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Engineering of Mechanical Manufacturing from the Cradle to Cradle

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Abstract. The sustainability of manufacturing processes lies in industrial planning and productive activity. Industrial plants are characterized by the management of resource (inputs and outputs), processing and conversion processes, which usually are organized in a linear system. Good planning will optimize the manufacturing and promoting the quality of the industrial system. Cradle to Cradle is a new paradigm for engineering and sustainable manufacturing that integrates projects (industrial parks, manufacturing plants, systems and products) in a framework consistent with the environment, adapted to the society and technology and economically viable. To carry it out, we implement this paradigm in the MGE2 (Genomic Model of Eco-innovation and Eco-design), as a methodology for designing and developing products and manufacturing systems with an approach from the cradle to cradle.

Keywords: Sustainability, Eco-process, Eco-efficiency, Cradle to Cradle, Life Cycle Analysis.
PACS: 88.05.Lg, 89.20.Kk, 88.05.Hj, 88.05.Np

MECHANICAL MANUFACTURING AND SUSTAINABILITY

Since the Industrial Revolution, industry and its installations have satisfied the growing social demand for products and industrial systems. At the same time has brought about high environmental impact, characterized by the cost of energy and material resources (needed to cover the inputs and outputs required in production chains). This situation over the last decades has triggered off research and development of new objectives, which can turn the industry in sustainable. Commit to social, economic and environmental responsibility entails bringing a set of limits, criteria and specifications that can help to prevent impacts, control pollution and promote sustainable consumption; with them the production and future demand will be guaranteed. The new approach shown in Figure 1 is necessary. This implies a rethinking of all industrial practices (activities, processes, services required, creation and management of infrastructure). Specifically, these new perspectives [1] in the scope of mechanical engineering are based on the main challenges of design, planning and production management, which allows the satisfaction of the demand and provide solutions that help improve and optimize the use of resources (energy and material inputs). Increase productivity (in eco-efficiency), reduce costs and maximize performance are the main principles. This task is complex because it involves the coordination and organization of all stakeholders, maximizes the dynamism of

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personnel, machines, equipment and operations. Currently the deployment of sustainability [2] is achieving satisfactory results thanks to the I+D activities, which are related to industrial ecology (Figure 1). The strategy for tackling these objectives is complex because there is no one method that suits all types of manufacturing for current industries. MGE2 integrates products and industrial systems under the ISO standard (14000 series), Ecodesign, EMAS, eco-labeling ISO and C2C certification and it is supported by concurrent engineering environments and PLM (Product Life Management). Thanks to constant review with a Life Cycle Assessment - LCA, this model allows to carry out quality solutions which respect the environment.

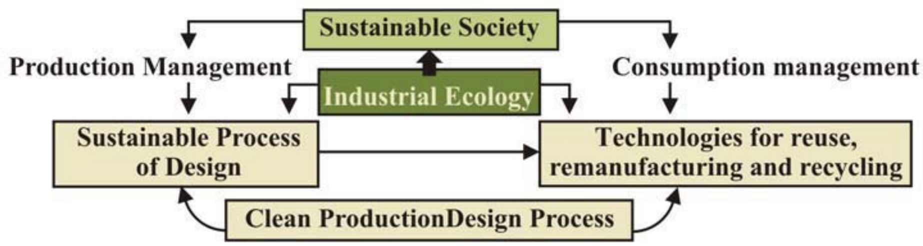

FIGURE 1. Design process and sustainable production Management and Planning [2]

THE NEW PARADIGM CRADLE TO CRADLE – C2C

The three areas of sustainability [3] include the economy, equity and ecology. If these are applied individually in the process, they fix the criteria and objectives only partially, leading to unsustainable solutions. C2C is a revolutionary approach that links these three dimensions (3E) located in a fractal triangle, where they can interact dynamically, reaching solutions with triple bottom line, fulfilling the current needs of society and environment, allowing technical and economic viability, and ensuring the survival of the planet and future generations. C2C starts in 2002 [4], when William McDonough and Michael Braungart published the book Cradle to Cradle: Remarking the Way we Make Things. It was defined by the authors as the new industrial revolution. From all stages of design process and development of product, it poses activities based on the search of value, to link the end of life of products with the extraction of raw materials; its character is bioinspired and it shares the principles of natural systems, which are set in the nine following statement:

P1: Proactive approach. Works from the root of the problem before generating impacts.

P2. Systemic and integrated design metabolism of product. This principle adapts metabolic pathways in closed cycles, transforming wastes of one to resource for others (waste = food).

P3. Fractalization sustainability. The 3E strategy provides sustainable solutions compatible with the environment (eco-friendly), adapted to society, technically and economically viable.

P4. Bio-inspired Eco-innovation (Biomimicry) [5]. This principle transforms the solutions of nature in successful innovations, for the manufacture of products and industrial systems.

P5: The product as a living being, and its associate system (SAP) as an ecosystem. The flows of nutrients (technical and biological) will be closed cycles without losses or damage to the environment.

P6. Eco-intelligence. It is necessary to design products or systems for the whole of life cycle (LC), they are eco-friendly and beneficial to the environment and the agents involved.

P7. Respect and promote nature and technical diversity. The manufacture, use and disposal of products shouldn't affect adversely the environment.

P8: Eco-effectiveness against eco-efficiency. We must act "correctly", maximizing the positive effects, against doing things "right" by minimizing the negative effects.

P9. Use of renewable energies. This principle eliminates the exploitation of resources that provide fossil fuels, devastated regions, ecosystems and species.

Of these nine principles, it is necessary to achieve the correct combination of eco-intelligence, biomimicry [5], use of cycle metabolism and renewable energy. New sustainable solutions could be raised from the development of ecological intelligence; they are carried out through processes and activities whose interactions with the environment and stakeholders, and are compatible with the planet. This is achieved if decisions are made according to the metaphor "product-living being", creating resemblance between industrial and natural flows (with closed systems of materials and open in energy, which are shown in Figure 2). For this purpose the following closed material flows are designed: biological (associated with the natursphere) and technical (related to the technosphere).

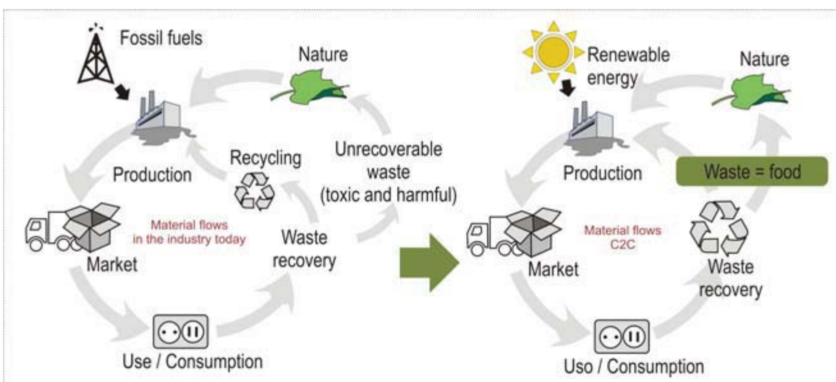

FIGURE 2. Industrial development to the C2C system.

Thanks to the *biological metabolism*, the materials flow continuously through a cycle where nature can degradete it totally; these are the nutrients of natursphere, where there aren't no toxic substances xenobiotics or harmful to the environment. Technical metabolisms of technosphere are responsible of extraction, processing, production and recovery of technical nutrients. In this flow are supra-recycled nutrients, which do not lose quality (for example glass) and are recoverable in full. And the under-recycled, which lose value when subjected to one or more recycling processes (xenobiotic substance). For maintenance of these closed metabolisms is necessary a continuous supply of energy, which, by analogy to natural processes carried out by nature, must be provided through renewable resources (respecting biodiversity).

MECHANICAL MANUFACTURING ENGINEERING

Mechanical manufacturing engineering is the field of engineering responsible of the processes, production methods and product development and industrial systems. It is a wide discipline made up of several independent specialties, whose activities are based on the study, research, processing and handling of resources (material and energy), to find solutions that respond to complex problems demanded by society. It includes various fields of knowledge, which recently have incorporated sustainability, embracing new methodologies, techniques, standards and regulations for the care of the planet.

Sustainable Mechanical Manufacturing Engineering

At the beginning of XIX century, the Industrial Revolution and the growing societal needs for products that made it easier every day, made the research fields related to engineering, become fields of study complex, linked to the invention machines that must support high stress and operate with other types of energy (including fossil resources). This situation entailed major advances and huge environmental problems. The design and development of these new tools come out a specialized field of mechanical, based on the study of statics, dynamics, thermodynamics, heat transfer and fluid mechanics. Currently this industry sector applies advanced and specific technologies with which are dealed with the mechanical manufacturing processes. And thanks to the development of sustainable conscience, also organizes its objectives under issues that protect the environment [6], in areas such as process efficiency, minimization and resource management, waste control and pollution prevention. They are, for example, the implementation of ISO 14000, statistical process control (SPC), studies with LCA, assessment of air quality, environmental audits, energy efficiency and control of atmospheric emissions. These situations have determined the purpose of developing a new model under the C2C paradigm, with the aim of designing bio-inspired products and manufacturing systems. The result of this target is the research carried out in the University of Seville [7], which has allowed to develop the MGE2.

GENOMIC MODEL OF ECO-INNOVATION AND ECO-DESIGN

On the original C2C paradigm, MGE2 is created as a framework for designing bio-inspired products and industrial systems. It consists of the basic techniques of eco-design, which are oriented to eco-effectiveness and are support with biomimetic design strategies [5] within the areas of eco-industry and industrial ecology. The MGE2 is based on the standards of environmental management, is backed by the LCA. It introduces in industrial systems basic criteria required to be included in the current eco-labeling programs [8]. Its application gives the product similar characteristics to natural beings under [9]:

Static dimension (self-compatible product), which makes reincarnated at the end of your CV, thanks to its autopoietic character (self-regenerable), environmentally friendly (assimilated and carrying capacity for the receiving environment), metabolizable (whose substance flows and materials are closed cycles) and systemic (considering the projective scenarios and their interactions with their SAP).

Dynamic dimension, which determines the variations in different generations of products; it gives an evolutionary character (resilience and robustness). It consists for two groups of processes: natural selection (environmental pressure) is responsible for defining the factor of "learning", assistance by the interaction of the internal characteristics of the product with the environment, and recombination and mutations that simulate the processes random of genetic transmission between generations of products.

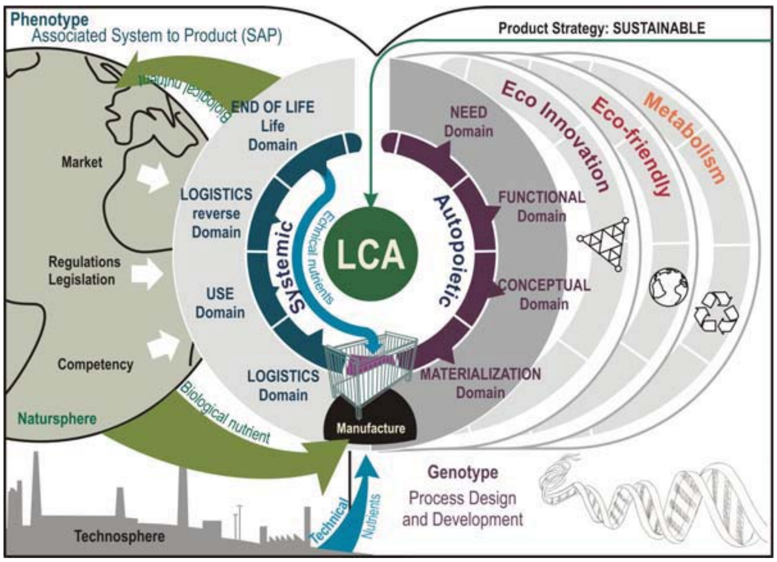

FIGURE 3. Basic tools and techniques MGE2

To get all these features incorporated in the design process, the steps should interact throughout the LCA. For this, the model has been divided into phenotype and genotype. These are terms selected to describe the analogy between "natural entity" and "product". Thus, the design and development becomes the process of establishing the genotype (definition of "genes" or internal characteristics) and the phenotype in interaction with product's SAP (market, regulatory, competitors, logistics, use and ELC), which express the gene of product.

Genomic Model for Mechanical Manufacturing Sustainable Engineering

The MGE2 is compatible with any industrial sector and adaptable to the objectives and strategies proposed in projects. For each one [10], provide a workspace with four key stages:

1. Complete analysis of SAP (market, company, competitors, regulatory) and definition of design criteria applicable to industrial systems and manufacturing processes, evaluated with LCA of the product and its related system [11].

2. Defining the 3E strategy under C2C, to generate the set of values 3E. in C2C, which will allow integration of autopoietic, systemic and eco-friendly carácter. At this stage, the set of values are generated 3E [4]. then The strategy isparameterized in techniques and tools provided by the MGE2. A good strategy of cost, quality and positive impact is crucial for the industry and product.

3. *Design and development of product and specification of their SAP*. Aspects of the eco-industry and clean production are integrated at this stage. It is based on the series of standards ISO14000, EMAS, ISO 9001 and Environmental Management System, technologies related to the design of sustainable systems and quality processes. It is subdivided into an first phase of genomic design. It is subdivided into an first phase of genomic design genomeñlkñlk, where environmental standards are met and which are incorporatedsuccessfully autopoietic, systemic and eco-friendly character of MGE2. In the second phase the tools for sustainable production are used to design products and systems whose processes having a character metabolizable (environmental footprint assimilated by the medium), through the design of material and substance flows (AFM - AFS) [11]. C2C cyclical metabolisms are designed too: thanks to this, the solution becomes consistent with its associated system, creating open cycles of material and closed in energy (avoiding the use of toxic substances and reducing under-recycled nutrients or xenobiotic substances).

4. *Evaluation, validation and global optimization of the product and its SAP*, from a new LCA. With these data, the Environmental Statement will be drafted, which will introduce the product in any of the current eco-labeling programs (series ISO 14020 and C2C certification). [12]

Case Study: MGE2 for the design and development of an office chair

The MGE2 is designed to be applied to all projects with a sustainable perspective. This case study, an office chair is designed [7]. As an example we emphasize the manufacturing stage and how the processes involved influence the all LC.

A. Stages 1 and 2 are done, with which we define the performance of the product (its SAP) due to LCA, 3E strategy and improvements to be implemented in a new product.

FIGURE 4. Product material flows

B. We must carry out product design under the principles of C2C. To do this, we start with the genomic design: we detailed study of each domain and in areas of eco-innovation, eco-compatibility and metabolism process, applying several tools needed to define all the requirements that will transform the product will be sustainable.

C. We proceed to verify and validate product interactions with the environment. Metabolic routes are defined by setting the associated processes from disassembly diagram, which defines the product flows (Figure 4): the inputs (raw materials) and outputs (waste) of all processes involved in the manufacture.The strategies that transform the conventional production processes to sustainable activities, are based on the application of techniques and solutions which promote the use of clean energies, allow to decrease the number of processes and have as main objectives the management and reduction of waste. To minimize the impact of intrinsic transport in this domain, the routes should be reduced by acquiring materials and prefabricated parts from local suppliers or next to the plant. Figure 5 shows a summary of the various alternative materials and processes that can be selected for one of the pieces [13]. For the element in all his LC is sustainable, important aspects should be taken into account (environmental influence, possibility of recycling, recovery ratio in the ELC, energy consumed in the process of transformation, etc). In this case, the processes are based on cuts, initial assembly, injection molding, surface finishes and cleaning, not including toxic substances (such as metallic finishes with a high ecotoxicity as galvanizing, non-degradable paints and lacquers or synthesized damaging as PVC). The final product assembly isn't carried out (it is done by the user), so that the energy and processes necessary for this process are eliminated. This decision optimizes the logistic domain, because the final volume of the packed product is reduced.

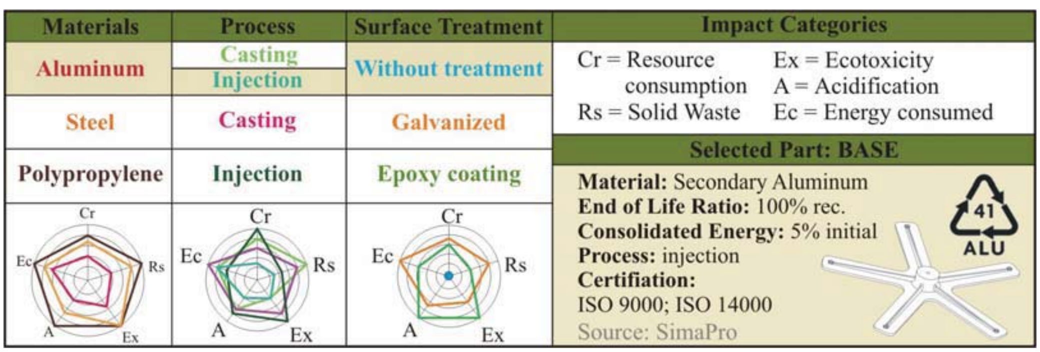

FIGURE 5. Comparison and choice of materials and processes.

To plan a manufacturing process of these features, all stages must operate under the regulatory framework ISO 14001, EMAS and Environmental Management System (EMS). they certify their environmental conditions. Thanks to the effective and clean production, based on proper management of the activities, emissions to the atmosphere are reduced (including CO_2) as well as waste to land and water, clean water and energy saving are encouraged and toxic substances are eliminated; furthermore, this stage prepares product for subsequent management of efficient end of life. If the company makes an investment in BAT (Best Available Technology), its activities will minimize the environmental impact and increase the process eco-efficiency (Directive 96/61/EC).

D. Finally, a new LCA is made, to collect all the results that will adapt to the criteria and requirements with which the product can achieve an eco-label ISO or certification C2C

CONCLUSION

The design, development and manufacture of products and industrial systems are complex processes. It is necessary to incorporate criteria to transform life cycle of products in eco-efficient and environmentally friendly, creating environmental value and recovering the planet of all negative activities carried out since the industrial revolution. Methodologies, strategies and techniques that allow achieve these targets are characterized by structured procedures which provide quality solutions, bringing together social, economic and ecological aspects. The MGE2 is adequate to raise all types of sustainable projects. This includes the 3E strategy and principles of the new paradigm C2C. It is based on clean production prospects, environmental management and value creation. The model can be defined as a guide to design bio-inspired products and systems, plus quality solutions with cyclic metabolism maintained alternative energy can be obtained.

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