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TRAINING APPROACHES IN ECO-DESIGN AND LIFE CYCLE ASSESSMENT

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Abstract: Eco-design represents an environment-based methodology used in the products design to minimize their environmental footprint by simultaneously preserving the same performance level and functionalities. The recent and future industrial evolutions (evolutions from the technical, economical and lawful points of view) as well as the normalisation of the LCA (Life Cycle Assessment) methodology are factors contributing to the development of eco-design abilities for students integrating the technical sector in the Bachelor's and Master's degrees. Then, the question of an evolution of the pedagogical content of these degrees is asked. These evolutions aim to propose good quality case studies or courses for the concerned students. In the present paper, several aspects related to this new pedagogical approach are presented. Four pedagogical experiments are presented and discussed after an application in the French high school of engineering ENSIAME (Valenciennes University, France), and in the "eco-design innovative products" vocational licence, Lille 1 University, France. A virtual course (Introduction to the Life Cycle Assessment - ACVBAT) has been recently developed for the Numerical University of the Environment and Sustainability (UVED) of the French Ministry of Education. This resource constitutes the common basis on which the previously cited universities worked together; its use made it possible for students to acquire abilities in eco-design or LCA methodology application using a Problem-Based Learning (PBL) approach.

Keywords: Sustainability, Life Cycle Assessment (LCA), eco-design, Problem-Based Learning

1. Introduction

For a few years, environment has taken an important place in the society but also in the companies.

This is mainly due to the media coverage of different studies dealing with the climate change for example, such as those of the IPCC¹ [1]. In the same time, many dramatic ecological events and indisputable facts such as the depletion of resources has led people to pay attention to the environmental footprint of the products and services. Consequently, this new behaviour has led the companies to propose "green" products to their customers.

This is closely linked to the notion of sustainable development, which appeared for the first time in an official report in 1987 [2]. Beyond the reference to the future generations, this concept is known to be represented by the intersection of three pillars or spheres (Fig. 1) representing the environment, the society and the economy.

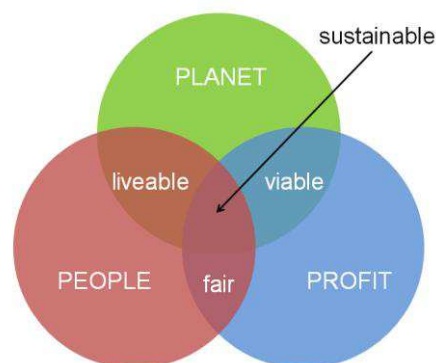


Figure 1. Classical representation of sustainable development

This conventional representation is sometimes opposed to another one where the sustainable development is a policy which is literally "sustained" by the three pillars (Fig. 2). This notion is very important because it is clear that each pillar must have the same importance. Sustainable development is consequently a part of development, which pillars are currently named "the three P" for Planet (environmental pillar), People (social pillar) and Profit (economical pillar).

¹ International Panel on Climate Change

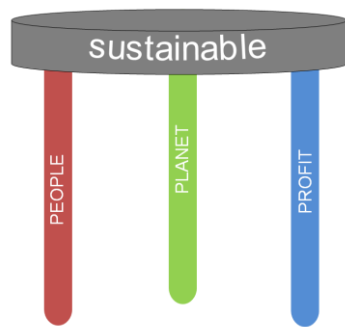


Figure 2. The three pillars of sustainable development

Twenty five years later, the sustainable development is still present in the society, essentially because of this last notion. It is clear that the goal of a company is to develop enough profit to develop itself. In such cases, the sustainable development is not only a way among others to reach this objective, but it can be the main way to do it, for example if a company makes a market share gain, stealing a march on one's competitors.

To help the companies and the organisations to develop their sustainable policy, an international standard is currently used [3]. This standard deals with the environmental management leading organisations to improve their environmental policy. This methodology is a so called **site approach**, essentially based on the quality management methodology international standard [4] applied to environment, according to the famous Deming wheel [5].

Another standard has recently been published [6], with the objective of Social Responsibility. This standard is essentially based on stakeholders. The main objective is to offer guidance on socially responsible behaviour and possible actions. This standard does not contain requirements and, therefore, is not certifiable, in contrast to ISO management system standards [3] and [4].

However, particularly in the case of an industrial site, it could be strange to follow a policy according to the ISO 14001 or ISO 26000 standards without aiming an improvement of the products which are developed.

In other words, environment should be an important element of not only processes but products themselves. This can be made by introducing eco-design in the product development or in the industrial processes. This so called **product approach** can be found in the continuation of the ISO 14001 standard: the ISO 14006 [7] and the ISO 14062 [8] standards.

Eco-design can be simply defined as

follows: introducing environment during the design phase of a product in order to reduce its environmental impact throughout the whole life cycle. Of course, the performance level must be preserved and the product must have the same function(s). This difficulty has been described in Ref. [9] and [10].

In fact, the question is generally to know if design and eco-design must be opposed [11].

A common way to develop eco-design is to use the Life Cycle Assessment (LCA) methodology, as it is presented in the international standards [12, 13]. This approach, currently called "cradle to grave" has been followed by a more drastic one named "cradle to cradle" [14].

In few sectors, such as building, the LCA methodology can be used as a choice criteria methodology to help the designer in choosing building materials [15]. Generally the objective is not to improve a system or a product but to choose the one which has the lower impact on the environment.

Several studies are dedicated to the presentation of eco-design tools for engineers and designers [16, 17], but they are generally intended to great organisations where "eco-designers" do exist, even if they have acquired their abilities on the job.

Le Pochat has presented an appropriation method to decline eco-design in small organisations [18], but it remains difficult, especially because of the lack of time.

Consequently, the main problem of the eco-design approach in industrial sites is the training of the designers. In fact, eco-design needs to use complex tools, and the teams which are involved in this approach must have multidisciplinary abilities and knowledge.

This requirement has led to serious modifications of pedagogical course and methods, particularly in Bachelor's and Master's degrees, but also the creation of new special fields and cursus. In France, this necessity was identified a few years ago by Puyou and Teulon [19] and more recently by Schiesser et al. [20]. Let us notice that what is true for conventional first-degree courses is true for in-service training and continuing education.

Since eco-designer is not really a trade, the question is to know how it is possible to train designers, engineers or superior qualified technicians for practicing eco-design and life cycle assessment. This paper tries to answer this question via the presentation of few examples.

In a first time, the stakes of environmental

management and eco-design are presented, and the main eco-design tools. Then four pedagogical experiments are described and discussed:

- One is dedicated to students who will be higher qualified technicians in the field of eco-design (Lille University, France)
- Two other experiments are applied to a French high school of engineering (ENSIAME) which trains general engineers.
- The use of a virtual course developed for a "numerical university", called UVED² [21], is described.

This "last" pedagogical experiment is not only the link between the previous experiments but also a powerful tool which can be adapted to different educational or professional trainings. Some lines of approach are then mentioned in the conclusion.

2. Environmental management vs ecodesign: two approaches for sustainable development

As seen above, the sustainable development concept has been developed in companies to generate a sustainable policy based on the continuous improvement concept (management of quality). This was easily feasible in firms which have already developed an ISO 9001 certification [4], and sometimes it led to an integrated management system [22]. This application of sustainable development is a **site approach**.

The other approach, especially for an industrial site, is the development of environmentally friendly products. Let us notice that the two approaches, represented on Fig. 3, can be developed in parallel, which is in any way a recommendation of the standard ISO 14001 [3] for a single reason: this standard requires an environmental analysis of the site which will necessarily go through an evaluation of the environmental impacts of the activity, and consequently on the manufactured products. This evaluation must be made on the whole life cycle of the product, using tools as the LCA methodology. When this evaluation of the environmental impacts is made, it seems logical to improve the product, which leads to eco-design. This second approach is the **product approach**.

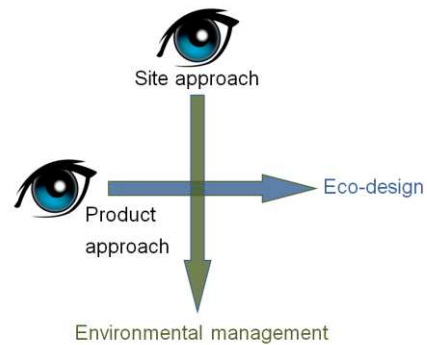


Figure 3. The two approaches of the sustainable development on an industrial site

Obviously, if we deal with an environmental analysis on a site or with the eco-design approach (using the LCA methodology), we must estimate environmental impacts.

Environmental impacts are classified in three categories:

- **Resources depletion**, mainly renewable and non-renewable materials (mineral and biologic materials) and non-renewable energies obtained from fossil fuels;
- **Pollutions due to human activities**, which can be measured in the air, the water and the ground; these pollutions generate different impacts (acidification, eutrophication, additional green-house effect...); these impacts can be identifiable at a double scale: local and global;
- **Toxicity and risks on human health**, which can be due to accidents or the use of dangerous substances (chemicals).

Let us notice that an environmental impact is in fact a potential impact. Many others environmental impacts can be observed and studied, but generally, a specific study is limited to few given impacts, said to be the most significant.

The method currently used to evaluate the impacts of a product or a process is the Life Cycle Assessment.

3. Ecodesign methodology

To set up eco-design in companies, but also to train designers in that way, it is necessary to integrate the environment in the design phase, to apply the main principles of the methodology, and to know the main tools used in the field. For

² UVED Université Virtuelle de l'Environnement et du développement Durable (Virtual University of environment and sustainable development)

more detailed explanations, the reader can refer to the virtual course ACVBAT³, chapter 2 [23].

3.1. Integrating environment

As seen above, eco-design consists in integrating environment in the design process. Eco-design is not a new method of design but it also represents the integration of an “environment-based thinking way” in the classical methods of design. The environment is consequently a supplementary constraint for the designer [24], which is at the same level as the other constraints such as the client expectations (obviously at the centre of the concept because a product without client is not appropriate...), technical feasibility, and cost management (Fig. 4).

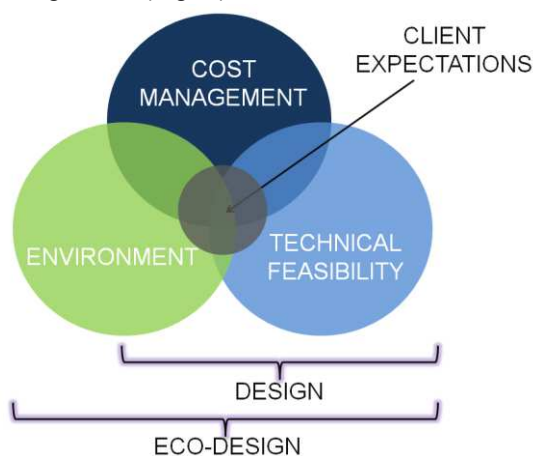


Figure 4. Main stakes of eco-design

The design of a product is one of the more pertinent phases for integrating environment in a company. It is known that about 90% of the costs generated by a product during its life cycle are a direct consequence of the choices done during the design phase. Then we can admit that it is the same for the generated environment impacts. Now the generated costs of the design process are said to be generally inferior to 10% of the total cost of a product (on its whole life cycle). Then, we can reasonably suppose that a good control of the environmental impacts during the design phase will not have a significant influence on the total cost of a product (including the use phase and the end of life).

The sooner environment is integrated in the design process, the more efficient is eco-design because the environmental impacts which are identified at this step can lead to adequate design choices. On average, as soon as 20% of

the time used for the development of a product is gone, 80% of the technical choices are made and can't be easily modified. After this step, all the other choices, even those dealing with the environmental aspects, could only be minor choices.

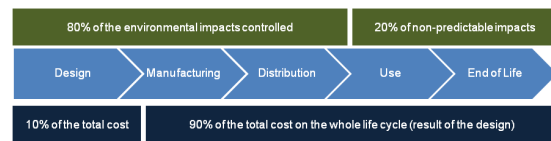


Figure 5. Financial and environmental costs of a product

3.2. Main principles of eco-design

The ISO 14062 standard [8] deals with eco-design: it describes the concepts and the practices for integrating environment during the design and the development phases of a product or a service. The general idea is to develop a process following two main concepts:

- The continuous improvement;
- The experience feedback.

Let us notice that a second international standard defines the principles and the methodology of eco-design [7].

Accordingly to the latter one, three main principles should be applied for the eco-design of a product:

- A **multi-steps approach** must be developed, i.e. a “life cycle thinking” must be adopted, which means that the different steps of the life cycle must be described (Fig. 6);
- A **multi-criteria study** is necessary, i.e. several environment impacts must be considered;
- The product is described as a **multi-component system** including for example packaging, consumables, maintenance, or communication...

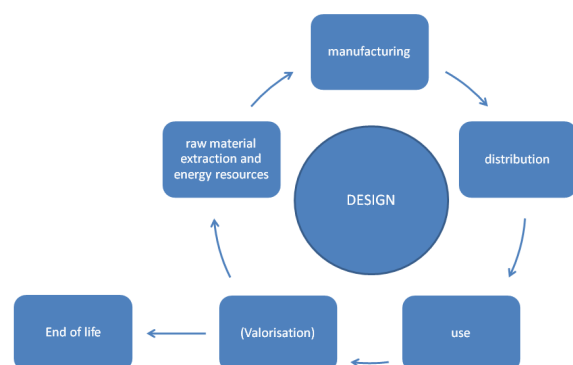


Figure 6. Life Cycle Assessment for a design process [7]

3.3. Main tools for eco-design

Two main categories of tools for eco-design can be identified:

³ ACVBAT - Démarche d'analyse du cycle de vie. Principes, méthodologie, exemples d'application aux matériaux et éléments de construction (Life Cycle Assessment Approach). Principles, methodology and examples applied to building materials and building elements.

- The **exhaustive approaches** dealing with a global evaluation of the environmental impacts.
- The **selective approaches** permitting to reduce some of the environmental impacts, generally said to be the more important.

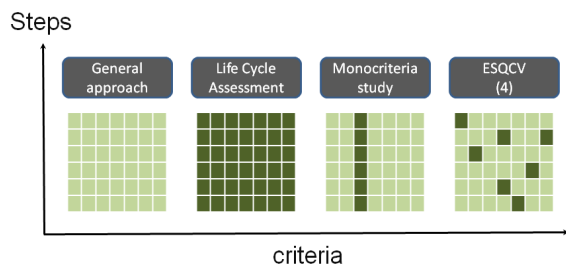


Figure 7. Main approaches in eco-design [23]

Fig. 7 presents the main examples of different types of eco-design tools. As seen above, it is inappropriate to consider only a single step of the life cycle, but a study can be limited to two or three significant steps of the life cycle. It is also possible to consider only few criteria for the environmental impacts, and in some cases, the study of a single criteria is possible (mono-criteria study), for example the energetic content or the carbon foot-print of a product. This can be due to a financial constraint but this choice can also be the consequence of a previous study which could have shown that the other impacts are not significant for the product.

Among the selective approaches, some of them are qualitative, as ESQCV⁴. Such tools can be sufficient in some cases for a first approach in eco-design.

Many eco-design tools are presented in ref. [23], notably eco-design Pilot [25] which can be useful for designers who want training themselves in eco-design.

Among all these tools, the Life Cycle Assessment is an exhaustive approach which has been previously described by the authors in a previous paper [28] according to the international standards [12, 13]. The general scheme of the methodology is presented on Fig. 8.

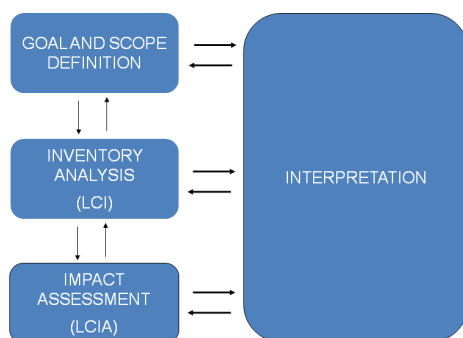


Figure 8. Methodological scheme of the Life Cycle Assessment methodology [12, 13]

Following these concepts, designers, engineers and higher qualified technicians can improve their abilities towards eco-design.

4. Pedagogical and training experiments

Beyond the “self-training” of designers in companies, another question is to train students or auditors to this methodology. This section deals with some experiments which have been developed in two French Universities and via the numerical course ACVBAT [23] which can be found on the web site of the UVED University [21]. This course proposes an academic presentation of the LCA methodology, and describes several case studies applied to the building sector. The examples are treated using the free software called Bilan-Produit® [29].

The general idea is to use a non-conventional approach which is in any way the one which will be discovered in the companies and in the organisations by the students or the auditors. This method is called the Problem-based Learning (PBL) and is described in many papers and books such as ref. [30].

This pedagogical method is more interesting for students and auditors because it directly deals with real cases. Besides, the student is no longer a “listener” but becomes an actor of the methodology, which permits him to acquire knowledge and abilities more quickly and more durably. This method deals with “organisational learning” already tested with a certain success at the Valenciennes University [31] according to using the balanced scorecard (BSC) methodology [32]

4.1. ACVBAT – a virtual course dedicated to Life Cycle Assessment

As seen above, ACVBAT [23] is a specific course on the UVED numerical university [21] which exclusively deals with LCA. The main interest of this course is to present the LCA methodology using real examples, contrary to many trainings which just present a specific software tutorial.

The general idea of this course is to give free elements to teachers and trainers, who can directly re-use them in their presentations or teachings supports. This course can also be appropriated by self-learning.

It is built to be not only the methodological core of the LCA approach (Fig. 9), but an application to the building sector. Then it is possible to apply the methodology to other industrial sectors without any difficulty.

⁴ from French : Etude Simplifiée et Qualitative du Cycle de Vie (Simplified Qualitative Life Cycle Assessment)

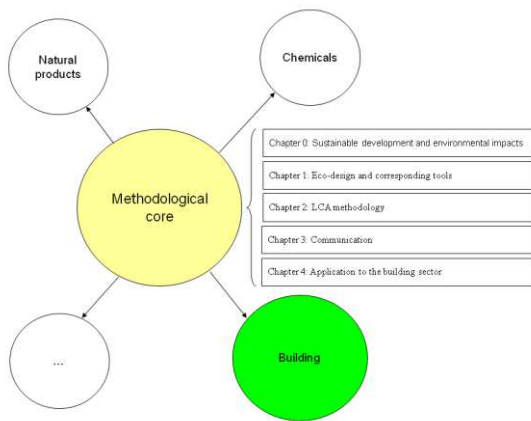


Figure 9. The ACVBAT structure [23]

Inside this resource, the « reader » will find different elements such as videos presenting LCA applications, different examples, tests to validate the acquired level of knowledge... Throughout the course, different case studies are presented, notably the case of a door. Another case study is completely done. This case study has been partly realized by students coordinated by the authors (see parts 4.2 and 4.3) and the results have been rendered in a graphical tool called the ACVBAT radar (Fig. 10). This tool helps the user to validate his or her approach, and can be properly used as a powerful communication tool.

Table 1
Chosen indicators for the environmental impacts

designation	Impact	Unit
NREC	Non-Renewable Energy Consumption	MJ eq.
RD	Resources Depletion	kg Sb eq.
GWP	100 year Global Warning Potential	kg CO ₂ eq.
A	Acidification	kg SO ₂ eq.
E	Eutrophication	kg PO ₄ ²⁻ eq.
PP	Photochemical Pollution	kg C ₂ H ₄ eq.
AT	Aquatic Toxicity	kg 1.4-DB eq.
HT	Human Ecotoxicity	kg 1.4-DB eq.

Tab. 1 lists the used indicators for the considered environmental impacts in the present methodology. In Fig. 10a the wall is considered as an assembly of different materials. The user can choose different material to build virtually the wall, and the results appear in the ACVBAT radar. Fig. 10b gives an example of the results for a given configuration of the wall assembly.



Figure 10a. The given wall assembly studied in ACVBAT [23]

(caption in French)

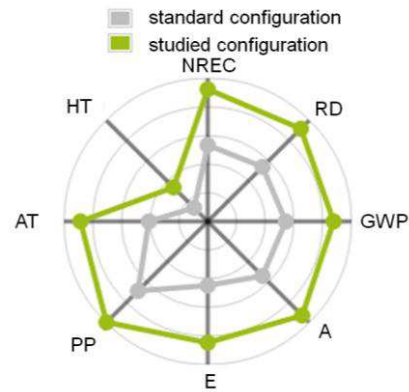


Figure 10.b The corresponding ACVBAT radar according to data from fig. 10a [23]

It can be seen that ACVBAT is not only a classical course for students in universities, but also a free-access numerical resource which can be used by everybody in a professional context (eco-design for example) or for self-training.

This resource has been used with a certain success in a few cursus, notably in the "eco-design innovative products" vocational licence at the Lille 1 University, France (section 4.2), and at the high school of engineering ENSIAME, Valenciennes University, France (section 4.3).

4.2. The vocational bachelor's degree in industrial production, speciality "eco-design of innovative products"

The technical staff trained in the vocational bachelor's degree dedicated to eco-design at the University Lille 1 - Sciences and Technology, will be the privileged holders of an eco-designed approach, in a position to disseminate and implement innovative concepts and principles. They will have the technical, scientific and organisational resources required towards that goal by companies with an eco-designed approach. Through a comprehensive process of designing a product and its life cycle, they will be able to interpret environmental regulations, to practise the environmental management, to set up the product specifications starting from a need and translate them into a functional diagram. Within the company, these students will be in charge of improving the products performances such energy consumption, biodegradability, optimal recycling, etc., by seeking solutions that lowers the environmental impact.

More than 40 % of the courses are provided by industrial and institutional partners. This course, integrated in the LMD scheme (Degree-Master-Doctorate) consists of 7 modules, totalizing 450 hours of training, spread over two academic semesters and worth 60 ECTS (European Credits Transfer System).

The tutored-project as well as some materials-science related courses are realized by integrating the "learning by doing" concept. As an

example we describe here the example of the materials identification procedure used in evolutionary design, recently presented at the 5th Materials Education Symposia [26].

The main outcome of this project is respectively the evolutionary design. By accounting the market need, the design requirements are formulated. The scope is to design an energy-greedy product and it's packaging by increasing the performance, by decreasing the costs and by considering its environmental footprint. The need of process and materials data is underlined in this context, especially with respect to their environmental footprint. The design constraints are the shape, the manufacturing, the cost and the eco-impact. Several practical case-studies are considered, they allow to students discovering new concepts such the design for the environment, the design for sustainability and to perform energy balances for the embodied energy, for the process energy and for the end of life potential.

Note finally that the results obtained in the previously presented tutored-projects constitute also the basis for the development of a new course in the framework of the UVED University, the so called ECO-PEM project [27].

4.3. LCA for general engineers

The high school of engineering ENSIAME does not "produce" specialists in a specific field but general engineers. Some on them will work in Fluid Mechanics and Energetics, which are identified as main specialties in the curricula. Environment is taught as an important application of the scientific domain but very few students will become designers.

In order to present the environmental footprint of products, the idea is to lead different case studies as specific projects, following the PBL methodology [32]. The subject is chosen by a group of two or three students who realise the whole study exclusively using the Bilan Produit ® software [29] and ACVBAT [23].

The project must be done according to the LCA methodology represented in fig. 8. A report must be written and an oral presentation is made at the end of the project, for the final evaluation. The data must be provided within the Bilan Produit ® worksheet and the results must be analysed. A specific A4 sheet is required as a communication support of the project. A Part of the work is made with the teacher, who can guide the students to follow the appropriate method, but the work is continued at home by each team. A specific rating table is used to evaluate the level of the produced work; it takes into account each part (conformity of the methodology, written report, oral presentation, A4 sheet, calculations, analysis of the results...).

Fig. 11 represents an example of such a supplied work, as a specific A4 sheet.



Figure 11. An example of the provided work [23]

The course itself is evaluated by the students, so that the teacher knows if the objectives are reached, and can adapt the pedagogy in the future if necessary. It has been shown that the course is appropriate for training (according to the students...). Some of the projects have been presented in different conferences [33, 34] or have been published [35]. Several students have easily found an industrial placement in the field, and some of them were able to win a job, generally considering the abilities they acquired in the calculation of environmental impacts.

4.4. Eco-design and industrial design

The ENSIAME high school of engineering also produces engineers in product design. Then classical tools of engineering design are tackled, such as functional analysis for example. The difficulty is to lead the students towards eco-design.

The idea is to use again the PBL methodology, using another aspect of design: the **industrial design** [10]. Teams of students are set up and must work about a given subject, for example improving a toaster considering its environment impacts, by the use of eco-design and LCA. Different methods are used, such as brain-storming or creativity.

The idea is to propose different solutions of lower environmental footprint products, according to a pedagogical methodology similar to the one described in part 4.3. (a specific project is to be realized).

Different complex design software tools are used by the students, but also specific LCA software if necessary. Generally, the single use of Bilan Produit ® [29] is sufficient enough for a first approach.

This pedagogical approach leading to product design and using industrial design and eco-design has been recently presented [36, 37]

and the results are very interesting. Fig. 12 shows different results which are shown to be innovative for the example of a toaster.

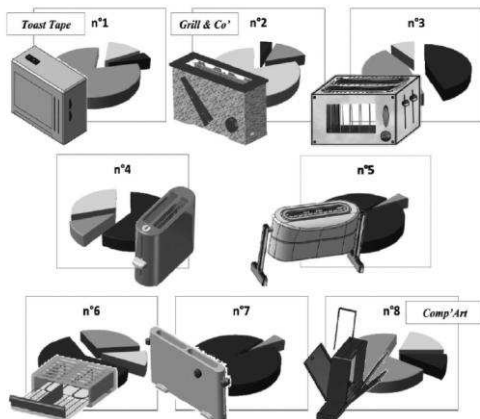


Figure 12. Some results for industrial design projects [36]

5. Conclusion

In the present paper the necessity and/or the opportunity of eco-design approaches in industrial companies have been presented. It has been shown that eco-design is the product approach of a sustainable policy, whereas environmental management is the site approach of this concept.

The way to go from design to eco-design is not easy to follow, especially because of lack in training and pedagogical curricula.

Several tracks have been investigated. It has been shown that a single academic course is not sufficient. Contrarily, the use of the Problem-Based Learning methodology permits in all the cases to train students, auditors, or designers in place. Besides, the results in terms of the appropriation of the subject are better than those which could have been obtained using conventional pedagogical methods. Sometimes, these approaches lead to creativity, innovation, or scientific results.

This pedagogical approach has been applied to sustainable development, eco-design and Life Cycle Assessment, but it is clear that the field is not so limited. In the present economic crisis, innovation coupled with environment stakes will probably help firms to develop better against their concurents. The training approaches presented in the present paper are probably some ways among others to generate such possibilities.

6. Acknowledgements

This study has been partly made using the free Bilan Produit ® software [29] jointly developed by the French Agency for the Environment and the

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