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ECOLOGICAL DESIGN OF SYSTEMS

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Abstract: "Ecology is the science of the struggle for existence," says Greg Cooper in his paper titled "The Science of the Struggle for Existence." Indeed, the 21st century will be the century of the "science of the struggle for existence." The paper presents some exhortations to engineers, who must find solutions "before nature dies." Eco–friendly product design is one of the solutions to this global problem. Several basic concepts of eco–design, several eco–design strategies, traditional design strategies versus eco–design, are presented in this paper.

Keywords: ecology, eco–design, eco–product, conceptualization

INTRODUCTION

Engineers need to find solutions to the challenges of the millennium *"*before nature dies". The environment is an essential part of any development process and encompasses the links and interdependencies that exist between human beings and natural resources. As a result, the changes that the environment goes through are generated not only by natural events, but also by the practical manifestation of development patterns, practices and lifestyles. What is certain is that man has often erred in relation to nature, through the excesses made, and nature sometimes takes revenge. The great J.W. Goethe rightly said: *"Nature is always true, serious and severe. It is always right, and the errors are always those of man. "*

The effects of environmental pollution, manifested by the emergence of serious health problems and the disturbance of the ecological balance, were recognized internationally at the Stockholm Conference of 1972, held under the slogan "Only One Earth". The main document of this conference was the Final Declaration on the Environment, which highlighted the inseparable link between the quality of life and the quality of the environment, proclaiming the duty of every human being to protect and improve the environment: *"*The world's natural resources, including air, water, land, flora and fauna and, in particular, representative samples of natural ecosystems, must be protected in the interests of present and future generations through careful planning or management, as required." In 1986**,** the United Nations established the World Commission on Environment and Development, aiming to study the dynamics of environmental degradation and provide solutions for the long–term viability of human society. The document addressing the human right to a healthy environment was the *Report of the World Commission on Environment and Development* titled *"Our Common Future",* also known as the *"Brundtland Report"*: "Sustainable development is development that seeks to meet the needs of the present without compromising the ability of future generations to meet their own needs." *(Dulgheru, 2020).*

As a matter of fact, "ecology is the science of the struggle for existence" (G. Cooper). Ecology, defined over 100 years ago as the science that deals with the study of the interdependencies between living organisms and, especially, their interdependencies with the environment, has developed strongly in the last 15 years. It is carried out mainly through research in academic environments and specialized institutes, resulting in a large number of sophisticated ecological models and methodologies, evaluation techniques, rules and design guides, etc. It should be noted that environmental issues differ from one geographical area to another, sometimes even from one country to another, which is why no ecological model, methodology or tool has yet been imposed worldwide as being applicable to any type of product or process.

Therefore, speaking from an engineer's perspective, a problem has arisen. The environment in which we live faces many problems: global warming, water pollution, acid rain, gas emissions, which cause smog, transmissions of toxic substances, radiation. Which is the solution? How can all these harmful effects that affect the sustainable quality of life be dealt with? The solution to the problem is the ecological design of the products or the Ecodesign.

Eco–design has emerged as a growing need to protect nature. One of the first forms of eco–design was product recycling. As early as the beginning of the twentieth century, artists used collages from newspapers, packaging and other unused materials to make their works of art. Renowned artists such as Pablo Picasso and Georges Braque are among the pioneers of this initiative. There has also been a great demand in Western European countries to decorate their homes in the most "*green*" style possible. For this purpose, a series of products made of recyclable materials have been designed, which have a natural appearance.

So, eco–design can be implemented in various fields, whether it's art, building or arranging a house or designing industrial products. Eco–design is a growing responsibility of the designer to understand the ecological footprint of the planet. In connection with such global problems as overcrowding and environmental pollution, it is strictly necessary for designers, for engineers, to find environmentally friendly solutions that lead to a reduction in

the consumption of materials and energy, and that the materials used are as recyclable as possible.

The range of green industrial products is very wide. It ranges from durable goods such as televisions, refrigerators, home appliances, automobiles, computers, mobile phones, to building materials and subassemblies, transportation, and industrial equipment. With the explosive development, especially in the last 30 years, of material products and, therefore, of manufacturing industries, there have been serious negative effects on the environment with major, sometimes catastrophic, implications. In connection with this, a series of measures have been taken, through which "pressure" is exerted on the economic and industrial environment in several ways: environmental taxes, directives and laws for producer responsibility, vouchers for pollution prevention initiatives. Several international (WCED – World Commission on Environment and Development attached to the UN, EMAS – European Eco–Audit and Management Scheme) and national organizations specialized in environmental issues (SETAC – Society of Environmental Toxicology and Chemistry, USA; ICME – International Council on Metals and the Environment, Canada; UBA – German Federal Environmental Agency) have been set up to implement these measures. Thanks to a well–balanced environmental policy, implemented over about 20 years, Germany, a major energy consumer, now covers more than 40% of its consumption with "green" energy.

In 2005, the EU adopted the Ecodesign Directive, which set out a framework on mandatory environmental requirements for energy–related products sold in its 28 Member States. Representatives of European manufacturers in the industry, such as Bosch, Siemens, Haushaltsgeraete and Philips, were involved in the consultations and welcomed the new rules. The directive covers more than 40 product groups, which are responsible for 40% of all greenhouse gas emissions. A further revision took place in 2009 (2009/125 / EC), which extended the scope to other energy–related products, such as windows, insulation materials and certain water–consuming products. The purpose of the Ecodesign Directive is for manufacturers of energy–using products to use, in the design stage, materials that reduce both energy consumption and adverse effects on the environment. The policy, known as eco–design, is in line with the EU's goal of reducing fossil fuel imports and greenhouse gas emissions *(*** https://www.green–report.ro/...)*.

WHAT IS ECOLOGICAL DESIGN?

The environment is seriously affected by existing products on the market, which produce a number of negative environmental effects such as: depletion of raw materials, energy consumption, water consumption, the effect of global warming, ozone depletion, photochemical fog, air acidification, air toxicity, water eutrophication, water toxicity, noise or radiation. What about artificial plastic islands (human products!) formed in the Planetary Ocean?!

Eco–design is a broad topic, but the basic idea is to reduce the negative impact on the environment throughout the entire product life cycle through improved product design. Ecodesign means "reducing the impact on the environment throughout the life cycle of a product through better product design" *(*** https://biblioteca.regielive.ro/ …)*.

Directive 2009/125 / EC – Ecodesign states that "eco–design is the integration of environmental characteristics into the design of a product in order to improve the environmental performance throughout the life cycle".

Ecological design can also mean a configuration of products and services from both environmental and cost perspectives. Eco–designed products must meet certain criteria, such as: recyclability, low material and energy consumption, durability, avoidance of toxic materials, optimal customer benefits, use of regional resources *(Lasliu et al., 2019)*. In ecological design, the whole evolution of the product – from manufacturing to disposal – is kept under observation, the most profitable and most environmentally friendly solutions being developed.

The eco–designer assesses the impact of a product or process on the environment throughout its life cycle. He / she takes part in the technological choice of components and materials, so that maintenance and recycling are easier. The main missions of the eco–designer are the research of technical solutions and their industrial development. The basic idea in eco–design is to reduce the impact on the environment throughout the product life cycle through improved product design, while achieving similar performance and features. The life cycle of the eco–product is as follows: purchase of raw materials, manufacture of a component part, assembly of the product, distribution and sale, use of the product, repair and reuse, disposal, recycling of materials, and final disposal *(Lasliu et al., 2019)*.

All products have a certain impact on the environment throughout the life cycle, namely through the use of raw materials and natural resources for manufacturing, packaging, transportation, storage and recycling. The designer's problem is to minimize this impact. In general, about 80% of the environmental impact of the product can be determined during the design phase. Ecological design involves taking into account the environmental impacts of the product, right from the first design stage. In terms of lifecycle costs, the situation is pretty much the same. In these conditions, it is crucial to take into account the economic and environmental aspects in the very design phase of the product.

Directive 2009/125 / EC – Ecodesign sets out some generic requirements, which do not set limit values, but may impose:

- designing an "energy efficient" or "recyclable" product;
- providing information on how to use and maintain the product in such a way as to minimize its impact on the environment;

≡ performing a product life cycle analysis to identify alternative design options and solutions for possible improvement.

The general principles of European environmental policy are *(Fernández Fernández, 2018)*:

≡ Precautionary principle: If there is clear evidence of a new environmental problem, without full scientific confirmation, precaution measures will be taken;
≡ Prevention principle: Try to avoid any form of pollution or damage to the environment, instead of remedying the effects it produces when the damage cannot be avoided;
≡ Rectification of the principle of pollution at source: Immediate implementation of the resolution in due time to neutralize as much as possible the effects of the attacks produced and to prevent their progress;
≡ 'Polluter pays' principle: aiming at elaborating the regulation which establishes the responsibilities before the actions, the identification of the offender to whom the damage caused to the environment can be attributed and the damages to be repaired.

The introduction of new minimum requirements may result in a ban on the marketing of all non–compliant products in EU countries. For example, incandescent bulbs have been phased out since 2009.

Basic eco–design requirements:

≡ are adopted according to the product;
≡ set minimum standards for product performance to reduce environmental impact;
≡ must be met by all products marketed in the EU;
≡ are based on the environmental impact throughout the life cycle of the product (design, production, distribution and recycling).

The scope of the Ecodesign Directive was extended in 2009 to all products with an energy impact (the use of which has an impact on energy consumption), including:

≡ Energy consuming products (ECPs), which use, generate, transfer or measure energy (electricity, gas, fossil fuel), including consumer goods – such as boilers, computers, televisions, washing machines, light bulbs – and industrial products – such as transformers, industrial fans, industrial ovens, etc.;
≡ Energy labels show where an appliance is located on a scale from A to G, depending on energy consumption. Class A is the most energy efficient and class G is the least efficient (Figure 1);
≡ Energy labels offer consumers the opportunity to save money by choosing products that consume less energy;
≡ Other products with energy impact (ERP), which do not use energy but have an impact (directly or indirectly) on energy consumption and can therefore contribute to energy savings, such as: windows, thermal insulation materials, sanitary ware, taps, etc. Directive 2009/125 / EC – Ecodesign on ecological design does not provide mandatory product requirements, product requirements are set out in European Commission Regulations.

Figure 1 – Energy label of a home appliance

Thus, the implementation of Directive 2009/125 / EC – Ecodesign consists in establishing a framework for establishing the eco–design requirements applicable to energy–related products. In this way, the Directive aims to reduce the environmental impact of the product life cycle (from raw material procurement, production, assembly, distribution, retail, use, transport and recycling) by designing it better.

EcoDesign means better products, but better and more effective tools are needed to design better products. There are several types of tools, from guides and checklists to selection indicators and life cycle assessment, including methodologies, process simulation software and databases of materials and processes. The pressure exerted by the governments of the economically developed states in the post–1990 period through legislation to implement the requirements of sustainable development in industry, the attitude of citizens towards the purchase of environmentally friendly goods, and the prospect of depleting essential resources for production and consumption are the main factors that have accelerated the transition from non–organic industrial products to organic industrial products.

Based on an analysis of several guidelines found in some company guides and in various textbooks, the professor Luttropp et al., 2006, at KTH, Stockholm, formulated 10 golden rules, which are very generic and need to be transformed and customized to be really used in product development. The rules are not listed in any order of preference:

1. Do not use toxic substances and utilize closed loops for necessary but toxic ones;
2. Minimize energy and resource consumption in the production phase and transport through improved housekeeping;
3. Minimize energy and resource consumption in the usage phase, especially for products with the most significant aspects in the usage phase;
4. Promote repair and upgrading, especially for system–dependent products;
5. Promote long life, especially for products with significant environmental aspects outside of the usage phase;
6. Use structural features and high quality materials to minimize weight. Nevertheless, these shall not interfere

with necessary flexibility, impact strength or other functional priorities;
7. Invest in better materials, surface treatments or structural arrangements to protect products from dirt, corrosion and wear;
8. Prearrange upgrading, repair and recycling through access ability, labelling, modules;
9. Promote upgrading, repair and recycling by using few, simple, recycled, not blended materials and no alloys;
10. Use as few joining elements as possible and use screws, adhesives, welding, snap fits, geometric locking, etc. according to the life cycle scenario.

BASIC CONCEPTS OF ECOLOGICAL DESIGN

The number of consumers who show greater responsibility for sustainable consumption of products and resources is growing day by day. Consequently, this type of consumer aims to support environmental sustainability by requiring companies, especially manufacturing companies, to demonstrate respect and commitment to the environment and natural resources, consolidating the entire product life cycle with actions that demonstrate such a commitment. Regarding these types of activities, the most remarkable action is the ecological design, which has become the main methodology, which can be used by companies to make their products more sustainable and environmentally friendly. We can define eco–design as a "systematic incorporation of environmental aspects into product design in order to reduce its impact on the environment throughout its life cycle". For any manufacturing industry, eco–design supports the need to incorporate environmental and sustainability criteria into the basic requirements of product design, such as cost, function, utility, aesthetics, reliability, safety, and so on. These environmental criteria range from the fight to minimize all consumption and the reduction of emissions and pollutants throughout the life of the product, not only during the manufacturing process, but until the end of its useful life.

Environmental psychology, behavioural psychology, consumerism, business, environmental policy, and additional research in the social sciences were used to define cognitive concepts that led to the purchase and use of environmentally friendly products. The basic concepts and explanations of eco–design are *(MacDonald et al., 2015)*:

- responsibility, a sense of personal control over actions and results;
- complex decision–making skills, mental tools, which structure complex decisions;
- decision heuristics, mental shortcuts, which simplify decisions;
- the link between altruism and sacrifice, an assumption that doing good requires personal sacrifice;
- trust, the degree to which a person believes the information given to him / her;
- cognitive dissonance / guilt, mental processes, which can occur when a mismatch between intention and action is identified;
- motivation, intrinsic and extrinsic satisfaction, which determines the designer's behaviour.

Eco–design is focused on monitoring the product life cycle. All the stages that the product goes through, from the purchase of raw materials, which will be part of it or its generation from natural resources, to the moment of its final disposal. Consequently, this cycle covers the forms of raw materials until final disposal, through the intermediate stages of manufacturing, packaging *(Monteiro et al., 2019)*, logistics and distribution, sale, maintenance and even reuse. Companies that decide to include eco–design in their product development as part of their business strategy not only demonstrate environmental sensitivity, but increase their competitiveness by having better products, better projects, better manufacturing with a clear distinguishing factor. In other words, at the beginning of the third millennium, deeply affected by the global problems facing humanity, organic products are selling better. Companies that promote the ecological development within sustainable development must demonstrate that an appropriate balance has been achieved between economic, ecological and social growth, which contributes to sustainability *(QuellaDr., 2013)*:

- At the economic level: demonstrating the rational use of resources, in particular in the key stages of the value chain (supply, manufacturing, transportation and waste management).
- At the environmental level: demonstrating that the type and origin of the raw materials, the energy consumed for their manufacture, the pollution caused and all aspects that could affect the environment have been deeply considered.
- At the social level: demonstrating that the company maintains and consolidates its corporate social responsibility, being part of an elite of companies, which demonstrates that it ensures the well–being of the affected workers and work groups (partners, employees, etc.).

Therefore, eco–design takes off as an essential tool for achieving the desired sustainable development (Figure 2). From a "key business factor" perspective, design is an increasingly important factor in the competitiveness of companies.

The current competition, globalization and high customer knowledge have transformed the association, which requires not only a well–balanced quality cost, but also a demonstrable respect for the environment. This is why companies need to consider the environment, operationally and especially strategically, as a key factor. Therefore, the first step of eco–design is to integrate the environmental factor into the design and manufacturing of the product, to clearly try to prevent any potential contamination associated with a

product through all the stages it goes through (design, manufacture, use and disposal). However, it should be clear that eco–design not only aims to ensure that the product is environmentally friendly, but also to implement a global environmental concept, which determines the maximum involvement of the company by integrating an identification–based methodology, control and continuous improvement of all environmental aspects of manufactured products.

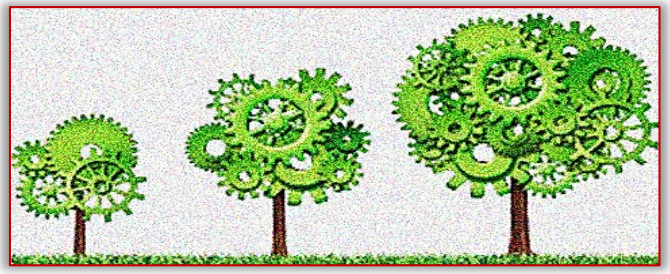

Figure 2 – Evolution of sustainable ecological design

ECOLOGICAL DESIGN STRATEGIES

Ecological design highlights a number of strategies, the main objective of which is to help prevent, reduce and / or minimize the impact of the product on the environment, associated with its life cycle. These strategies highlight a number of considerations that must be applied during the development of a new product.

The products are very different in terms of design, creation process and purpose of use. The nature of the product is assessed when the applicable strategies are to be selected. It is important to keep in mind that due to the close relationship between different strategies and life cycle stages, when implementing strategies, the impact of one stage must be taken into account and not transferred to another stage.

Figure 3 – Eco–design strategy wheel in the product life cycle

The development of new products will have a considerable impact on the environment. An eco–design strategy can be pursued to minimize this impact *(Fernández Fernández, 2018; Anghel et al., 2018)*. The eco–design strategy wheel (Figure 3) shows the strategies that can be followed. Thus, the implementation methodology can be structured on four different levels:

- conceptualization (includes strategies 0 – 2);
- manufacturing (includes strategies 3 – 4);
- application (includes strategies 5 – 6);
- end of life (includes strategy 7).

TRADITIONAL DESIGN VERSUS ECOLOGICAL DESIGN

Eco–design is like a design philosophy, which supports the need to include environmental criteria in the basic requirements of a product, such as cost, utility, aesthetics, reliability, safety, etc. Obviously, environmental requirements support the optimization of consumption, emissions and any possible contamination during the life cycle of the product. Eco–design does not refer to a substantial change in the traditional stages of the product design and development process, but to providing a new perspective, considering sustainability issues as part of the essential requirements. The difference between the traditional design process and the ecological design are presented in Figure 4. The environmental criteria indicated in the eco–design at each stage are added to the traditional design and development.

— The legal framework of ecological design

The European Union began to develop regulations and legislation in the field of green product design as early as the 1990s. Eco–design is of vital importance in European environmental policies, as demonstrated by the European 'Sustainable Development' Strategy of 2009, which established Sustainable Consumption and Production as one of the priority areas for action.

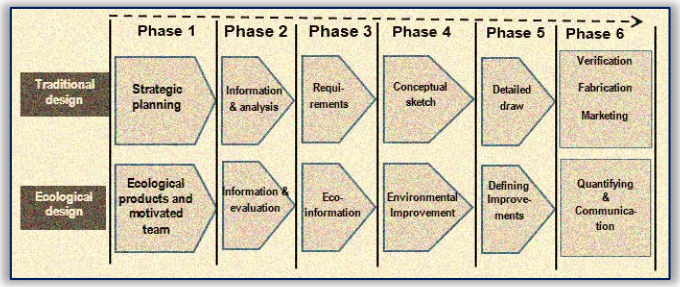

Figure 4 – The difference between the traditional design process and ecological design

For the quantitative assessment of the environmental impact levels, eco–indicators are defined and implemented by going through the following phases:

- inventory, which involves compiling a list of relevant inputs and outputs to identify factors that contribute to an ecological problem;
- characterization, which is the process of quantifying the description of the contributions;
- quantification, which involves the quantitative assessment of the characterizations relative to each other.

Eco–indicators are methods that are used to calculate the environmental impact, usually assessable in the form of an associated global score, of materials and processes. There is a possibility of errors on each phase. Studies and analyses are currently being carried out on eco–indicators based on life–

cycle methods in order to identify the sources of error as well as to assess the validity and scientific objectivity. An illustrative methodology is wheel graphics, which allow users (designers, manufacturers, managers) to identify priorities for green development. Figure 5 shows the cost diagram of the industrial product: total production costs (TPC), life cycle costs (LCC) and social cost accounting (SCA), highlighting the environmental costs of the product life cycle.

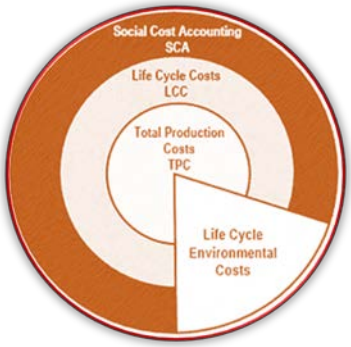

Figure 5 – Industrial product cost diagram

— Eco–design aspects in engineering: the stages of the ecological product design process

Product and process designers must ensure that they excel in all aspects, which lead to meeting customer demands by ensuring functional performance, cost–effectiveness, reliability and, equally, environmental impact.

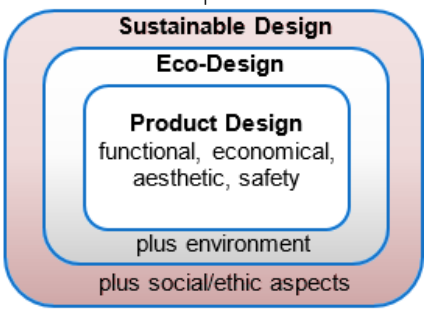

Figure 6 – Sustainable design of an industrial product

The purpose of ecological design in the context of sustainable design (Figure 6) is to minimize the impact (negative effects, harms) of products and processes on the environment throughout the life cycle, while maximizing the benefit, performance and quality. Sustainable design requires consideration of social and ethical implications in addition to functional economic and environmental issues.

With the growing importance of environmental issues, specific information systems, models, methodologies and tools have been developed to make products and processes better for reducing environmental impacts (increasing environmental performance), which can be varied levels of quantification. In the last period of time, intense efforts are being made to introduce in the study programs at all levels notions and even advanced elements of industrial ecology, ecological design, sustainable design, etc. On the other hand, the future development of integrated EcoCAD / CAE / CAM tools will lead to high performance in the long–term optimization of the planetary existential complex.

Acknowledgement

European funding has been granted, under Competitiveness Operational Programme POC 2014–2020, call POC–A1–A.1.1.3–H–2016, financial agreement no. 253/02.06.2020, signed between INOE 2000 and the Ministry of Education and Research for the project titled "Horizon 2020 Support Centre for European Project Management and European promotion PREPARE", MYSMIS2014 code 107874.

Note: This paper was presented at ISB–INMA TEH' 2021 – International Symposium, organized by University "POLITEHNICA" of Bucuresti, Faculty of Biotechnical Systems Engineering, National Institute for Research–Development of Machines and Installations designed for Agriculture and Food Industry (INMA Bucuresti), National Research & Development Institute for Food Bioresources (IBA Bucuresti), University of Agronomic Sciences and Veterinary Medicine of Bucuresti (UASVMB), Research–Development Institute for Plant Protection – (ICDPP Bucuresti), Research and Development Institute for Processing and Marketing of the Horticultural Products (HORTING), Hydraulics and Pneumatics Research Institute (INOE 2000 IHP) and Romanian Agricultural Mechanical Engineers Society (SIMAR), in Bucuresti, ROMANIA, in 29 October, 2021.

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ISSN: 2067–3809