Preparing Engineering Students To Meet The Ecological Challenges Through Sustainable Product Design

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Abstract: In the era of market globalization and the expansion of product responsibility into the entire product life cycle (PLC), cycle economy has emerged as a new paradigm for industry. "Green" design is catching up very fast due to increased governmental regulations and customer concerns for the environment. Graduating engineers are ill-equipped to handle environmental issues since it has traditionally never been a part of the engineering curriculum. Exposing students to green engineering concepts will help students to develop environmental consciousness. This paper presents our efforts to incorporate *Sustained Product Design* into the engineering curriculum with special emphasis on disassembly, serviceability, remanufacturing, reuse, and recycling aspects. The objective is to promote environmental consciousness amongst engineering students from all disciplines.

Keywords: Sustainable design, ecology, engineering education

1. Introduction

In the era of market globalization and the expansion of product responsibility into the entire product life cycle (PLC), cycle economy has emerged as a new industry paradigm. Driven by public concerns, government regulation, and most important, self-realization, more and more companies are adopting environmentally conscious design and manufacturing practices [1-3]. Industries have found that a well-planned *green* strategy can reduce risk of expensive environmental law violations, and increase consumer appeal and corporate competitiveness [4]. Industries also want to anticipate future environmental constraints, liabilities and opportunities to take action ahead of legislation, and to self direct their use of these materials. By including environmental criteria in product design, they can explore low cost material and capital conservation potentials in recycling [5-6]. The overall goal of all of these practices is ultimately to yield products whose aggregate environmental impact is as small as possible [7]. Product decisions made at the design stage have a profound impact on the entire product life cycle costs.

2. Brief Background

The term "sustainable" design and several other closely related terms such as "green" design, "environmentally conscious" design, design for environment (DFE), life cycle design (LCD) have been coined by researchers to capture the essence of the cycle economy paradigm [8-14]. Sustainable development being such a large and complex discipline is very difficult to characterize in a simple and a straightforward way. There are several articles that provide an overview of DFE related work [15-17]. Environmentally Conscious design and manufacturing (ECDM) has been one of the prime focus of many international conferences such as *ICED, IEEE Symposium Electronics and the Environment*, and the new conference called *Eco-Design* (held in Japan in 1999). Various initiatives and centers have evolved in the recent past such as the Green Manufacturing initiative at Carnegie Mellon (http://www.ce.cmu.edu/~GreenDesign/), program for sustainable systems at the National Pollution Prevention Center, Consortium for Green Design and Manufacturing at UC Berkeley, (http://greenmfg.me.berkeley.edu/green2/), environmentally conscious machining work done by the Machine Tool Agile Manufacturing Research Institute (http://mtamri.me.uiuc.edu/), and the IVAM Environmental Research group at the University of Amsterdam (http://www.ivambv.uva.nl/ivam/).

3 Missing Link: Green Technology Module

Graduating engineers are ill-equipped to handle environmental issues since it has traditionally never been a part of the engineering curriculum. Exposing students to green engineering concepts will help students to develop environmental consciousness. My educational task is to promote and create an awareness of sustained product development in a diverse student population (graduating engineers, practicing engineers, and non-civilian engineers (army officers) at Ft. Leonard Wood, Missouri). I would like to cover the following sub-topics within the sustainable design courseware module: Design for recycling/reuse/remanufacturing, Design for disassembly, Design for serviceability, life cycle analysis, and how our current research work on sustainable product development fits into these topics.

3.1 Design for R^3 (Recycle, Reuse, Remanufacture)

Several categories of materials are commonly recycled including metals, inorganic compounds such as alkaline compounds and acids, paper, and thermoplastics. Material labeling and identification facilitates recycling. Product cleanability considerations are necessary for recycling [18]. Today, Germany is the world leader in automotive recycling [19]. Design for reusability enables certain components (or subassemblies) of a product to be recovered, refurbished and reused [20]. Remanufacturing involves reuse, disassembling and cleaning to a predetermined standard with defective components being replaced by new, or reprocessed components [21]. The research group headed by Bras at Georgia Tech is actively involved in the remanufacturing area (http://www.srl.gatech.edu/research/).

3.2 Design for Disassembly (DFD)

Much work has been done in the area of design for assembly (DFA) as compared to design for disassembly (DFD). Identification of key research issues pertaining to DFD appears in [8,22,23]. DFD is the process of designing products so they can be easily broken down into similar materials for recycling, reuse, or remanufacturing [24-25]. It is difficult to perform disassembly for today's manufactured products due to lack of necessary information to plan the disassembly [16]. Many products are not designed for ease of disassembly in their product structure, joining methods, or materials usage. Product structure is optimized on the basis of functional and assembly requirements, resulting in a number of unwanted disassembly steps. Joining methods are chosen for simple assembly and safe joining, resulting in "non- loosenable" joining and difficult to reach joining elements. Materials are chosen so as to be economical and to provide optimum performance, resulting in a number of different materials (which are often unrecyclable) with high disassembly and sorting costs. Today, disassembly is mostly done manually. Hence, disassembly cost is higher than shredding. Higher quality of reclaimed materials usually does not pay back the costs of disassembly. However, environmental consciousness may justify some costs and social opinions and laws may require disassembly [26]. Many researchers [8,16,27-28] have discussed the general guidelines and criteria on design for disassembly. Some differences exist between DFD and DFA (Scheuring and Bras 1994)[29-30]. Most DFD guidelines positively affecting DFA are related to product structure; DFD guidelines negatively affecting DFA are related to making easily separable joints. DFD can be simplified by selecting joints which can be easily accessed and separated [30]. Methodologies have been devised for evaluating and improving the efficiency of disassembly process [31-32]. Disassembly plan and disassembly sequence generation have been reported [25,33,34]. Many organizations are translating disassembly experience into guidelines for designers. Sophisticated CAD tools covering material selection and assembly methods that simplify disassembly are needed [35]. Gadh and his students at the University of Wisconsin-Madison have made notable progress in DFD area and a wealth of disassembly information is available at http://smartcad.me.wisc.edu/groups/disassembly/ web site.

3.3 Design for Serviceability (DFS)

Product life extension is one of the most direct ways to reduce environmental impacts and can be achieved through the use of more durable materials or modular designs that facilitate repair or upgrading of product components. The various ways of extending product life are provided by Keoleian and colleagues (1994). Design for serviceability (DFS) enables the ease of performing all service-related operations including, maintenance, malfunction diagnosis and repair [36]. Many companies perform serviceability reviews only after the final design is complete, thereby, limiting the improvement scope due to high design change costs at the final design stages [37-38]. Work relating to DFS also appears in Wang and Allada [39-40].

3.4 Life Cycle Assessment (LCA)

LCA is a process to evaluate the environmental burdens by identifying and quantifying energy, material usage, and environmental releases over the entire life cycle. Various LCA methodologies have been reported such as Swedish Critical Volumes and Ecopoint methods, CML method in the Netherlands, the German KEA method and so on. This diversity of LCA methodologies prompted the Society of Environmental Toxicology and Chemistry (SETAC) to hold a series of workshops from 1991 to 1994 to find international consensus. Good information on LCAs appear in [41-43]. LCA provides a comprehensive view of environmental problems. The drawbacks of LCA are that it is quite complicated needing expert knowledge, and extensive databases for process related information and for impact classes (such as ozone depletion, smog, acidification, heavy metals, carcinogenics, etc.) with weighing factors for all materials, emissions, and other intermediate impact terms. More recently, researchers are working towards developing simplified LCA models by reducing the scope of the process data (for example, the German Material Intensity Per Sequence (MIPS), Cumulative Energy Expenditure (KEA), Eco-indicator method). While the general environmental problems are evident to the industry, specific solutions and tools to guide the design process are grossly inadequate. The research group at Fraunhofer Institute promotes the idea that a fast and practical environmental assessment method (though coarse) that needs less specific data is quite sufficient to the designer [44]. The practicality of LCA to the designers is still under intense investigation.

4. Integrated Product/Process Development (IP^{2}D) Architecture

I plan to achieve my educational objective by developing a modular courseware on sustainable design and incorporating it within the existing Integrated Process Development course (EMGT 354). Students will be required to understand the subject matter and apply it to their projects. Students in this course will identify and address the various environmental issues as is applicable for their products. I developed a new 3-credit hour course on Integrated Product/Process Development (IP^{2}D) in Winter 1996 semester [45]. The objectives of this course are threefold: i) emphasize the design policies of concurrent engineering and teamwork, and documentation of design process, ii) expose students to the various product realization activities from customer needs identification to prototyping through a semester project, and iii) emphasize the integration of various product realization activities. The architecture of the course is illustrated by IP^{2}D wheel in Figure 1.

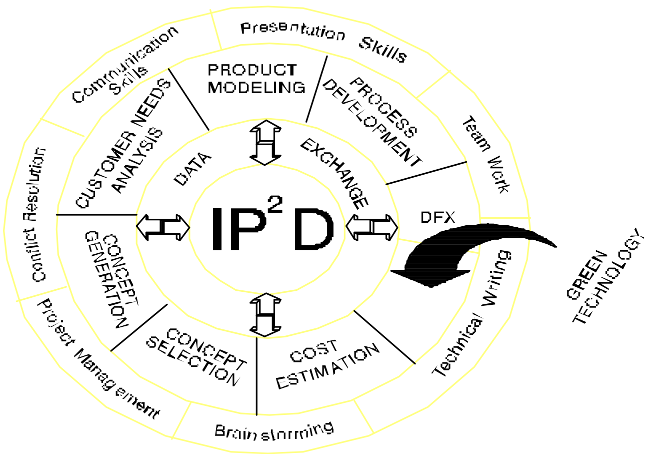

Fig. 1 Integrated Product/Process Development Architecture

I plan to transfer the sustainable design research conducted by our group into the classroom. The central hub represented by the IP^{2}D system is interfaced with the various product realization activities by product data exchange mechanism. The outer rim of the IP^{2}D architecture represents the auxiliary skills that are important for functional involvement of the students in team-based projects. Student teams are assigned projects that will give them an opportunity to perform concurrently the various integrated product realization tasks.

5. Conclusions

In conclusion, many approaches that are suggested in the literature for the development of green products are promising and thought provoking. A complex web of interactions and linkages exists between the economic and global ecosystem. The sustainable design courseware will attempt to fill one of the gaps of the traditional engineering curriculum by introducing the concepts of sustainable design -- a relatively new area. The development of a modular sustainable design courseware is well timed and will have broad student appeal.

6. References

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