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An approach to Sustainable Product Lifecycle Management (Green PLM)

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Abstract

Sustainable development has been, is and will be one of the worldwide main issues. Many initiatives have been launched to drive global conscientiousness to the problem of the impact of manufactured products. In order to become a "green company", eco-brands and recycling are well understood but many initiatives are in silos and the unintended wasteful impact to other activities in the company is not always noticed. The key of sustainability also covers all the in-between activities and it depends on a real commitment of society, research and manufacturing firms. The factory of the future must have a Green Product Lifecycle Management strategy sharing responsibilities within the whole supply chain that must be achieved through committed people. The present work describes an approach to green product lifecycle involving mainstay phases: design, manufacturing and service, including usability and renewal. The contribution suggests a framework for sustainable product development that takes the whole product lifecycle into account.

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1. Introduction

The world's awareness about environmental degradation has leaded international organization and countries to protect us through laws, directives and initiatives. Nowadays, we can find many actions of achieving sustainability in every action of our society. Since the second half of the twentieth century sustainable industrial development has

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been one of the main issues of interest for all countries [1]. As a result, many initiatives have been carried out from international organizations in order to drive global conscientiousness to the problem of contamination and natural resource limitations. Moreover, due to increasing consumer demand and rapid development, companies have invested great amounts of money in acquiring high technologies and skills in order to improve their core business and externalizing some activities to optimize internal cost that have had collateral effects to the European Union.

In the current context, companies have to figure out how to optimize the use of all their resources trying to take the advantage of the technology they already have minimizing the environmental impact. Getting out of the crisis requires not only being prepared to satisfy environmental legislations all over the world but also thinking and defining a long term strategy around sustainability for all the activities in the company. Today, eco-brands are well considered but the key issue, named the sustainable development, covers more than this and it depends on a real commitment of society and companies and it is therefore a need to define a clear ontology to integrate sustainable concepts [2], [3].

Through collaboration between companies and research organizations, there is an opportunity to organize the knowledge on sustainable development topics, allowing the companies to be more resource-efficient. By this collaboration, the company can be a "green" or "ecological driven" company not only in product design but also in manufacturing-production and in product end-lifecycle. This means that the whole product lifecycle must be sustainability-driven by all the companies involved in product development. Therefore, the "Factory of the Future" is a network of companies with a green product lifecycle management (PLM) strategy.

A Green or Sustainable PLM strategy could be defined as follows:

- Mission. To supply products satisfying customer needs taking advance of company's innovation, quality and sustainable production system considering all the lifecycle impacts.
- Vision. To generate data, information and knowledge within the organization and to manage it from the perspective of sustainable product design, development, manufacturing and disposal. The company will coordinate the generation, change and storage of all the product relative metadata with metrics that will assess the sustainability of all the product lifecycle phases.
- Objective. To share data, information and knowledge of all the product lifecycle stages among all the driving forces involved (internal and external) and to encourage the collaboration with clients, stakeholders and suppliers and to enable sustainability through Green Products and Processes (certified Green Factory).

The real problem is to translate this strategy to the private sector and the responsibility of public research organizations is to promote actions to build the initial blocks for changing the companies' culture and define concrete actions. With these considerations, and the suggestions from different organizations, there is a need of a New Generation of Green Factories that must optimize today's resources and facilities making possible a sustainable future. Moreover, it is believed that the product lifecycle affects not only the knowledge different professionals and companies but also the culture of the countries.

Therefore, the Factory of the Future has to be a reinvention from actual ones and it shouldn't be an isolated company but a set of regional competent small and medium enterprises that could compete but, at the same time, be available to collaborate when needed sharing knowledge and resources. With this strategy, the responsibility of a Green Manufacturing Enterprise should be focused on training specialists in issues related to green manufacturing-production but with a broad perspective of the product lifecycle from the product idea to the product end-life (cradle to grave). This contribution tries to put the mainstays of this approach in order to develop a framework that can help to define ontologies, processes, tasks and metrics or indicators that can help to deploy and achieve this strategy.

2. Research Background and Methodology Approach

2.1. Research Background

The surveys started with a deep review of the previous works that can bring us a different perspective mainly form the integration of sustainability in all the product life cycle. Although numerous works have been done in Eco-design activities, it is difficult to find research works about green development [3]. Authors remark that

environmental factors have become important in manufacturing planning due to governmental regulations, but manufacturing process planning decisions must also consider traditional dimensions such as production rate, costs and quality within the product lifecycle [4].

For this product lifecycle activity, major research issues must be focused on environmentally-conscious manufacturing process planning +and the comparative assessment of waste streams along the production and postproduction. In this activity the computational complexity of evaluating multiple manufacturing processing alternatives can be overcome with the discrete event simulation tools that ought to be used with this approach [5].

We would like to point out that special attention should be paid on green manufacturing which is mainly focused on four critical impact factors: social aspects, energy, environment and economics [6]. From the perspective of a green product lifecycle this stage should be considered critical as it supposes unfortunately the most contaminating one due to of greenhouse gases emissions and liquid and solid wastes that are not enough controlled [7].

The work done and lessons learned in sustainable production is mainly focused on economic aspects of the supply chain [8], [9]. There are also some works in work in logistic transportation [10], but always from the particular point of view of the environmental effects of the vehicle rather from the origin of the problem, the globalized production. The research here must be directed to help organizations become environmentally-friendly through reducing wastes (excessive use of energy, water, raw materials, hazardous substances, etc.) that do not add value to the customer. From the industrial perspective we can find some works in the inventory management field [11] and some trends are arising in the green total productive maintenance field with a cornerstone of waste elimination.

Research related with responsible use and maintenance is mainly concerned about approaches to the maintenance and operation of buildings with the aim of increasing the life of products, reducing exposure to chemical and toxic substances, and reducing the cost to operate equipment. For consumer products, the impact of the product design is easy to evaluate here, since the perspective has been focused on energy efficiency of home appliances (washers, dryers, dishwaters, vacuum cleaners, etc.) or transportation vehicles (electric cars). However the impact of the rotation of consumer products should be reviewed since they have a shorter lifecycle and, therefore, the number of products to be recycled is increasing exponentially. This last stage should be feedback all the previous ones exposed the must be aspects phase of sustainable green disassembly are the impact of materials recycling that should be included in the early stages of the product design [12].

The thread running through many of these research contributions around sustainability has helped us deploying a vision of managing the whole product lifecycle from the green perspective. Although there are published works about Product Lifecycle Management there are no works about the integration of sustainability in life cycle management from the manufacturing field [13] and frameworks for green product development [11]. Therefore, we think that there is a need of developing an integrated research of green aspects managing and measuring the product design and manufacturing activities.

Consequently, we started to propose a Green Product and Processes Lifecycle Management (Green PLM) framework, mainly focused on the manufacturing of discrete products. This framework will include the architecture, methodologies, tools and processes and the corresponding assessment and implementation plan to enable Green PLM strategies.

2.2. Methodology Approach

The research has been focused on different areas of the product lifecycle and the approach of the work is to analyze the issues (activities) in product lifecycle that contribute to hazardous waste, carbon footprint and other problems that contributes undesirably to international policies and company sustainability strategies, and to propose how product design, product development and manufacturing production activities can avoid or minimize them.

Our approach is that a green product should be not only an environmental friendly product but also a product whose maintenance should be sustainable and with minimum wastes. Furthermore, its lifetime may have a third age and it could be reused so it will imply that while for the first world this product has no use, the product could have chance to be useful for other people. The research methodology has combined qualitative and quantitative activities.

As a starting point the general objectives of the research were defined as:

1. Defining the Green PLM Framework matching strategy to operative actions (processes, methodologies, tools, etc.).
2. Outlining collaborative methodologies and tools for globalized market. Define all the needed methodologies, assessment procedures and selection guidelines (green product and process design, manufacturing, production logistics, etc.).
3. Developing key green manufacturing technologies and plant design. Analyze current technologies and research on improvements for alternative solutions.
4. Launching the Green Factory. Define and launch a pilot project according to the particular / general training plans.

These general objectives have been deployed in theoretical works and applied tasks. It is expected to achieve the objectives that will contribute to the knowledge in multidisciplinary areas.

For the theoretical works we have defined the following ones:

TW1. Defining Design Methodologies for an integrated green product / process / material selection.

TW2. Exploring on sustainable manufacturing issues, paying special attention to hazard manufacturing processes such as casting, plastic deformation, machining or surface treatments (materials and energy efficiency perspective).

TW3. Researching on manufacturing efficiency, waste reduction and logistics for a sustainable production not only from the energy efficiency perspective but also it has to consider the automated production and worldwide available resources.

TW4. Defining a Green Product Lifecycle Management Framework, which could be a reference model for organizations strategy deployment.

For the applied tasks we consider that five key actions should be

AT1. Improving design for manufacturing and production methodologies based on green product design and development processes for globalized markets.

AT2.Adapting selected manufacturing technologies (molding, plastic deformation, machining or surface treatments), in order to minimize impact (materials and energy efficiency perspective).

AT3. Optimizing manufacturing and production resources and facilities from the flexibility, automated production, maintenance, recycling and disassembly of manufacturing equipment.

AT4. Testing and verifying case studies of green factories pilot projects for future implementations.

AT5. Establishing a framework for Computer Aided Product Lifecycle Management environments (procedures, workflows, etc.) considering the sustainability approach.

3. Results and Discussion

As an initial view of our research results we describe some of the main findings. For example, in order to define the lifecycle we have established key competences for the Green Manufacturing Enterprise:

- Eco Design (eD). To design products considering all environmental impacts not only from the recycling perspective but from any product stage perspective.
- Green Development (GD). To develop manufacturing plans (Meta, Macro and Micro process) considering the environmental impacts of manufacturing technologies.
- Green (Sustainable) Manufacturing (GM). To manufacture using materials and processes that minimize environmental impacts, conserve energy and natural resources, ensure safety for employees and society.
- Sustainable Production and Logistics (SPL). To consider how mass production and outsourcing contribute to Green PLM.
- Responsible Use and Maintenance (RUM). To define intelligent control that will help in the supervision of product's use and maintenance in order to feedback metrics to ecodesign activities.
- Product Social Response (PSR). Reduce, Reuse, retire and/or recycling of products in order to close the cycle.

From these competences it has been defined a first framework ok product lifecycle, trying to stablish stages and phases that, generally speaking, must cover the whole product life. It has been divided in three phases: design and

development, manufacturing and service. For each stage a number of phases have been identified in order to draw a balanced view (Table 1).

The initial framework defines the green product lifecycle activities and a model for managing workflows that will help to implement a PLM tool. This new model will allow optimizing decision making within geographically distributed environments taking into account sustainability issues.

With this general analysis of the product lifecycle, the key competences have been matched in order to have a first conceptual framework of the Green Product lifecycle (Fig. 1). This initial version allowed us to establish the key actions of each phase.

After the definition of all this key actions it will be necessary to identify the information and data flow and to establish the links between them. It will be also required to recognize the sources of information and data and drive them to sustainability perspective.

Therefore, we propose to identify any kind of resource, used in each action, and the tools and/or methodology used to define any particular aspect of the product. This will help to classify the data, information and moreover, knowledge, that will be used to empower any of the previous competences defined above.

Table 1. Proposal of stages and phases for a Sustainable Product Lifecycle strategy.

Sustainable Product Lifecycle Activities			
	Stage	Phase	Main activities
1	Design Development	Strategic Planning	Product Design Specifications and Requirements
		Conceptual Design	Axiomatic Design, Functions and Features definition
		Embodiment Design	Product and parts Embodiment and initial Analysis
		Detailed Design	Final tridimensional models, tolerance analysis and Drawings
			Material and manufacturing technological processes selection (MetaPlan)
		Manufacturing Planning	Materials and Processes Selection (Macro and Micro Plan)
2	Manufacturing	Resources Management	Machinery, tools, raw material and parts procurement
		Production Planning	Methods, Techniques and Processes
		Production	Parts Green Manufacturing
		Assembly	Product Manufacturing, Assembly processes
		Storage	Product and parts storage (inventory)
3	Service	Logistics and Distribution	Packaging and distribution (picking)
		Marketing Sales	Brand manage, advertising and sales
		Delivery	Distribution, User-Product Interaction
		Client Service	Maintenance, Product Functions and Features Optimization
		Reduce Reuse / Retire Recycle	Product Disposal and/or product end of life

The sustainable lifecycle is achieved by planning the activities of each stage, and product development management is the main element to control the environmental impacts, as well as to determine the efficiency in each process. Therefore, sustainable product lifecycle management is established by planning all the activities that are performed regarding the product design, its manufacture, its usability and its end-of-life. Further still, if the necessary sustainable scorecards are established to control the consumption of resources, then the environmental, social and economic impacts will also be controlled.

The model will also help on improving the key competences with the use of PLM tools, Computer Aided tools (CAx) for engineering applications and Information and Communication Technologies (ICT) and their interoperability.The definition of a balanced scorecard for green product lifecycle will be possible from top to down, from the most general indicator to the use of a particular resource.

The framework focuses on managing the three stages of the lifecycle through a control of activities, which ensures that the activities of each stage are developed under the principles of eco-design and sustainable

manufacturing. Hence, each stage has its own particular resources to be applied in its activities in the most efficient way; the resources proposed to achieve sustainability in each stage are as follows:

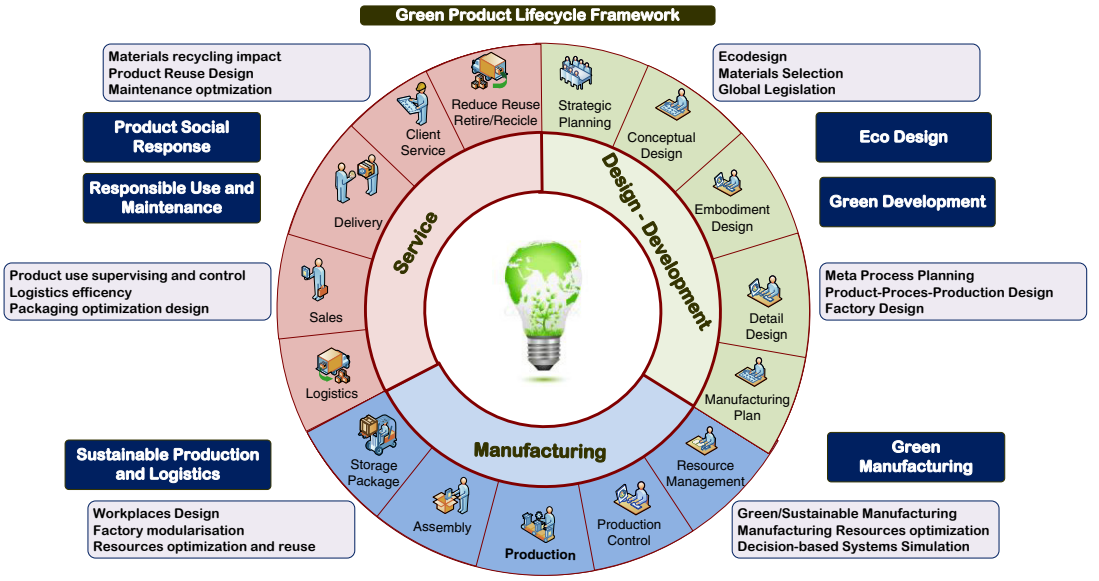

Fig. 1. Initial approach to product lifecycle with green competences.

Methods: Collection of different defined methodologies that help in product design from conceptual to detailed design and also in defining sustainable manufacturing processes.

Tools: Available engineering tools, and also technologies, that will allow achieving sustainability actions. For example CAx tools that help to quantify the CO2 print or the energy consumption in a particular manufacturing process. Different tools can be used in each phase of the product lifecycle.

Knowledge: The integration of data, information and their interrelationship will allow establishing sustainability knowledge for all the processes. Knowledge will assess mainly the new product development process and the application of the sustainable directives included in the company strategy.

The proposed framework that integrates the whole perspective for sustainable product lifecycle management is shown in Fig. 2. The conceptual model suggests that the efficient functioning of each stage is necessary to optimize the processes of the next stage. Therefore, if we represent previous defined resources as layers that evolve all the product lifecycle, there is a need of integration and interoperability of all the applications (tools).

For example, the design and development stage establishes the specifications for the product for all others stages and it will drive the optimization of the components of the product at the end of its useful life. Regarding to methods, Design for Environment (or ecodesign) can be used. Along with it, Eco-Standards applications must be used to regulate the processes that are used in the development of product parts. Moreover, eco-standards provide the parameters for using natural resources and establish the limits for the consumption of resources.

For this stage Eco CAD/CAE/CAM tools can help the activities. These software tools are used to predict the environmental impact of product parts, and are used to determine the efficiency of processes by the consumption of resources throughout the course of the lifecycle. Some commercial used tools can help to perform the analysis of the impact of the transformation of materials. Authoring tools such Ecologicad helps to identify the impact of the composition of the product and Greenfly analyzes the environmental impact of the product and packaging.

But the key point here are the Product Lifecycle Management tools (PLM tools). PLM tools help to collaborate and to plan the process determining the flow of information between each stage of the lifecycle. The integrated view can help not only in product design but also to control the consumption of resources, reducing the environmental impact to increase the efficiency of the manufacturing processes.

Finally the knowledge can be integrated through the related data and information with a Product lifecycle assessment that analyzes the environmental impact produced by applying the processes at each stage of the lifecycle. Knowledge is also used here for the Materials and processes selection developing the appropriate criteria needed to select processes and materials in the design of product parts.

In the Manufacturing Stage we can implement Methods such Design for Sustainable manufacturing or Green Supply chain management. The first one establishes the guidelines to be able to optimize the consumption of resources in each process and the strategies for controlling the generation of waste. The aim of the second one is to establish the parameters to shorten the flow of materials during the manufacturing processes; and to reduce time-costs in the manufacturing of product parts.

For this stage, Tools used are Intelligent Sensors and Controls to control over the activities to prevent the loss of resources during the manufacturing processes and to optimize the efficiency of them. These tools perform activities such as diagnostics, feasibility studies and calibrations, and identify programmed situations. Besides, Green Energies technologies for reducing CO2 emissions can be applied.

Knowledge concerns in this stage to new materials and new manufacturing technologies. The new materials have to be chosen not only to reduce the environmental impact, but also to increase the options for regenerating the damage caused to environmental resources. New manufacturing technologies generate options for reducing production time, optimizing the energy, and avoiding loss of material in the production process.

Finally, the last stage, Service, includes methods for sustainable maintenance and service systems that must help in the interaction with the customer. Tools and Knowledge deals here with the energy consumption of the product during its use how much it last in service conditions.

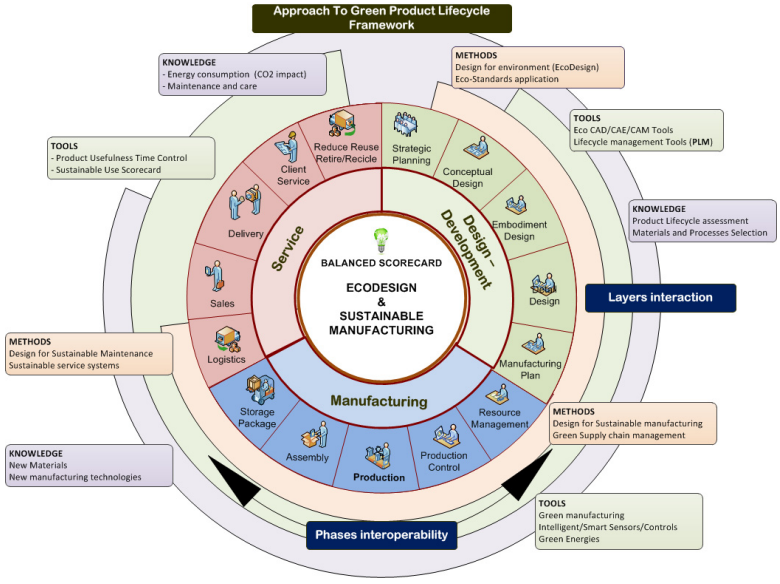

Fig. 2. Initial approach to product lifecycle with green competences.

However it is important to pay attention to the last phase, the end of life. Here critical decisions must be made, sometimes conditioned by the initial phases of the product design. Decisions about product disposal and the selection and separation of each product parts will close the cycle. A “6R Analysis”, which deals with product end of life, must be done and there could be some different options: Retire, Reuse or Recycle some parts. If we Retire we must have a Waste Management Disposal strategy. If we Reuse we must have a product parts reintegration in a new product or a Remanufacturing strategy that will suppose a New Product Lifecycle. In any case the knowledge

generated in this phase will help us to Reduce and to Redesign in the next lifecycle establish a new product Renewal strategy that closes the sustainable product lifecycle management.

4. Conclusions

The importance of acquiring a sustainable product lifecycle management vision is considered a key issue for next generation manufacturing enterprises. It is considered that this strategy will help to draw companies to a new perspective that will establish the links between the activities product development and will clarify all the needed requirements for achieving a sustainable production. With this aim, the proposed framework in this work develops the key stages for a sustainable product lifecycle strategy.

The contribution describes a model that establishes all the processes carried out through the product lifecycle and indicates the application and interaction of specific methodologies, tools and knowledge at each stage that will help to achieve sustainability. The processes applied are controlled by means of the ecodesign and sustainable manufacturing approach throughout the lifecycle of the product. This makes it possible to increase the efficiency in product development and sustainable lifecycle management.

This methodological proposal stresses the use of methods, tools and knowledge needed to reduce the impact generated in the product lifecycle. Although the design stage can be defined as the main one to drive the sustainability impact and to yield benefits for industry and society, future works must be done in connecting it with the end of product lifecycle trying to renewal it in wide-ranging perspective.

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References

[1] I., Serageldin. How do we move forward to maintain sustainability for the future of humankind?, Technovation, 33 (4–5) (2013), pp. 105.
[2] M., Borsato. Bridging the gap between product lifecycle management and sustainability in manufacturing through ontology building, Computers in Industries, 65 (2) (2014), pp. 258–269.
[3] F. Brones and M. Monteiro de Carvalho. From 50 to 1: Integrating literature toward a systemic ecodesign model. Journal of Cleaner Production. (2014), pp. 1-14.
[4] K. Xing, H.-F. Wang, and W. Qian. A sustainability-oriented multi-dimensional value assessment model for product-service development. International Journal of Production Research, 51 (19) (2013), pp. 5908–5933.
[5] V. Albino, A. Balice, and R. M. Dangelico. Environmental strategies and green product development: An overview on sustainability-driven companies. Business Strategic Environment. 18 (2) (2009), pp. 83–96.
[6] B. S. Linke and D. A. Dornfeld. Application of axiomatic design principles to identify more sustainable strategies for grinding. Journal of Manufacturing Systems. 31 (4) (2012), pp. 412–419.
[7] Y. He, F. Liu, and J. Shi. A framework of scheduling models in machining workshop for green manufacturing. Journal of Advanced Manufacturing Systems. 7 (2) (2008), pp. 319–322.
[8] S. Vachon and R. D. Klassen. Environmental management and manufacturing performance: The role of collaboration in the supply chain. International Journal of Production Economics. 111 (2) (2008), pp. 299–315.
[9] C.-J. Chung and H.-M. Wee. Short life-cycle deteriorating product remanufacturing in a green supply chain inventory control system. International Journal of Production Economics. 129 (1) (2011), pp. 195–203,.
[10] B. Beškovnik and L. Jakomin. Challenges of green logistics in southeast Europe. Promet - Traffic – Traffico. 22 (2) (2010), pp. 147–155.
[11] C.-J. Chung and H.-M. Wee. Green-component life-cycle value on design and reverse manufacturing in semi-closed supply chain. International Journal of Production Economics. 113 (2) (2008), pp. 528–545.
[12] O. Heidrich and A. Tiwary. Environmental appraisal of green production systems: Challenges faced by small companies using life cycle assessment. International Journal of Production Research. 51 (19) (2013), pp. 1–13.
[13] L. V Barreto, H. C. Anderson, A. Anglin, and C. L. Tomovic. Product Lifecycle Management in support of green manufacturing: Addressing the challenges of global climate change. International Journal of Manufacturing Technology and Management. 19 (3–4) (2010), pp. 294–305.