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Teaching Sustainability Design of Products to Engineering Students

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Abstract: Today we are producing a large number of industrial products and generating considerable volume of waste and these require an increasing area of the dumps and landfills at the end of the product life. Therefore it is necessary that among other things, we need accurate information about materials, manufacturing processes and assessment of environmental impact. In developing a sustainable product, the life cycle analysis plays an important role which at the same time is not an easy task to accomplish. The life cycle assessment in fact plays a key role to decide the best alternatives in the selection of materials and processes for a product. There exist several software to carry out life cycle assessment (LCA). In this article our aim is to discuss the material selection process for products and explore to carry out an LCA for some products of low technological complexity. Since Engineering students of today are going to be product designers of 21st Century, they must learn to select right materials and processes during the design phase. The results presented in this article highlight the complexity and importance of proper selection process of materials for sustainability.

Keywords: *Industrial design, sustainability, life cycle assessment, education.*

1. Introduction

With a large volume of industrial products being produced today, there has been an increase in generation of waste which adds up to the volume of the dumps and landfills. Therefore, many researchers from different fields [1-7] have drawn attention to the problem of alternatives for the disposal of technological materials affect the environment.

Furthermore there is a societal pressure for environmental friendly products and systems, and this has stimulated new environmental legislation, mainly in Europe. One of these makes producers responsible for the costs of collection, treatment and recovery of their products. These rules insist that the products must be designed so as to reduce its environmental impact, especially with the increased rate of recycling. Thus, the task of designing a sustainable product is indispensable for today's society.

A good product design depends, among other things, on accurate information about materials, manufacturing processes and on assessment of environmental impact. The selection of suitable material therefore is of prime importance in developing a product. Public acceptance and good performance of the final product are not only consequences of this step, but a set of steps that are part of its development. It is noticeable, thus, the importance of creating products with less material and that are easier to dismantle at the end of its life-cycle (design for disassembly), is a central theme of the design of products with a focus on sustainability. The use of design for sustainability

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allows reducing production costs and the use of materials with lower environmental impact.

An industrial design today has focus on sustainability and a tool that plays an important role to generate the best alternatives of materials and processes, is the Life Cycle Assessment (LCA) which has several software alternatives and different methods of analysis. The objective of this paper is to emphasize the importance of material selection in Life Cycle Assessment, and to present LCA developed at the University UNISINOS, in a bachelor's degree course on Product Design and Engineering. The study presented here examines one type of product, namely, a "squeeze"or a water bottle used in sports, and carries out a comparison of six different models of this product. The software used for the analysis of life cycle of assessment is CES EduPack along with Eco Audit Tool. Our aim has been to link theory and practice, and making students aware of the concepts and tools of sustainability and to make them understand all aspects of design phase in a product life cycle. These studies also seek to educate students about the role that a future designer may have to perform in relation to designing products for sustainability.

2. Environmental Implications

2.1. Waste – An Environmental Problem

With ever-increasing urban population, and an intensive industrialization, coupled with an improvement in the purchasing power of people, has in general contributed to the generation of large amounts of solid waste. The population increase also implies growing use of natural resources of the planet.

In Brazil, we continue to grabble with the problem of finding final destination of waste collected. According to a survey done by Abrelpe [8], the forms of disposal of municipal solid waste in Brazil contitutes: landfills to the tune of 58%, controlled landfills of the order 24.2% and garbage dumps, about 17.8%.

At present, one of the major producers of waste is the technological sector. According to Murugan [9] and Chancerel [10], the generation of WEEE waste rate is the highest throughout the world and continues to increase, and is one of the fastest and most growing waste flows. Widmer [11], argues that these items have constituted 8% of municipal waste in 2005. Huisman [12] states that in 2007 the production was of 8.3-9.1 million tons per year, which corresponds to about 17 kg per capita per year.

Henstock [13] points out that when the recyclability becomes a deciding factor in the design and manufacturing, this may help produce practical solutions. Design for recyclability makes the product easier to rebuild, so that its reuse is economical, which in turn reduces the amount of waste generated in consumption - recovery - reuse cycle.

At the university to improve the awareness of students with concepts and tools of sustainability, the students were asked to visit Household Waste Recycling Centre (HWRC) to understand the problems linked with the issue. The aim of the visit was to show the reality prevailing in HWRC to students of the course. Since the reality around us often goes unnoticed, so it was necessary to shoe the reality of the problem that exists today. The major problem is actually the large volume of waste that is produced as shown in Figure 1, of which only a small amount can be recycled or reused. This is because of the difficulty of identification and separation of materials and components of a product.

Figure 1: Picture of the Household Waste Recycling Centre (HWRC) visited by the students of Design course of UNISINOS. Source: Author.

3. Sustainable Design of Product

An increasingly debated topic in today's society, is sustainable development. Sustainable development is development that meets present needs without compromising the ability of future generations to meet their needs. More broadly, sustainable development policies encompass three general policy areas: economic, environmental and social [14].

According to Bygget [15], any approach to achieve the sustainable products should eventually encourage and assist in the transformation of society towards sustainability. The objectives are: (i) identification of potential problems of the present or planned products caused by substances and activities during the life cycle of the product, which are critical with regard to the principles for sustainability, (ii) guidance to find solutions to potential problems by modifications of the present or planned product, and (iii) stimulation of new products and ideas based on aspects of sustainability.

Manzini & Vezzoli [1], states that the role of design can be summarized as an activity that, by connecting the technically possible with the ecologically necessary, gives rise to new proposals that are socially and culturally sensible. For these authors [1], the design may have four basic levels of interference: the environmental redesign of the existing products, the design of new products or services to replace the current ones, the design of new products / services inherently sustainable and the proposal of new scenarios that correspond to the sustainable lifestyle.

3.1 Design for Sustainability

Many terms have been used to mean sustainability, and until recently we had concept of Ecodesign, but sustainability goes far beyond these concepts and methods. According to Ljungberg [3], many new concepts have been created to achieve the development of products, as well as the environmentally friendly products, and some examples of common strategies to achieve sustainable design are shown in Table 1.

For several researchers [1, 4, 5, 16], Ecodesign is a technique that proposes a new strategy for product development, linking the environmental management system to materials and manufacturing processes. In the activity of product development, it seeks to incorporate the environment variable from concept stage, considering the environment with the same degree of importance as efficiency, aesthetics, cost, ergonomics and functionality. So, it is a holistic view in which, it is essential to know the environmental problems and their causes, that begin to influence the design, choice of materials, manufacture, use, reuse, recycling and final disposal of industrial products.

Table 1: Concepts related to Sustainable Development. Adapted from Ljungberg [3].

Concept	Characteristics
Eco-design	This is also known as Design For the Environment (DFE).
Modular design	Easy repair and change of components are important. *e.g.*, parts in copying machines and computers.
Design for material substitution	Substitution of materials with high environmental impact to more superior materials in terms of sustainability.
Waste source reduction design	Reduce the amount of material both in terms of the product itself and packaging.
Design for disassembly (DFDA)	A product should be easy to disassemble, *e.g.*, snap fits, mechanical locks, *etc.* in order to recycle the materials.
Design for recycling (DFR)	DFR focuses on maximum recycle-ability and a high content of recycled material in the product. Different materials should not be mixed if not necessary and different parts should be labelled for easy materials separation.
Design for disposability	Assures that non-recyclable parts or materials can be disposed in an ecological way.
Design for reusability	Focuses on possible reuse of different components in a product. The reused parts could be freshened up and reused.
Design for service (DFS)	The design of a product is made here in order to obtain easy service from the outer regions.
Design for substance reduction	Undesirable substances, which are used during the products' life cycle, should be minimized.
Design for energy recovery	The design here is made with materials suitable for burning with a minimum of toxic or harmful emissions.
Design for life extension	Reduced waste through prolonged life for components or products is the aim of this strategy.

The pressure from society for environmentally friendly products and systems has led to new environmental legislation, mainly in Europe. According to Gehin [17], many manufacturers in Europe are required to be responsible for the final destination of their products, primarily due to the development of laws and responsibilities of the manufacturer and the high level of environmental awareness existing in those countries. The same author [17], defines the producer responsibility (EPR), which is a policy to promote environmental improvements of the total life cycle of product systems by extending the responsibilities of the manufacturer at various stages of the total life cycle of the product, and especially to its collection, recycling and final disposal. The extended producer responsibility (EPR) is accompanied by the administrative, economic and informational policy.

Design for sustainability aims to find the product design suitable for the nature, be it by employing materials to be reused, recycled, or with parts easier to identify and to separate, making this an increasingly significant area for product designers. Adding this tool from the earliest stages of design ensures the ultimate realization of environmentally friendly products.

3.2 Materials

Ashby [18] believes that throughout history, the materials have played a great role in the design of products. The ages in which man lived have also been named by the materials used at that time, *viz*., stone, bronze, iron. But the present age is not the age of a particular material, it is the age of a wide range of materials. There has never been an era in which the evolution of materials was faster and the scale of its properties more varied than now. Dieter [19] also considers that the relative importance given to materials has led their increasing use; their specific properties are explored in an ever more productive manner, so that man can start to identify needs for new products, creating their requirements and has evolved *Materials Engineering* to provide new alternative materials.

According to Dieter [19], at the beginning of civilization the use of materials had little influence over the environment, because the latter also did not exercise influence over the material - namely, animal bones and skins, stones, leaves and sticks. The environment acted on the formation, but not on use. Furthermore, the existing quantity of material on the surface of the earth was more than enough to meet the needs of an early man. In Figure 2, the evolution of materials, represented by the timeline, identifies the transformation of materials to the present stage, revealing the growing use of synthetic polymers in recent decades and an even greater tendency to use these materials in the coming years [18].

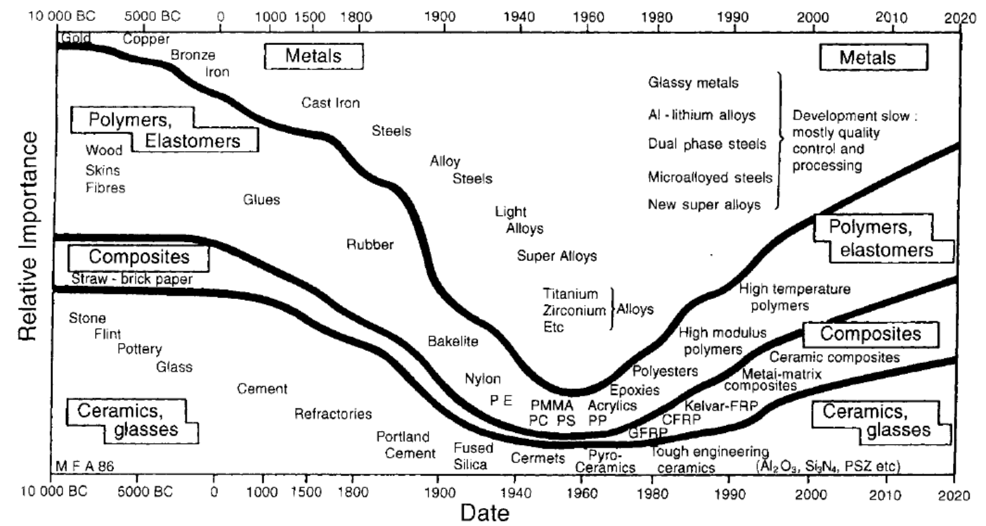

Figure 2: The evolution of engineering materials with time. 'Relative Importance' in the stone and bronze ages is based on assessments of archaeologists: that in 1960 is based on allocated teaching hours in UK and US universities; that in 2020 on predictions of material usage in automobiles by manufacturers. The time scale is non-linear. The rate of change is far faster today than at any previous time in history. Source: Ashby [18].

3.3 Material Selection

As stated by Ashby [18], Design is the process of translating an idea or a new market need into detailed information saying that a product can be manufactured. Each of its stages requires decisions about the materials that the product should be made of and the process of making it. Usually the choice of material is dictated by the project, but sometimes it occurs in another way: the new product, or the evolution of the existing one, have been suggested or made possible by the new material.

For Dieter [19], the importance of materials selection in design has increased in recent years. The high activity of materials science worldwide has created a variety of new materials, so the range of materials available to the designer is much broader than before. In conformity with Ljungberg [3], it is estimated that there are more than

100,000 different types of commercial materials in the market, including all variants in the composition of materials, mixtures, thermal treatment, *etc*. Structural materials for the products can be divided into six groups: metal, ceramic, synthetic polymers, natural organic materials, inorganic materials and natural composites. These groups will probably cover more than 99% of all materials used in Mechanical Engineering, Civil, Electrical and Design.

According to Ljungberg [3], a material can be sustainable for the product during use and recycling, while its extraction can lead to serious environmental impacts. The composites should be used with special considerations, also taking into account the possibilities of how to separate the specific materials [19 and 20].

A product is usually made of various materials. Ljungberg [3] points out that during their life cycle, they undergo different stages, such as the extraction of materials, manufacturing, packaging, transportation, use and disposal. All these stages cause some environmental impact, especially for the materials involved. In this sense, the selection of materials for a particular product is of vital importance, when it determines the use of natural resources such as the amount of energy used to manufacture and use of the product.

According to [5 and 21], the process of selection of materials should be considered an essentially interdisciplinary task, to which one requires knowledge and information from other areas such as marketing and strategic planning. In product designs, the ones responsible for their conception, initially, are based on determining their criteria for selection of materials, among which are: a) Dimensional considerations; b) Considerations of form; c) Weight considerations; d) Considerations of mechanical strength; e) Resistance to wear; f) Knowledge of operating variables; g) Ease of fabrication; h) Requirements for durability; i) Number of units; j) Availability of material; k) Cost; l) Feasibility of recycling; m) Value of scrap; n) Degree of standardization.

For Ashby [18], design problems do not have a single or “correct” solution, then the first tool that the designer needs is an open mind, willing to consider all possibilities. The author shows that the materials selection depends on three criteria that are interacting: the function, process and form, displaying the lack of an ecological criterion for the material selection.

According to author [21], the fact is that not only the objective methods for the selection of materials must be observed, but also the subjective ones must be considered, which makes the selection more complex. During the process of selection of materials, information is needed about the technical characteristics, classified as tangible and subjective characteristics, classified as intangible assets. The technical characteristics are important for the practical functions of the product. The subjective characteristics relate to perceptions, associations and emotions evoked during human-object interaction, These are depicted in Figure 3.

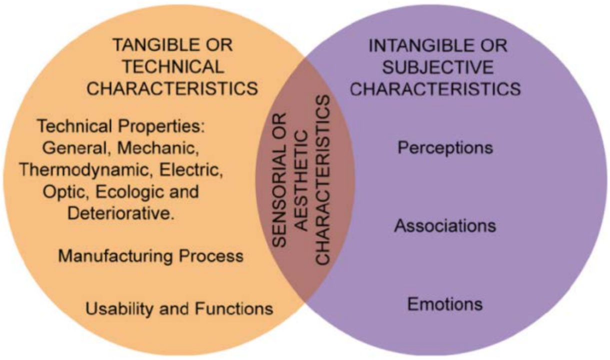

Figure 3: Materials and Products Characteristics. Source: Faller [21].

One of the tools for the selection of materials, which includes subjective and objective variables, is through a Materials library (Figure 4), which is being used in the design course at our university. It makes it possible to stimulate the tactile and visual perception of the students, through exposure and manipulation of materials, having technical and subjective information.

Figure 4: IMateria, Materials Library of UNISINOS School of Design. Source: Author.

Ashby [18] considers that the challenge is to think about the use and selection of materials to minimize environmental impacts while avoiding conflict with the natural growing need to minimize costs. According to Ljungberg [3], then, developing successful products in the future requires a shared vision. A good designer should be aware of these changes and continually seek new solutions.

4. LCA - Life Cycle Assessment

It is usually difficult and often confusing to quantify the environmental consequences associated with materials, processes and products. Difficulties are, for example, the determination of the environmental effects associated with the objects of comparison, the almost impossible task of comparing different environmental effects and the amount of data required comparing related products. Often the required data are scarce or inaccessible, so it is hard to define then analyzing environmental burden [6].

For Ljungberg [3], in terms of the Life Cycle Analysis (LCA), there is not a 100% safe way to compare different production and recycling methods in relation to environmental factors. The evaluation makes it easier to compare different materials, manufacturing methods, the intensity of service *etc*., which is of vital importance when developing sustainable products. It is seen in Figure 5.

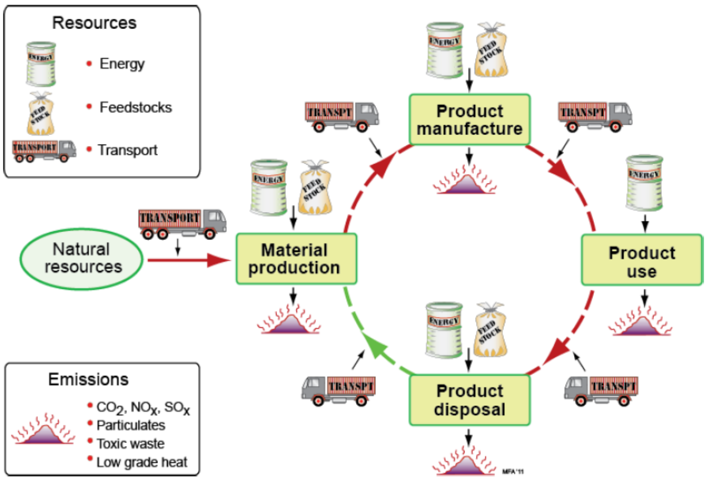

Figure 5: The material life-cycle: material creation, product manufacture, product use, and a number of options for product disposal at end of life. Transport is involved between the stages. Source: Ashby [7]

Andrae [10] states that there are a number of methods and tools related to environmental assessment, such as Life Cycle Assessment (LCA) and carbon footprint, all with the intent to indicate which alternative is better compared to other. Manzini and Vezzoli [1] considers that the product should be designed with respect to all its phases, *i.e.*, the concept of life cycle. It is the product from the extraction of resources necessary for the production of materials that compose it ("birth") until the last treatment ("death") after using the product. From this analysis it is possible to determine what material is the most practical during the process and as the material and manufacture affect the environment.

Thus, the design assumes a systemic perspective, going from product to system-product as a whole. One of the tasks for the development of new products will be to design the total life cycle of the product, that is, designing the Life Cycle Design (LCD). All products designed this way will have a higher added value, including the end of its useful life, which will be relevant to the complete success of separation and recycling of materials, avoiding the improper disposal of waste generated.

In search of progress in the techniques of selecting materials and their interpretations or comparisons with other existing, Ashby [1] created the "maps of properties" , which gave rise to software for Materials Selection, named Cambridge Engineering Selector® - CES with the support of the developers of Granta Design® [22 and 23]. This software allows you to separate the materials best suited to the proposed project, limiting them to a few units for application, after several steps of restrictions. In the 2011 version of the software, other applications have been introduced, one of these is Eco Audit allowing comparison of materials considering all stages of the life cycle of the materials, as shown in Figure 6. Thus, in this version of the software, it is possible, for example, to compare different materials by performing an environmental comparison, searching through some parameters to get evidence of which material is appropriate for a particular use. This software was chosen for the Life Cycle Assessment.

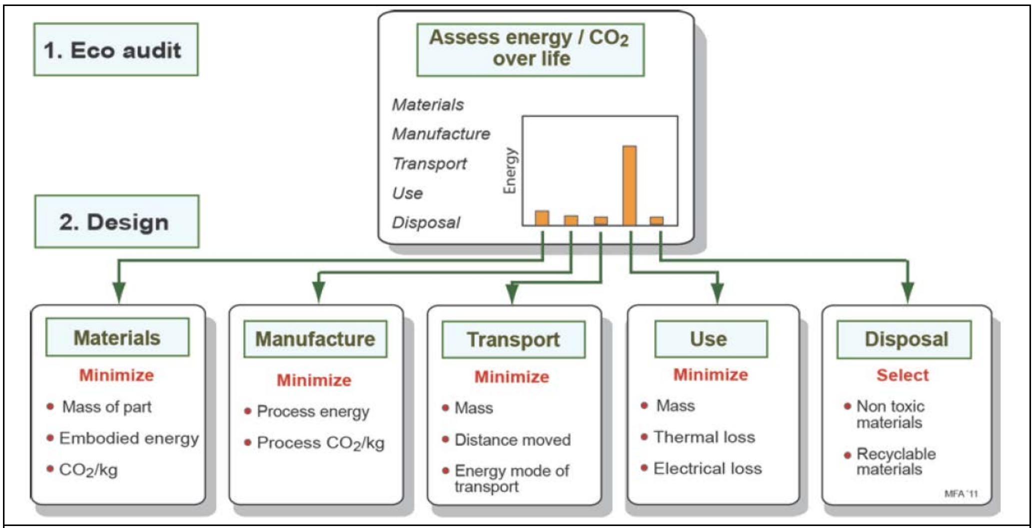

Figure 6: Software ESC Edupack 2011 integrating the Life Cycle Assessment tool. Source: Ashby [7].

At the university of *UNISINOS,* one of the assignments undertaken is the analysis of similar products, seeking to investigate how many products today are designed in terms of its disassembly and material selection and then seek to improve the products. It is done, also, to ensure that the methodologies used for designing products include environmental variables. These analyzes are focused on structural aspects, the junction elements and materials of the similar products, because it is understood that these are important environmental variables. After that the students try to understand all design phases involved in the life cycle of a product early in their course. These analyzes are focused on information from manufacturers, with some analysis of existing materials, depending mainly on information by the manufacturers.

5. Methodology Used by the Students

The methodology used in this study was divided into three phases:

Phase 1: Disassembly and Data Collection:

- Disassembly and separation of product components.
- Identification of different components, their materials and processes used.
- Weighing with a digital scale of the different components.
- Search of information materials on the manufacturer's website if was not available from the specification on the products.
- Research on the recycling of different materials from the data in the software.

Phase 2: Entering Data in the Software:

- Entering the quantity and material of each component, the percentage of recycling (0-100 %), the weight, the primary process and the final destination of the component (landfill, incineration, downcycle, reuse, remanufacturing, recycling). It was first used for the information of the student and then research on the potential components of our concern.
- Enumeration of the various types of transport and the distances in each phase of the life cycle that the transport makes use of.
- Reckoning of energy costs involved in the use phase of the product. In the case of the bottle the energy spent in cooling.

- The products analyzed were: 6 types of bottles of different existing models, as shown in Table 2. These were chosen by the students by placing the product used over the time (lifetime).

- In this phase was used in the software CES EduPack 2011 with the tool Eco Audit to the carry out Life Cycle Assessment, as depicted Figure 7.

Table 2: Information about bottles used in the Software. Source: Author.

Phases of the life cycle	**Bottle “A”**	**Bottle “B”**	**Bottle “C”**	**Bottle“D”**	**Bottle “E”**	**Bottle“F”**
Product						
Materials	- Aluminum Alloy - PP - EVA	- PP - Neoprene - Aluminum Alloy	- PP - PET - PE	- PEAD - PS - PELBD - PP	- PET - PP - Paper	- PET - PS - PEAD
Lifetime	8 years	5 years	2 years	0.5 years (6 months)	0.25 yr. (3 months)	0.08 year (1 month)
Mass (kg)	0.250	0.,260	0.062	0.045	0.034	0.031
Transport	Truck: 217km	Air freight: 10.140km Truck: 1200km.	Truck: 3474km	Truck: 1520km	Truck: 85km. Air freight: 10.600km. Rail freight: 185km	Truck: 419km. Air freight: 9.650km
Electricity (for cooling)	192 days per year, 2 hours per day.	324 days per year, 2 hours per day.	216 days per year, 2 hours per day.	200 days per year, 1 hour per day.	90 days per year, 2 hours per day.	30 days per year, 2 hours per day.

<u>Phase 3: Analysis of the Data:</u>

- Analysis with regard to energy costs in each of the phases.
- Analysis about the generation of CO_2 in each stage.
- Comparison of the different samples of each product.
- Comparative analysis of life cycle in relation to “bottle” more life estimates.
- Analysis by the students of the products analyzed and their life estimates depending upon on their use.

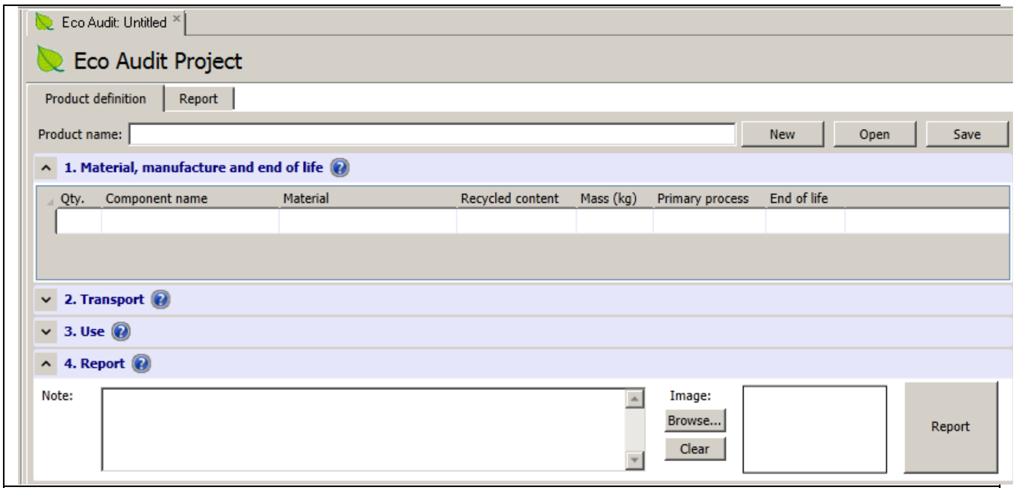

Figure 7: Home Eco Audit in the Software CES EduPack 2011 [11].

6. Results and Discussion

The work presented here was done at the University of UNISINOS, involving a comparative study of six types of bottles available in the market. At first the students perform the disassembly of products, in order to realize the practical difficulty of this process, and to identify the components and materials of an existing product.

The software used (CES EduPack 2011, tool Eco Audit) functions on the inputs like the energy consumption and CO_2 emissions caused by the choice of material and its manufacture, the means of transport and distance, as well as the consumption of energy in the use phase. In this product, the energy consumption with cooling was used. This life cycle data of energy costs and CO_2 generation is presented in Table 3..

It may be noted from the Table 3, that the bottles of “A” and “B” type involve a large amount of energy consumption and consequently CO_2. The bottle “A” having an estimated life of 8 years absorbs this environmental impact better than the bottle “B”, of 5 years. The consumption of energy in the use phase is high for the two bottles, “A” and “B”, due to the materials used and the weight involved with them. As for the benefits at the end of life bottle “A” provides good returns on these energy costs and CO_2 generation, since the bottle “A” consists of metal (aluminum alloy), which can be recycled and thus “recovers” the energy expended during the production. The bottle “B” also has a higher potential in late life, because the most of the materials present in this bottle can be recycled. But if bottle “B” is produced in another country, it must be reflected in energy consumption and CO_2 generation during transport of this product.

About bottle “C”, with an estimated short life of 2 years, has a lower energy and CO_2 generation, but has a value at the end of life small. The bottles “D”, “E” and “F” have a small mass in kg, which entails small energy consumption during the material phase and on the workmanship, also during the transport phase. But the bottle “E” that was produced in another country had a high value on shipping even being lightweight. The bottle “D” cannot recycle all elements of the body. While for bottle “E”, all components can be recycled, for bottle “F” none of the components can be recycled, and all the components eventually shall be put in landfill. These options of components that are used in the software whether they can be recycled or landfilled were students’ own choices, based on their commonsense about what they would do with these products at the end of their useful life.

Table 3: Comparison of Energy Consumption (MJ) and CO_2 generated (kg) for 6 bottles analyzed. Source: Author.

Energy Consumption (MJ) for One Product							
Bottles	**Material**	**Manufacture**	**Transport**	**Use**	**Disposal**	**Total (for first life)**	**End of life Value**
Bottle "A"	20.6	2.17	0.0461	0.0578	0.175	23	-14.7
Bottle "B"	25	5.3	21.7	0.0609	0.154	52.3	-17
Bottle "C"	5.51	1.23	0.183	0.0163	0.0434	6.98	-3.19
Bottle "D"	4.16	0.912	0.0319	1.67	0.028	6.8	-1.56
Bottle "E"	2.75	0.555	3	0.846	0.0238	7.17	-1.05
Bottle "F"	2.62	0.602	2.47	0.0591	0.00616	5.76	0
CO_2 Generated (kg) for One Product							
Bottles	**Material**	**Manufacture**	**Transport**	**Use**	**Disposal**	**Total (for first life)**	**End of life Value**
Bottle "A"	1.02	0.163	0.00328	0.00216	0.0123	1.2	-0.739
Bottle "B"	0.784	0.402	1.46	0.00228	0.0107	2.66	-0.552
Bottle "C"	0.155	0.0922	0.013	0.000608	0.00304	0.264	-0.0898
Bottle "D"	0.14	0.0684	0.00227	0.0626	0.00196	0.275	-0.0618
Bottle "E"	0.0867	0.0416	0.201	0.0317	0.00167	0.,363	-0.0357
Bottle "F"	0.0755	0.0451	0.166	0.000881	0.000431	0.288	0

6.1 Comparative Study of Bottles in relation to Bottle with the Highest Life Estimate

The second part of the study was to use the bottle of maximum life estimation, as a reference and to make an estimation of the number of product that would be required for use in eight years of the life of the first bottle. Shown in Tables 4 and 5, the number of bottles that would be required during the same lifetime and energy (MJ) and the generation of CO_2 for 8 years of useful life.

Table 4: Comparing the Number of products of Other Bottles over the same lifetime as that of Bottle "A". Source: Author.

	Bottle "A"	**Bottle "B"**	**Bottle "C"**	**Bottle "D"**	**Bottle "E"**	**Bottle "F"**
Useful lifetime	8 years	5 years	2 years	0.5 years (6 months)	0.25 years (3 months)	0.08 years (1 month)
Number of products	1	1.6	4	16	32	100

Table 5: Comparison of Energy Consumption (MJ) and CO_2 generated (kg) of Bottles with respect to the product with the highest estimated life. Source: Author.

Energy Consumption (MJ) for 1 Product								
Quant.	**Bottles**	**Material**	**Manufacture**	**Transport**	**Use**	**Disposal**	**Total**	**End of life Value**
1	**Bottle A***	20.6	2.17	0.0461	0.0578	0,175	23	-14,7
1.6	**Bottle B**	40	8.48	0.07376	0.09248	0.,28	36.8	-23.52
4	**Bottle C**	22.04	4.92	86.8	0.2436	0.616	209.2	-68
16	**Bottle D**	66.56	14.592	0.5104	26.72	0.448	108.8	-24.96
32	**Bottle E**	88	17.76	96	27.072	0.7616	229.44	-33.6
100	**Bottle F**	262	60.2	247	5.91	0.616	576	0
CO_2 generated (kg) for 1 product and the comparison with more products								
	Bottles	**Material**	**Manufacture**	**Transport**	**Use**	**Disposal**	**Total**	**End of life Value**
1	**Bottle A**	1.02	0.163	0.00328	0.00216	0.0123	1.2	-0.739
1.6	**Bottle B**	1.2544	0.6432	2.336	0.003648	0.01712	4.256	-0,8832
4	**Bottle C**	0,62	0,3688	0,052	0,002432	0,01216	1,056	-0.3592
16	**Bottle D**	2.24	1.0944	0.03632	1.0016	0.03136	4.4	-0.9888
32	**Bottle E**	2.7744	1.3312	6.432	1.0144	0.05344	11,61 6	-1.1424
100	**Bottle F**	7.55	4.51	16.6	0.0881	0.0431	28.8	0
* Reference for comparison.								

The inference obtained from the Life Cycle Assessment realizes that the bottle “F”, has the greatest environmental impact. This is because 100 bottles must be used in the 8 years time to meet the reference bottle performance. This becomes clearer from Figure 3, which shows a big difference between the bottle “F” and the others.

This case study highlights the importance of a product design based on factors like material selection, selecting materials with less energy consumption and CO_2 generation, or in relation to it being recycled, or being lighter and easier to dismantle and other such aspects.

Another point highlighted from Figure 3, is that the issue of sustainability is more problematic if one goes by the value at the end of life such as in case of bottle “F”, which is zero, in other words, it has no potential to recover all the energy spent on it. Comparing the product with the longest estimated life of bottles analyzed, it is possible to have a real dimension comparing their useful life. So considering these analyzes the bottle “A”, even with materials that require more energy to produce and to manufacture, proves to be a good choice over its life and because of its expected life is high, and this improves its performance in relation to sustainability

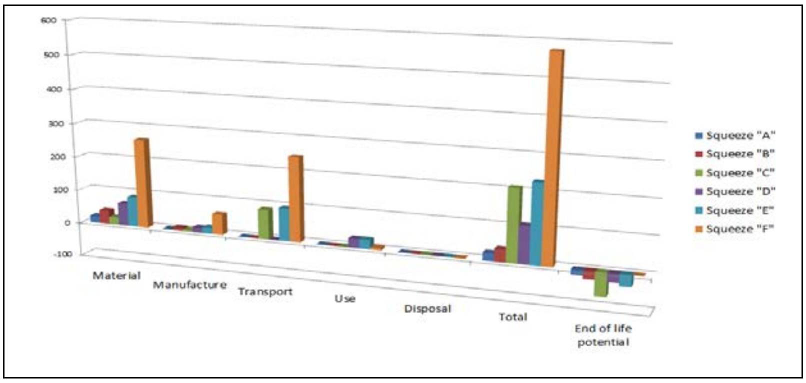

Figure 3: Comparison chart of the 3 products analyzed in relation to energy consumption (MJ). Source: Author.

6.2 Results of Analysis by Students

From this type of study by the students, it is possible to appreciate the role that these future designers may have to play in relation to sustainability. This also shows how designers can reflect on the values and lifestyle that are stimulating the aspirations and desires that are driving the consumer to, in a more comprehensive, inclusive and creative rethinking to create new concepts and products.

The salient conclusions of the study made by the students can be summarized as follows

- In relation to materials, and studying the amount of these, various compositions, which are aggregated to produce the simple day-to day objects helped them rethink and reassess the concepts used in design.
- Allowed them to question the amount of materials that could be better spent, with respect to time and use.
- It underlined the large consumption of the same product, generating more unnecessary disposal of materials.
- The students also understood the importance of the durability of a product, to improve sustainability.
- They observed that simple ideas can help towards preservation of the environment by showing the importance of conscious consumption.
- Also stressed on the importance of awareness of people and changing their habits.
- All these factors helped them rethink and reevaluate the products.
- Through this the students were able to understand some aspects regarding the analysis of the life cycle of a product, and use of LCA in the design phase to reduce the environmental impact.

7. Conclusions

The concern and responsibility towards the environmental appears to be a new challenge for designers in 21st Century. While nature's resources become scarce progressively and the environmental pollution increases, recycling, waste disposal and sustainable projects must be resorted to more seriously. Agreeing with this, it is proposed that a designer should be aware of changes and continuously look for new solutions, particularly in relation to aspects related to environmental issues.

Faced with these challenges in relation to sustainability, product design activity has can make use of the Life Cycle Assessment (LCA) which allows the use of materials with lower environmental impact and contributes to sustainable development while applying new concepts to a product design and development.

Through exercises in design for sustainability analyses show up different designs for the same type of product, depending on the choice of materials and processes used. In the present paper we used Life Cycle Assessment in a product of low technological complexity, namely, the bottle. Through this exercise students learnt to analyze the products of different materials and assess the influence they have on the environmental impact. Students were able to understand the issue of sustainability, and analyze the entire life cycle of product. Students become conscious of the issue of correct selection of materials in the design phase, which affect all stages of the life cycle of these products.

The study also demonstrates that the development of sustainable products is possible. All that is needed is the initiative and commitment, from business houses, technical managers and the society. Using design tools for sustainability from the earliest stages of design ensures the ultimate realization of environmentally friendly products.

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