Restatement of Subjects of Design in Engineering as a Contribution to the Training of Engineers with a Sustainable Approach

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Abstract—**This paper proposes a new methodology for the training of engineers in Mexico. The authors propose that engineering courses incorporate the process of recovery management and waste management for the design of new products. This methodology contributes toward improving ecological justice because many factories make products without evaluating the use of recycled materials. If every new product incorporated the processes associated with waste management and recovery in question, future engineers, whom these new skills develop, may think about products not only in terms of utility, but also in terms of reuse or recycling. According to Reverse Logistics, we will be able to create quality standards in productive process based on a sustainable model. In Information Technologies, we make use of several tools such as AutoCad, CAM, Databases, agents and mobile technologies for making decisions. This methodology has been effectively tested in a classroom, using mobile technologies and agents.**

Keywords- Reverse Logistics; sustainable approach to engineering; Recovery Management; Waste Management; agents and mobile technologies

I. Introduction

Currently, there exists a problem in engineering education in Mexico, and other countries, because the curriculum does not have an approach to evaluate production including reduction, recycling and reuse. If the public policies of the state government had established these kinds of ecological engineering plans, many enterprises could have evaluated other production alternatives. Within the current paradigm of the professional engineer with the tools to solve technical problems by applying scientific and technological knowledge, several important functions are referred to. These are designing and making process designs and prototypes for industry. We seek to optimize all processes by using different ICT (Information and Communication Technologies) and to design tests to verify that these processes and prototypes accomplish performance standards established in both domestic and international regulations, taking into account that we are engaged in commercial globalization [1]. This means that design is identified as a central and distinctive element of the activities of an engineer.

In this regard, when a design is carried out, the importance of teamwork is highlighted combining efforts on a specific objective can include, for example, team members working together on forms, features or materials that are included in new products.

In addition to the cited substantive function, we now have the obligation of proposing, especially in developed countries, sustainable production projects, i.e., those which ensure, through good use of existing natural resources, the survival of future generations of human beings.

Thus, the need to start the formation of ecologically conscious engineers is crucial. Universities must encourage students to focus, from the design stage and prototyping stage of industrial products to production processes, on a sustainable approach.

We propose that a sustainable engineer be able to create and manage new materials, and analyze designs and proposals for improvement. The engineer must contemplate the use of color, create designs that improve space utilization and consumption of energy, and give priority to designs inspired by nature.

Some of the objectives that should arise in the context of the functions of "sustainable engineer" are as follows:

- To conceive, create and characterize composite materials, plastics or meta-materials with new properties, different from their original components.
- To analyze specific designs as a starting point for the detection of engaging experiences not yet offered.
- To learn to deal with the current trends of color and shape, its application in product manufacturing, the psychology of color in its use and consumption.
- To create designs which improve the use of space and energy.
- To create designs for everyday items that are inspired by nature, in their form and functionality.

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Within this new approach, solutions to minimize environmental impacts should extend to methods of production and packing materials and shipping. To accomplish this task, the use of recycled or biodegradable materials should be a priority. All of this represents a conceptual and technical basis as a starting point for proposing innovative designs. We must now focus our attention on the tools needed to lead to efficient designs.

There are some commonly used software tools, e.g., Solid Works, EDCAM Professional, and uPrint Plus, among others [2] that facilitate the achievement of the posed objectives, at least in regard to conception, design of parts, accessories or complete products.

One way to evaluate if the new scopes of engineering education are showing results is by comparing the costs, time and advantages in the production of prototypes made by any engineering student with a sustainable formation. In our university, we did some tests in a new course, which will be shown in this paper.

This new course proposal, which has been incorporated into engineering education in the Master of Engineering at the Instituto Tecnológico de Puebla, must be evaluated by other university professors who will assess the success of the program in order to make it a requirement.

II. State of the art

The integration of sustainability issues into a regular industrial engineering product design course is a challenge. Experiences at Delft University of Technology show that in course development, one of the most important aspects is credibility in written and spoken form.

Additionally, by putting sustainability in a wider scope to include social issues like safety, it is likely both students and staff without sustainability backgrounds will feel enthusiastic about the new approach, which is likely to result in better learning processes and assignments, with a higher credibility and more acceptance.

According to [3], Delft University has proposed the following elements to foster sustainability:

- Agreements between organizations (such as ANUIES in Mexico) and government institutions,
- Professors at institutions of higher education that develop coursework focused on this area, and
- Some higher education institutions must implement sustainable development processes to support teaching.

However, no one has proposed a methodology that covers a deeper level, which is the aim of our evaluation of prototype development under a sustainable approach. We propose a model of engineering education that seeks to improve the manufacturing processes.

This model has a great advantage over operations previously carried out:

a) The master of engineering program at Instituto Tecnológico de Puebla has established an innovation course, with the sustainable approach, that involves the development of products under this approach; so far a product with the sustainable approach has been developed in partnership with Universidad Politécnica de Puebla.
b) There is a learning process for all engineering programs, not only for those that include the sustainable approach.

At Instituto Tecnológico de Puebla, knowledge of sustainable developing and design is applied when students create innovative products; we have gone beyond teaching ecological culture [4].

III. Theoretical framework

Based on the model proposed by [6], which is explained below, we propose a model that includes several additional aspects such as management of how inputs will react, energy and production time. This model will be implemented in the areas of product design for engineering students at the Instituto Tecnológico de Puebla.

Additionally, we are hoping for improved production yields, based on the new engineering education. It seeks to promote good, sustainable practice and to take the first step in creating high added value from low cost materials. And, in addition, the new education seeks to aid in the future the creation of patents and self-employment. Some background in RL management is listed below.

Europe has been the continent where RL has been most developed. RL arose during the '80s from the concern, over rising levels of electronic wastes and the return needs of defective products. This led to the European Directive 2002/95/EC on electrical waste and electronic equipment collection.

In 2005, member countries of the European Union established a plan for collecting this type of waste and determined that the manufacturers would be responsible for financing the collection and processing of them. In the United States (U.S.), this practice spread during the '90s. In Mexico, the electronics industry is investing in RL.

Different authors agree to some extent on the activities of RL that are applied in industry. To carry out this work, the cited activities in Figure 1 were done. They are briefly explained below.

Let us define some of the terms considered in the scheme shown in Figure 1.

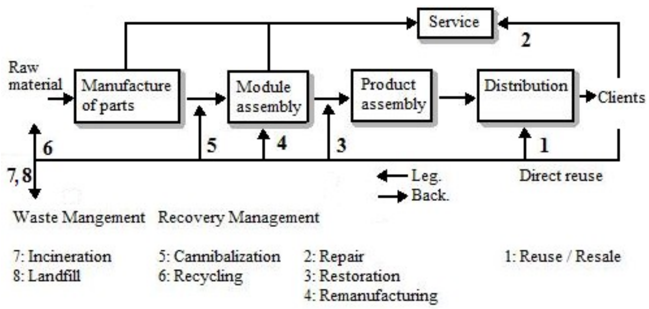

Figure 1. Activities of RL [5].

A. *Reuse*

This term means to recover a full product to give it a new use. It is difficult to apply widely, largely because of the fast obsolescence of products in an age of strong technological evolution.

B. *Repair, Remanufacturing and Cannibalization*

These three options involve an overhaul and improvement of product quality. Repair options differ in the complexity of treatment, so that means less effort than restoration, but this option is less desirable than remanufacturing. Cannibalization is based on the recovery of certain components to be incorporated into other products.

C. *Recycling*

Recycling is commonly understood as a reuse of materials, i.e., recovery of materials for reuse as raw material in another manufacturing process.

D. *Energy Recovery*

This alternative consists of removing, by combustion, the energy content of certain parts of the products. This option is not recommended because obtaining energy from the combustion of these wastes could be a new source of emissions that must be strictly controlled.

E. *Discharge*

Although it really would not be a valid recovery alternative this would be the last resort in the disposal of products at the end of their useful life.

It should be noted that all these activities of RL, constitute a development and adaptation to the concept of the so-called strategy of the three "R's" (Reduce, Reuse, and Recycle) considered within the so-called recycling logistics.

IV. RL Strategies

A. *Approaches*

The RL strategy is a coherent model, unifying and integrating decisions that determine and reveal the purpose of the organization in terms of long-term objectives. The RL strategy focuses on prioritizing the allocation of resources and selecting the current or future products of the business, in order to achieve a long term sustainable advantage [6]

In developing a strategy, it is very important to have the reasons for implementing such a strategy clearly defined. In the literature about RL, possible reasons why companies around the world use RL strategies are cited. Among the reasons listed in [5], we are particularly interested in the following ones:

- Legal and environmental problems of landfills
- Retriving the value of the product and/or resources

B. *Strategic Aspects of RL*

The implementation of RL strategies, along with considerations of the environmental impact of disposal and recycling products, at the end of their useful life, lead to a change in design criteria and manufacturing processes.

RL strategies are characterized by practical production needs. These strategies can generate significant differences, especially in the cost-effectiveness of a production process because using recycled material is cheaper, in addition to being more sustainable. However, we do need to think about the cost of collecting the recycled material. It is also necessary to define the time requirements for transporting the materials to the production site.

For the reason that they satisfy the RL strategy, pure generic strategies and their hybrids can be implemented.

1) *Environmental Strategy*

This strategy is aimed at minimizing the negative environmental impact of waste, for which reason it can be costly [5] [7].

2) *Recovery Strategy*

This strategy is focused on recovering all that can be reused in order to reduce production costs. According to [8], "RL is the last frontier for reducing costs". According to the designed RL strategy, different objectives will be present, which may be present either in one or another strategy, so that the corresponding target-strategy will depend on the importance accorded to them. Listed below are some objectives that may be present in the strategies of RL [5] [9].

a) Maximize the value added to products and materials that have returned to the company, making maximum use of recycled resources.
b) Minimize the cost of returning the goods and materials, i.e., the network to operate efficiently.
c) Minimize the negative impact of these products and materials on the environment.
d) Increase customer service.
e) Reduce the cost of production.

V. Reverse Logistics in engineering education

A. *Subjects Involved*

According to what has been stated so far, it is obvious that RL is a methodology that can have wide applications in industry due to the benefits it represents. However, Mexican institutions of higher education have not included it in their curriculum as a compulsory subject or optional, at least.

In this sense, as new generations of engineers must reverse the current paradigm of industrial design, especially

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because of its environmental consequences, universities should incorporate such methodologies in the curriculum of engineering degrees.

To illustrate the changes that must be made in an engineer's education, we have taken as an example the curriculum and syllabus of a course taught in the industrial engineering degree from the Instituto Tecnológico de Puebla.

Synthetically, this proposed change seeks to modify the content of the design subjects for the practices carried out including the development of products that take into account the selection of materials and processes from the point of view of sustainability. The main idea is to always add to the waste and composing parts recovery process, as done in the European electronics industry.

An existing course within an industrial engineering degree, in which certain issues relating to RL are touched, is modified as follows.

B. Courses

Course Title: Marketing
Field: Industrial Engineering
Contribution to Graduate Profile:

Students will learn techniques and qualitative and quantitative methods for decision making related to the conditions set by different markets.

Main Objective of Course:

This course focuses on conceptualizing the role of marketing in order to improve its application in several processes. Students will study market research, product development, pricing decisions and distribution in order to have a basis for decision making in marketing. They can use these skills to provide the customer with the quality, quantity and opportunities her or she needs.

Topics:

1. Overview of Marketing
2. Market research
3. Market Segmentation
4. Design and Product Development
5. Price Allocation
6. Distribution of the Product
7. Promotional Mixture
8. Cases of Successful Marketing

As can be seen in the previous agenda, there are clear areas of opportunity in regard to design and product development, especially in those areas that involve primarily packing materials, packaging and shipping, as product characteristics. Reverse Logistics is also applicable to the life cycle of the product. Our proposal is to incorporate the subject of RL in the training of all engineers, with the aim of fulfilling the objectives outlined in the introduction.

A suggested course, which incorporates the environmental focus mentioned in this paper, would have the following outline.

Course Title: Reverse Logistics
Field: All Engineering Degrees
Main Objective of Course:

This course seeks to analyze the factors which determine the selection of sustainable materials in the manufacture of products. Students will acquire basic skills for managing processes of waste management and material recovery.

Topics:

1. Importance of Reverse Logistics
    - 1.1 Strategic Use
    - 1.2 Barriers to RL
2. Returns Management
    - 2.1 Improving the Returns Process
    - 2.2 Lifecycle
    - 2.3 System Information in Reverse Logistics
    - 2.4 Zero Return
    - 2.5 Remanufacture and Restoration

3 RL and Environment
- 3.1 Availability and Cost of Landfills
- 3.2 Packaging
- 3.3 Returnable Packaging
- 3.4 Case Study

C. Suggested Practices

- Development of new materials
- Conception and design of new products, including their packing
- Recovery of materials from a product and its packing

The suggested practices are described in Figure 2, where the stage of the manufacturing process of a prototype that a student should perform is observed. Particularly noteworthy is the process of testing the prototype. This is the stage where one makes use of IT to perform and make decisions. As they have to solve difficult implementation problems the students have strong support, from instructors and laboratories.

Although the course was suggested in an industrial engineering degree, it is currently being implemented in the Master of Engineering at Instituto Tecnológico de Puebla.

Students of the pilot RL course created innovative products such as a discrete camera, USB carrying devices, and carrying devices for a professor, among others. To illustrate the creativity of the students, we selected one product which exemplified the use of recycled materials.

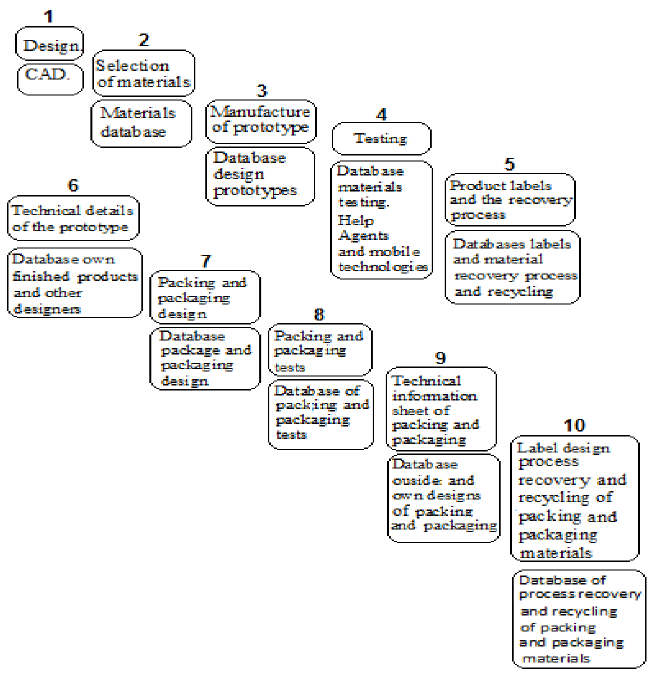

Figure 2. Process development of a prototype manufacturing practice and process of reuse and component recovery.

One student invented a unique backpack umbrella, which was named Handy Umbrella. To develop a prototype of the Handy Umbrella, the following skills were applied by the student: Marketing, to determine the market niche, and Reverse Logistics.

For this prototype, various tests were carried out. Three people with different physical characteristics of weight and height used three different Handy Umbrella models. The umbrellas used had the following characteristics:

1. Light weight, thin handle, and pole height of 65 cm.
2. Heavy weight, medium handle, pole height of 78 cm.
3. Average weight, handle, pole height of 53.5 cm.

The Handy Umbrella fits nicely on to, people's backs, but it occasionally needs to be modified to fit the individual. Like clothing or footwear, backpacks have varying sizes for better comfort, though they are perfectly adaptable.

As for the umbrellas, the best adapted to the end product was of average weight.

The product was tested for protection on sunny days and rainy days, showing good performance in both situations. It was also tested on a windy day.

The only drawback the evidence presented is that it becomes a cumbersome umbrella if you are in a very small or crowded place, which could lead to an improvement in future work.

The proposed design at first yielded an ergonomic, adjustable, stable, lightweight, reusable and easy to install product. The product is also hands free because the umbrella is placed in the backpack.

In addition to being practical, the student's umbrella was made from previously processed products. Table 1 shows the product compared to other products on the market. Highlighted are some features of the Handy Umbrella such as cost, average weight, and which materials used.

TABLE I. FEATURE COMPARISON OF DIFFERENT MODELS

Product	Stability	Weight	Recycl.	Handy	Mex.Cost	USD
Shoulder brella	middle	220 gr.	No	Middle	***354***	***30.33***
Nubrella	high	1000 gr.	N o	Low	765.50	65.59
Porbel	high	-	No	Middle	316.20	27.09
Handy umbrella	middle	470 gr.	Yes	Yes	180.0	15.42

As can be seen, by the end of the course the student had created a product that was not only original but also more sustainable and cheaper than other similar products on the market.

Commenting on the reception of the course, we can say that the course was popular among students because for the first time they gave suggestions that will be incorporated next semester.

VI. RESULTS

So far, there have been some laboratory practices which have been able to obtain designs of products that include the 3D model of the product: label design, process design and recovery of waste materials. The latter is aided by creating a database accessible by design. When students require information to design a new product, when they modify a previous design or when they need to find out about the recovery process, they can access the database.

The databases are the repository for agents (software programs that monitor the development of a model meets the specifications) [10] that take the information and report back to the designer about how well the prototype is developing. This reporting happens in real time.

When the designer is making the prototype test of the product, the agent retrieves information from the product of the database server and the user's request is to modify the timely intervention part design or material recovery process. Similarly, when you are doing performance testing of the product, in the laboratory, usually in a workshop, it is best to make inquiries of other materials through access to performance information from the experience of using different components.

Accessing this information is valuable because *in situ* people need to make decision based on experience. Undoubtedly, the crux is this part of the proposal, i.e., discussing the support of mobile technology tools and agents simultaneously to provide support and enrich the experience of an engineering student learning to make decisions. Who, under pressure, can decide how to implement the most appropriate material selection, taking into account the performance of the material, the lifetime of the components, and the recovery cost of the selected material. In short, the students apply the main criteria for deciding how to the manufacture a sustainable product.

Another important part of these courses is the instructors, who must be prepared to evaluate product prototypes designed by students. The instructors must also analyze the use of new material, make test for each type of product and reach an agreement with student as to the expected quality of the product.

Once a student has acquired skills in RL, it is clear that this is the fundamental approach to training as a sustainable engineer and, therefore, it will not be difficult to incorporate these experiences in the register of practices of his or her professional life in industry. In order to evaluate the success of this proposal student work can be compared with the items produced under traditional criteria. Companies will appreciate this approach. In a few years it will be a quality standard applied throughout in the country, and employers will choose to hire engineers trained in sustainable production process.

Thus, incorporating this model in universities, for the benefit of future generations, is expected. This method of teaching could even become a state policy in the near future.

VII. Conclusion and Future Work

Because it has been accepted as a model for training students, the process of prototype development is expected to improve and it is expected there will be an external user for each product manufactured.

It is expected that all items proposed in RL will be incorporated in a required course for all the engineering branches in the Instituto Tecnológico de Puebla once a university committee university has evaluated the results of the pilot RL course. We predict that the state government will evaluate the usefulness of RL and thus enact a public policy to mandate all universities in the state to include RL courses.

We conclude that the training of engineers should be modified. For the sake of environmental justice, engineering education should include an assessment of sustainable product elaboration. As has been shown with work in the RL course, students can acquire new skills and designed innovative items that consumers demand from producers.

The use of Information Technology supports all production processes in several ways: i) the use of databases to manage information and materials and products designed, ii) the search for information on the Web through agents, iii) the administration of the reminders of the scheduled dates of project activities by agents [10].

So far there has been one production test in a course, but if this model is extended to all engineering degrees, then there will be benefits to the environment. The RL method can also complement engineering specialties where prototypes are designed based on methods like Learning Based on Problems [11] and Development of Corporate Learning [12], thus amplifying the practice of sustainability in engineering.

We are only beginning to see the positive results of using Reverse Logistics in engineering education. If RL is widely adapted, it has the potential to create a better world for future generations.

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