alternative sources of renewable energy. This is demonstrated by the topics in the two lectures and three selected contributions, which present aspects on solar and wind energy technologies, two areas where Product Engineering is concerned both from the development of the systems themselves viewpoint and for the integration of this type of energy as much as possible into any other kind of product.

These apparently separate fields of research proved to belong to the same multidisciplinary mainstream and could not progress unless an integrated approach is adopted. New advances are now likely to produce changes in the entire product life cycle chain. This was illustrated within the ASI in many presentations from distinct sections illustrating similar methodologies used for different goals, e.g. the Virtual Reality techniques and Virtual Engineering in general, which are multi-purpose technologies or the particle model for CAD and simulation, which risen a special interest being subject of several lectures and contributions under different sections.

Taking into account the state of the art and the contemporary needs, this content is justifying the title of the book "Product Engineering: Eco-Design, Technologies and Green Energy", which addresses a wide audience in the engineering profession as the development engineers and practitioners, researchers, managers, academic staff, PhD and master students.

Doru Talab and Thomas Roche

Part 1

ECO- DESIGN

1. INVITED LECTURES

2. CONTRIBUTIONS

THE DESIGN FOR ENVIRONMENTAL COMPLIANCE WORKBENCH TOOL

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Abstract: The development of environmentally superior and compliant products and process is extremely important for electronic and vehicle manufacturers operating in, and servicing European markets. This is because of the existence of legislative drivers (Waste from Electronic and Electrical Devices, and End of Life Vehicle Directives), Standards (ISO 14000, EMAS) and increasing consumer pressure for the development of environmentally superior products. Design for the Environment represents an effective strategy for developing environmentally superior and compliant products (ESCP) and as an approach it needs to be implemented as early as possible in the design process. This paper describes a new framework for DFE methodology and tool development. A new CAD integrated DFE tool, called the Design for Environmental Compliance Workbench, which has been developed based on this new framework is also described.

Key words: design for environment, workbench tool.

1. BACKGROUND

Global pressure, critically depleting natural resources and increasing market consciousness for the health of the environment has made the environmental superiority of products a critical competitive factor for manufacturers in the future. The Electronics and Vehicle Manufacturing sectors have come under particular pressure with the emergence of new European directives that is forcing them to become responsible for the safe disposal of their products at the end of life. This legislation is driven by two directives namely, the Waste from Electrical and Electronic Equipment (WEEE) for the electronics Sector and End of Life Vehicle Directive (ELV) for the automotive sector. According to the legislation OEMs are required to

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provide environmental information to life cycle stakeholders and legislative bodies regarding their products. (e.g. information includes the materials and composition in a supplied product, location of hazardous materials and their removal route, special handling concerns and dismantling instructions). Furthermore automobile manufacturers are forced to comply with environmental targets for example they are required to make a vehicle 95% recyclable (by weight) by the year 2015. Additionally Environmental Management standards (such as ISO14000 and EMAS) require OEMs to continuously improve the environmental properties of the products produced. Although voluntary, environmental management standard certification is crucial to organizations because of the increasing consciousness of the market and indeed trade barriers that can result.

For complex products (such as automobiles) the environmental legislation and standards creates two major problems, firstly *the generation, management and control of environmental information* and secondly *the implementation of methodologies to aid decision making for continuous improvement programs*. These problems are mainly because of the volume, dispersion and availability of knowledge and information. Clearly, with thousands of components in a vehicle, and the *diversity* of environmental information required for each (e.g. material constituents, fasteners, disassembly route) results in a *critically high volume* of information. *Availability* of information is also difficult because OEMs typically have hundreds of multi-tiered suppliers who are often unwilling to provide detail on the environmental characteristics of the products supplied (because of a perceived competitive threat). Fifty percent of original design work in the automotive industry is now done by suppliers, which greatly increases the needs for common standards. Also, this information is wildly *dispersed* both geographically and temporally (e.g. recyclers are at the end of life) and it is therefore difficult to synthesize to meet legislative compliance. Methodologies to aid decision-making with regard to continuous improvement of products are also compounded by these problems. These methodologies must be available to decision makers dispersed across the enterprise and must use standard and controlled decision criteria and information. Clearly there is a need to use software tools that aid OEMS to synthesize and manage appropriate information and to influence the continuous improvement process across the enterprise.

All product information is generated at the design stage and it is well known in research that over 90% of the life cycle costs (including environmental costs) are defined at this stage [39]. Design for the environment (DFE) represents an effective strategy for the development of environmentally superior and ELV/WEEE compliant products [28]. The author has worked on the development of design for environmental compliance tools for over six years. This work began by the development of design process models for design tools and continues today in the form of commercialisation of a CAD integrated tool called the Design for Environmental Compliance Workbench tool.

2. STRATEGIES FOR ENVIRONMENTALLY SUPERIOR PRODUCT DESIGN

There are many DFE strategies and each requires the inclusion of specific characteristics in the product. As the DFE field addresses the full product life cycle it is useful to address these approaches in the context of the life cycle model presented in fig 1.

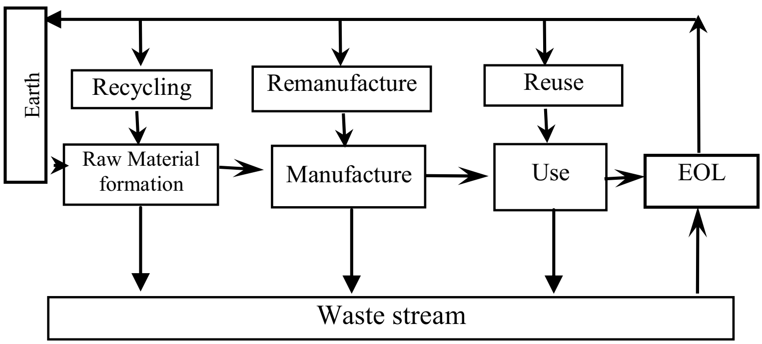

Figure 1. Product Life Cycle Model [28].

In this model the physical product passes through four generic phases in its lifetime, i.e. *raw material extraction*, *manufacture*, *use* and *end of life*. In each of these phases materials and energy are consumed either directly into the product or given off as waste streams.

When the product reaches the end of life a decision has to be made to reuse, remanufacture, recycle or dispose of it. Similar decisions have to be made regarding the materials and energies entering the waste stream. Four generic and interrelated strategies for the development of environmentally superior products can be derived from the model as follows [28]:

a) Select low impact materials and processes over all life cycle phases.
b) Reduce life cycle resource consumption (Materials and Energy)
c) Reduce life cycle waste streams (Materials and Energy).
d) Resource sustainment by facilitating first life extension and post first life extension, i.e. reuse, remanufacture and recycling.

Life Cycle Analysis (LCA) is the only method available to measure the *environmental impact* of products on the environment. The ISO14040 standard defines life cycle analysis as; "*a technique for assessing the environmental aspects and potential impacts associated with a product by: compiling an inventory of relevant inputs and outputs of a system; evaluating the potential environmental impacts associated with those inputs and outputs; interpreting the results of the inventory and impact phases in relation to the objectives of the study*" (ISO97). Life Cycle Assessment (LCA) is recognised as one of the most frequently used techniques for systematically evaluating environmental performance of a product throughout its life cycle [14, 38]. There are two main approaches to LCA, i.e. Full LCA and Abridged LCA. Full LCA is a rigorous quantitative method that systematically calculates and prioritises environmental impact of a product throughout its life cycle. Abridged LCA methods range from qualitative to quantitative methods that are less rigorous and data intensive and yield varying degrees of precision depending on the method applied. The important differences between the approaches, in the context of DFE, are represented in fig. 2.

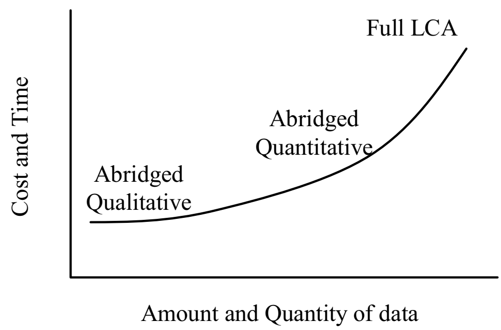

Figure 2. Different approaches to LCA, after [24].

There are many software tools developed to support the different types of LCA approaches, however many of the tools do not support the improvement phase and therefore need to be developed further for integration into the design process [28].

The reduction of *life cycle resource consumption* and life cycle waste streams requires resource minimisation solutions. Tools need to be developed and integrated into the design process to aid the designer to identify resource wastage directly and indirectly associated with the life cycle of the product. Some tools exist, however many are not integrated appropriately in the design process or indeed across the life cycle of the product. *Resource sustainment* is an extremely important and effective strategy for the development of ESCPs, particularly from the ELV and WEEE Directive implementation. First life extension may be achieved through designing for serviceability, maintainability, reliability and durability. Post first life extension strategies include policies to reuse, remanufacture, recycle and recover product at the end of life.

Reuse can be defined as the additional use of an item after it is retired from a clearly defined duty. Generic product characteristics that facilitate reusability have been synthesised from the literature as follows [4, 7, 19, 13, 16]: minimum number of components, serviceable, easy to clean, modular design, easy to disassemble, considers reduction of wear to components, considers corrosion protection, hazardous materials minimisation and the facilitation of part or subassembly removal.

Remanufacturing can be defined as a process that restores worn products to like new condition. Generic product characteristics that enhance its re-manufacturability include [4, 7, 19, 5, 13] : cleanability, modular design, and ease of disassembly, serviceable, testable subassemblies, and durable materials.

Recycling can be defined as a series of activities, including collection, separation and processing, by which products or other materials are recovered from the solid waste stream for use in the form of raw materials in the manufacture of new product other than fuel. Generic product characteristics that enhance recyclablility include [4, 19] : minimisation of material variety, minimisation of components, maximise material compatibility, minimise the use of hazardous materials, use recyclable materials, specify recycled content, label materials and facilitate ease of disassembly.

Clearly any holistic DFE methodology must be able to support the analysis, synthesis, evaluation and improvement of such characteristics.

As presented in the previous paragraphs the development of environmentally superior and compliant products is extremely complex. As much of a designer's work involves the use of CAD tools, there is an argument that new tools and methodologies need to be integrated in this type of environment.

3. LIFE CYCLE DESIGN FRAMEWORK

Traditional models of the design process have focused on the development of tools to improve the performance of a part of the life cycle of the product, e.g. design for manufacture or design for assembly. These tools can be described by the general term ‘design for X tools’, ‘X’ typically standing for assembly, disassembly or manufacture. The result is a proliferation of tools to aid the designer at individual life cycle stages with individual goals [17, 25]. As discussed in the previous section, new models must take a more holistic view, i.e. focus on the total life cycle system, to include raw material extraction, manufacture, use and end of life [20, 2, 3, 22, 36]. This is particularly true for DFE as a high degree of environmental coupling can occur across the life cycle stages [28, 15, 31, 6]. There is a need therefore to develop a life cycle design framework on which to build tools and methodologies to support DFE. By mapping the traditional design process model on to the product life cycle as shown in figure 3 a new design framework (called PAL) was derived.

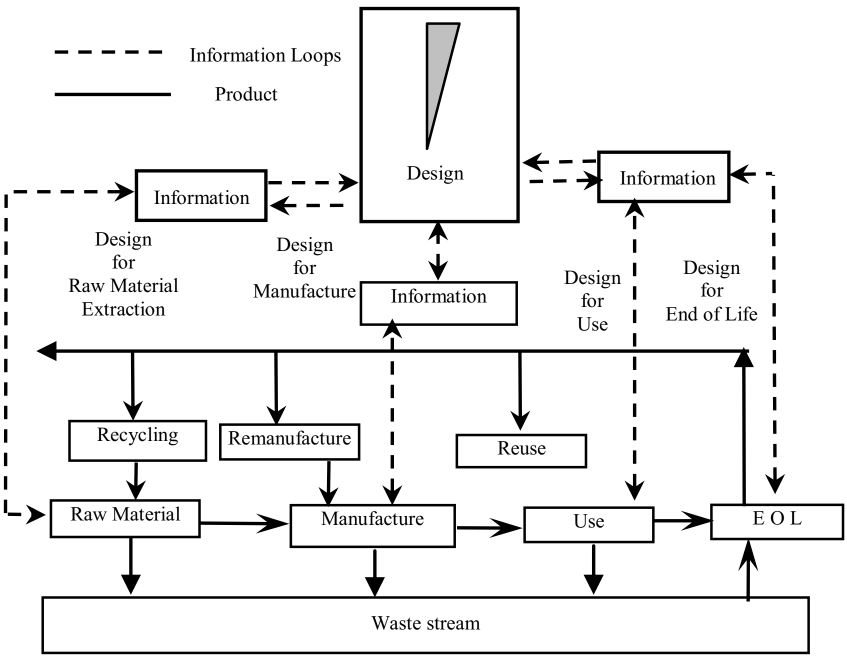

Figure 3. Mapping of life cycle phases to the design Process [28]

In the resulting model shown in figure 3 information is acquired through a set of life cycle design information loops, i.e. design for raw material extraction, design for manufacture, design for use and design for end of life. The design process transforms this information into product design characteristics, which are subsequently embedded in the product.

The resulting PAL framework for life cycle design is represented by a tri axial information transformation space, see fig. 4. The *vertical axis* consists of the degree of embodiment of a candidate design, i.e. the design traditional **Phase** (divided into requirements definition, functional design, concept design, and detailed design phases). On the *horizontal* axis is the phase dependent information transformation **Activity** that the designer is involved in at any particular design stage and is represented by the steps analyse, synthesis, evaluate in the model. In the context of DFE, environmental parameters and criteria have to be analysed, synthesized, evaluated and improved at every stage of the design process.

The life cycle information **Loops**, which define the third axis, represents the source of information for each life cycle phase of the product. These loops provide a focus for the type of information that has to be processed through the design framework. The activity and loop axis bound the life cycle problem-solving plane. This plane ensures the analysis, synthesis, and evaluation of life cycle information throughout each phase of the design process.

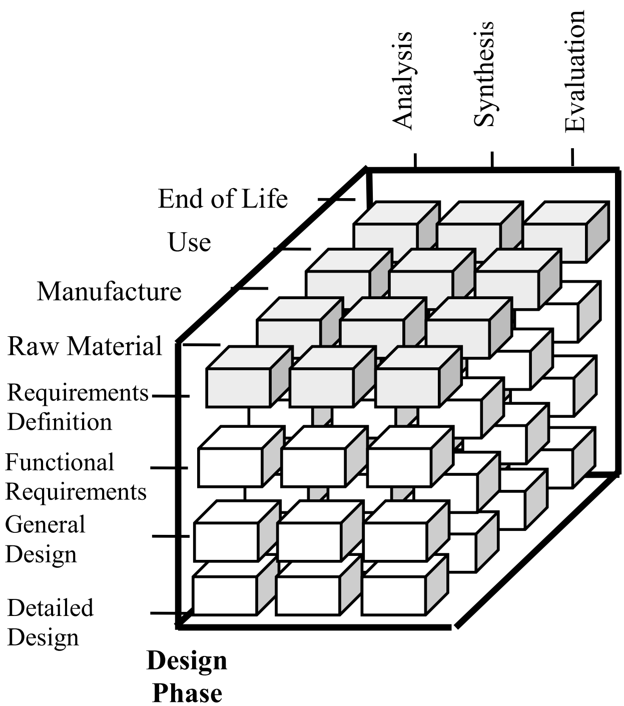

Figure 4. Phase Activity Loop (PAL) Life Cycle Design Framework [28].

The PAL Framework has been designed to support the development of methods, methodologies and tools to support life cycle design, particularly to cater to the coupling occurring between multiple product variables associated with DFE. It has formed the basis for the development of the DFEC Workbench described in this paper.

4. DESCRIPTION OF DFE WORKBENCH TOOL

The design for environmental compliance workbench exists at three levels of abstraction to facilitate the deployment of such tools in a distributed design environment i.e. DFEC Workbench Desktop, DFEC Workbench Enterprise and finally DFEC Workbench Global. The development of the DFE Workbench methodology is focused on the analysis synthesis, evaluation and improvement of life cycle product *General* and *Detailed* design information (from the PAL Framework). The DFEC Workbench Desktop exists in two forms, firstly the manual methodology, which is largely based on using special charts and reference information in a structured manner to evaluate and improve an emergent design. The second is a CAD integrated software tool, which effectively automates processes, associated with the manual methodology, as well as providing added functionality such as a WEB based report generator. The DFEC Workbench Desktop resides in a CAD Environment[1] and operates on virtual prototypes (VPs) created in that environment. The appropriate data is automatically synthesised from the virtual prototype and evaluated using different DFE tools. Each of the variables evaluated are prioritised and advice is given to the designer on alternative product or process characteristics that will enhance that variable. The designer optionally decides to accept the advice and makes the appropriate improvements in the CAD model. Data is then re-synthesised from the (new) model and the process begins again. This continuous improvement process continues until the best solution is found for that particular set of variables. The following fully integrated tools reside on the DFE Workbench.

- IAS Module
- SAM Module
- Advisor Agent
- Knowledge Agent
- Dynamic Report Generator

[1]The prototype DFEC Workbench has been developed in Solidworks 2000 and ProEngineer. Work is currently in progress to port the DFE C Workbench to CATIA V5.

4.1 Impact Assessment System (IAS)

The IAS is effectively a life cycle analysis tool that extracts the appropriate data from the virtual prototype. The user defines the life cycle processes and materials used by selecting options from the materials and processes databases. Improvements can be made at the *part* or *product system* levels.

4.2 Structure Assessment Method (SAM)

SAM focuses on the structure of the emergent virtual prototype in an attempt to enhance product structural characteristics in the DFEC context. SAM is a complex methodology, which quantitatively measures and records data such as follows:

1. Material Type and Variety
2. Material Intensity of Type/s (Mass)
3. Material Compatibility, (taking into account fasteners)
4. % Recycled Material Content
5. % Recyclable Material
6. % Hazardous Material
7. % Biodegradable
8. Number and Types of fasteners
9. Number and types of tools required for disassembly.
10. Total standard disassembly time
11. Standard part removal time and optimum route.

The coupling between all variables is managed and recorded by the DFEC Workbench Desktop. For example if an additional fastener is added to the virtual prototype then the number and variety of fasteners and disassembly times are recalculated for the product structure.

It should be noted that SAM is more focused on the product structure system therefore it can deal with individual parts and the relationships between them from an environmental viewpoint.

4.3 Advisor Agent

The advisor agent has two functions; firstly to prioritise variables generated by the IAS and SAM tools. Secondly the advisor agent actively gives advice to the designer on alternative structural characteristics to enhance either the environmental impact or structural characteristics of the emergent design. For example the advisor agent may suggest alternative materials or process to reduce the environmental impact of a product. The advisor agent uses a significant number of materials and processes stored in a propriety database, therefore making changes is very efficient. It should be noted that the advisor agent manages coupling between all variables in the product model. Hence, if the designer selects a new material then impact data and structural data is re-evaluated.

One important characteristic of the advisor agent is that it does not constrain the designer in any way. The designer is free to decide what he/she considers to be the optimal solution for the candidate design.

4.4 Knowledge Agent

The knowledge agent provides advice to the designer in a consultative mode. For example the designer can use the Knowledge Agent to find a material with specified mechanical properties and list them in increasing environmental impact. The designer can then use the selected material in the design.

4.5 Dynamic Report Generator

WEEE and ELV are likely to require reports to be created for compliance with directives. The report generator automatically generates reports on the product designed by the user. These reports are made available in two modes, i.e. as system reports that can be printed and viewed locally or as World Wide Web reports that can be made available via an Extranet model to people who need product data.

For example dismantlers may need to know the location of hazardous materials, the disassembly route and time for a specific product type. The report generator is designed so *that preferred dismantlers* can log on to the DFE Workbench site (of the associated manufacturer), type in a product descriptor code and get detailed product structural data directly for that *specific* product. If the designer makes a change in the product structure in the design process then the data is automatically updated on the web report server.

The *DFEC Workbench Enterprise* supports the synthesis, evaluation, analysis and prioritisation of both environmental impact and structural data associated with a full product system consisting of a number of subassemblies that have been previously analysed with the DFEC Workbench Desktop application. The enterprise version does not require a CAD environment to operate. The DFE Workbench enterprise identifies the highest environmental impact or structural problems associated with a particular subassembly/assembly and enables the system manager to notify the department developing the particular subassembly that modifications must be made in order to meet the desired environmental or structural criteria. Product Life Cycle Management tools are used to support this activity.

Both Desktop and Enterprise DFEC Workbench applications link directly with an oracle database server. The communication between the design team and system engineer/product manager is performed within an intranet network and allows instant access to the latest structural and environmental data from an emergent virtual prototype.

The DFEC Workbench Global has been developed as an intranet/internet application that allows easy communication and reporting of the environmental and structural data generated with the Desktop and Enterprise Workbench. It resides on a web server and is linked with the oracle databases, which allows customisation and control of data.

The DFE Workbench supports the development of environmentally superior products within distributed design environments. It allows easy collaboration between designers, as it is a centralised tool residing on oracle databases. The tool also allows quick access and customisation to meet the needs of various departments in a company.

The tool has been tested and validated with a large set of companies from the automobile and electronics industry sectors.

5. TESTING OF TOOL RESULTS AND CONCLUSIONS

The methodology was tested in three modes as follows:

a) In the analysis, synthesis, evaluation and improvement of an existing product using the manual method.
b) In the analysis, synthesis, evaluation and improvement of virtual prototypes in the design process, using the DFE Workbench software.
c) By performing consultancy for large multinationals in the electronics, automotive and electro-mechanical sectors.

Scientific tests on the DFE Workbench, using protocol analysis techniques were carried out with a large number of experienced engineers from both the electronics and electro-mechanical sectors. A summary of the results and conclusions established from the tests are as follows:

- The PAL Framework was a very powerful support for the development of tools and methodologies to support life cycle design activities.
- The proper application of the DFE Workbench methodology can result in the improvement of the design irrespective of the experience of the designer.
- It was established that the application of the DFE workbench took only 1.5% of the actual model creation time to use on a product, hence it can be concluded that the process of DFE did not have negative impacts on the process of design.
- The manual method takes a long time to complete. It is tedious to calculate all of the variables, particularly when having to iterate through a number of solution variants and having to recalculate every time. However the manual methodology was found to be a very useful, in fact essential tool for practical training on the principles of the DFE Workbench.

- The use of standardised criteria such as; standard times, labelling, and material compatibility's, is a very positive feature of the methodology particularly for benchmarking and design comparison.
- The strong and clear linkage between the global and local indices is identified as a very positive feature of the methodology.
- The prioritisation process was found to be very useful for the search and improvement activity.
- The inclusion of an advisor was seen as essential to the operation of the methodology.
- There are very distinct advantages for integrating the DFE Workbench in a CAD environment, not least the automation of data synthesis activity, the availability of quantitative data directly from the model, the manipulation of this data, the management of data interrelationships, and clearly the resulting improvement in a design before it is manufactured.
- The development of a web based dynamic report generator was viewed as a very positive feature of the DFE Workbench Software.
- A national award for eco design was won as a result of eco design work carried out by the DFEC Workbench for a local company.
- It is essential to have a company engaged with the development team in the future in order to focus development efforts on industry needs.

6. FUTURE PLANS

The focus of work on the DFEC Workbench suite of tools currently is in the commercialisation of the tool for the electronics and automotive sectors. In the next year the DFEC Workbench is undergoing continuous development at the author's institution. Resources are now in place to port the tool to CATIA V5 for the automotive sector companies. Additionally and concurrently with this development we propose to deploy a PLM approach and implementation methodology for enterprises for rapid roll out to the associated tiers in the relevant sectors.

For additional information on the DFE Workbench please contact Dr. Thomas Roche at the email address: Tom.Roche@GMIT.IE

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ECO-IMPACT ANTICIPATION BY PARAMETRIC SCREENING OF MACHINE SYSTEM COMPONENTS

An Introduction to the EcoPaS Methodology

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Abstract: The Eco-efficiency Parametric Screening (EcoPaS) methodology, described in this paper, offers a systematic approach to component selection based on environmental impact minimisation. Starting from functional systems requirements, which are known in a very early design stage and often form part of the task specification, designers can browse alternative solutions with the aim to translate functional block descriptions into specific system components. For this purpose different techniques are called upon, mapping functional parameters onto environmental cost defining physical parameters. These mapping techniques, inspired by cost estimating relationships (CER's,) offer opportunities to quickly screen system level design alternatives, resulting in early estimates for environmental performance indicators.

In this paper the different mapping techniques, used as underlying building blocks for the EcoPaS system library, are described. Practical examples offer better understanding of the concepts.

The functionality offered by the described methodology is illustrated by means of a comprehensive example of a machine system component.

Keywords: eco-design, conceptual design, parametric, environmental cost estimation relationship, EcoPaS.

1. INTRODUCTION

It is a well-known fact that decisions taken in an early, conceptual design phase can influence the outcome of a design exercise more significantly than any optimisation step later on in the design process [1]. In an eco-design approach an early recognition of favourable system component solutions is

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therefore of great importance. Generic eco-design guidelines form insufficient support for designers in this respect, while a detailed comparative study based on LCA techniques is too demanding in terms of required expertise and time consumption. Since material selection and exact dimensional specifications are typically determined in later design stages, building an LCA inventory only becomes feasible in an embodiment or detailed design phase (Figure 1). Even if appropriate competences would be available and time delay would not be an issue, the data requirements inherent to a conventional LCA study make the technique unsuitable as a support tool for conceptual design decision-making.

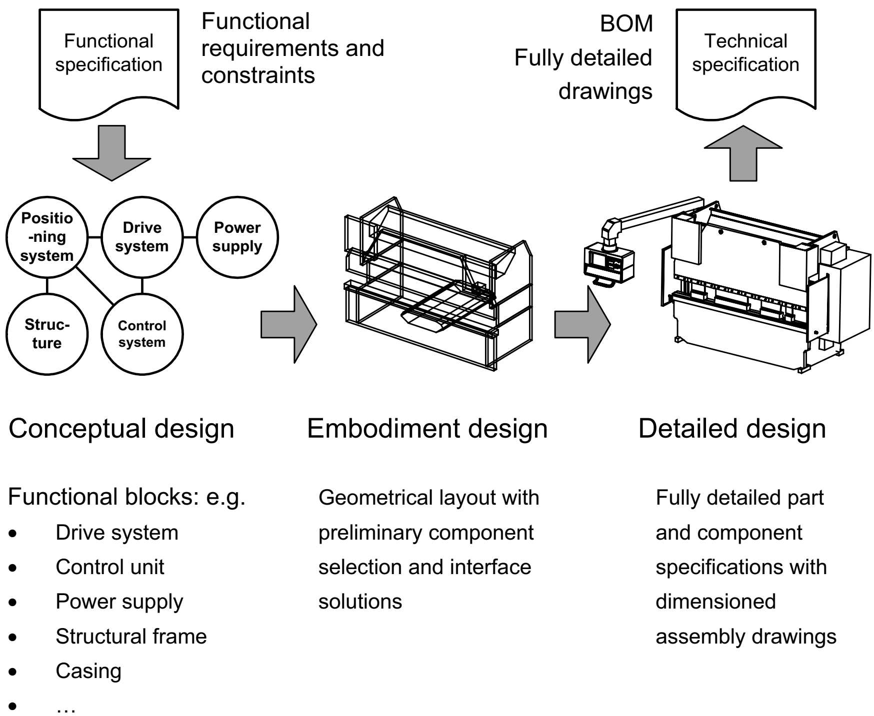

Figure 1. Decision scope and available information for eco-design support in different design phases

The specific nature of machine design offers opportunities to overcome this status quo. In a systems approach, design of machine tools largely consists of the identification of appropriate system components that can fulfil predefined functional requirements and constraints in an optimised way. The selection of such components leaves open a large number of possible configurations, since for each functional block in a conceptual design scheme a range of solutions is normally available. Design catalogues