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Social and environmental perspectives in the design of engineering and service systems*

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The globalization of most industrial operations has led to a high degree of disconnect between the consumers and the goods and services they consume. The connections between the manufactured products and the culture and place from which they originate and their place of consumption are often lost. This leads to accelerating environmental degradation and decreased quality of life for many people. The engineering community is partly responsible for this situation, due to their lack of consideration of the ecological and social consequences of design in a comprehensive manner by taking into account the rich contexts in which goods and services are produced and consumed. Adaptation and incorporation of ideas from ecological design and the development of appropriate curricula have the potential to change this situation significantly. In this paper, I describe an approach to accomplish these objectives.

INTRODUCTION

NEARLY FORTY YEARS after the publication of *Silent Spring*, and thirty years after the publication of the *Tragedy of the Commons* and the discovery of the thinning of the ozone layer, there has been little fundamental change in the way engineers design systems. Why is this so? Could it be the ignorance of the global effects, together with an active disengagement from the 'political' and 'business' processes around them? I believe that the reasons are more insidious. There is an increased disconnect and alienation from the environment in the 'antiseptic' lives of most engineers and business leaders. For instance, hardly anyone is aware of the environmental and social impacts of the manufacture and sale of an ordinary athletic shoe [21]. The flow of material and information between many countries in three continents, at considerable environmental cost, is not uncommon before the assembly of a shoe is complete.

The last quarter of the twentieth century has witnessed an accelerating trend in ignoring the environmental and, the closely intertwined, social consequences. This is in stark contrast with the historical practice of design and construction of dwellings and other engineered structures built in harmony with nature. The long history of humanity's affinity and love of nature, expressed in many forms, including poetry and prose, across different cultures, (e.g., [11, 12]) is well documented. The current practice is a significant departure from these trends.

I believe that a lack of awareness of the environmental and social consequences at a deep level among engineers, especially those who design manufacturing and service systems, is a major contributor to this state of affairs. In this paper, I explore some ways in which we can begin to make a significant, long lasting, and persistent change. Much of the change desired is cultural, in a broad sense, and hence fraught with the usual problems associated with influencing culture. Nevertheless, it is worthwhile and necessary to pursue this approach. The potential is much greater in the design of engineering and service systems, in contrast to simple artifacts: the cost and energy savings can be considerable.

Design in engineering is often concerned with the creation or modification of artifacts that stand alone or form parts of larger systems. Often, the scope tends to be rather limited and local. Even when the potential consequences of design and implementation are no longer local, for instance in the construction of massive dams, waste incineration (for example, disposal of chemical weapons), or burial of nuclear wastes, analysis and investigations rarely extend beyond the preparation of environmental impact statements. These are usually carried out by the same organizations or companies with a vested interest in carrying out such projects. Such practices are defended, sometimes rightly, by the claim that engineers are not knowledgeable about domains that are beyond their areas of competence. However, when the health and stability of the biosphere is under threat due to global warming, ozone depletion,

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and the accelerating losses of biodiversity, such a practice is no longer acceptable. Design must include a careful consideration of the broader impacts on society and the environment. (Two of the highly controversial projects include the Sardar Sarovar Dam on the Narmada in India, and the Three Gorges Dam in China. The environmental and social costs have been well-studied, see www.irn.org. Nevertheless, construction is proceeding.)

Real life design projects of wide impact are often the province of transnational corporations. Most transnational corporations are global in their operations, with design, sales, and service occurring predominantly in industrialized countries, while production and manufacturing are 'outsourced' to the developing countries, or essentially similar 'enterprise zones' in the US. Information necessary to link these distributed operations often fails to bring out the connections between the manufactured products and the culture and place. This is a result of the operations happening around the clock in places far removed from the consumer, and even most corporate personnel. As a result, the environmental degradation continues to accelerate, along with a reduction in the overall quality of life. In this paper, I begin by exploring the nature of this globalization, and its effects and the consequences on society at large. I then investigate the means to ameliorate this condition by a *pro-active* approach to design that emphasizes the integration of values, ethics, and ecological considerations.

BACKGROUND

The globalization of the commerce has led to the 'global village' lacking in one essential characteristic: whereas every activity in a traditional village was tightly connected to every other activity, in the global village the actors are no longer so connected. The global village is not, in fact, a village. As a result, the prevailing view is 'what one does not see does not hurt, and it does not even exist'. Hence one need not feel guilt or remorse for possible adverse consequences for one's actions of consumption. This 'out of sight, out of mind' attitude is by no means a recent phenomenon. What is new is its pervasiveness and the rather alarming rate at which it has spread with the raise of the service economy even in the 'developing' economies. The same information 'revolution' that is the engine of this globalization has exacerbated this situation. One can cite examples from any of the labor-intensive activities, from manufacturing of shoes, to apparel, to cheap plastics, to seemingly 'good' recycling operations such as the reclaiming of metals from old ships.

Environmental degradation and its consequences are often assumed to be the price one must pay for progress. Long-term consequences of resource depletion and contamination, etc., are either simply dismissed or downplayed. Or worse, when questions are raised either by thoughtful individuals and social and environmental organizations in the consuming nations or in the producing nations, concerning the safety and health of the workers or the environment, they are often dismissed as being against progress and development. Indiscriminate industrialization, frequently to satisfy the seemingly insatiable needs for consumer goods in wealthy nations, is often touted as having the ability to lift the workers, and indeed the entire society, out of poverty. In many developing countries, advocacy on behalf of the workers or the environment can lead to death, for example, Chico Mendes in Brazil, and Ken Saro-Wiwa in Nigeria.

It is unfair to single out the 'evil' corporations alone for such practices. The powerful elite and the governments in the developing countries are often directly responsible. The power elite in the consuming countries, and their governments, usually turn a blind eye, or at worst, join with like-minded parties in the developing countries by providing hidden subsidies that encourage such practices. Reference [4] provides a particularly relevant example in the domain of apparel manufacturing, and describes the sweatshop conditions in Bangladesh. Such a state of affairs is not uncommon within the developed economies, either. One only has to look at the siting of waste incineration facilities, and nuclear waste repositories.

It would be simplistic to look for a single reason for the prevalence of such practices. The reasons are many. The average person is quite ignorant about the processes and functions involved in production, because the unit processes are generally disconnected. This is true even among engineers, trained as we are to believe in the reductionist approach of isolating the design variables, and in the power of 'autonomous technology' that should not be questioned. There is a lack of commonly accepted methods to assess the value or cost of natural resources and services, in spite of significant progress in ecological economics, e.g., [5, 6, 10]. Other complicating factors include the long intervals of time between exposure and any perceptible effect, and uncertainties concerning the cost for restoration.

MOTIVATION

The political, social, and economic causes are important, since they are the ultimate drivers. Unfortunately, they are beyond the scope of engineering design as taught in universities, or even as practiced by the average design engineers. Organizing the information necessary to understand or clarify the deleterious effects of various steps in engineering, from design to manufacture to consumption, can be helpful to mitigate the negative effects. The design stage has the most to offer in terms of possible improvements, by familiarizing people with the life cycle effects and exposing them to alternate ways of viewing and handling the problems.

Ecological design [24], predicated around the total context of the environment, has begun to play a significant role in resource-intensive manufacturing. For instance, an innovative approach to the sale of carpets is to sell a service (such as floor covering), via perpetual lease, instead of selling the carpet the usual way. The emphasis is on services rather than material, with worn carpets replaced and reused in making new carpet [3]. While this is a welcome development, and can potentially contribute to a significant improvement in sustainable resource management, it does not go far enough [9, 10]. (While not explicitly developed in this fashion, the earlier architectural design efforts inspired by the work of Christopher Alexander [1, 2], do evolve from this perspective. His study of living environments in various cultures, that evolved over a long period of time, were based on ecological or 'situated' considerations that were closely interwoven with culture and place. His work can be viewed as the development of the principles for ecological design in architecture.)

Currently, the emphasis continues to be primarily on material use, with little consideration for the human or environmental costs. Resource reduction is through vertical integration, within a limited geographical area (see [15]). These approaches to managing resources likely result from well-intentioned goals of reducing wastes and generally reducing the ecological footprint, and realizing an immediate benefit from such actions. While the ecological design movement, as practiced currently, is about ten years old, the emphasis has primarily been on architecture (of buildings and landscapes, in an integrated design approach) and wastewater treatment [23].

Orr [16] offers the following summary of good design, inspired by ecological design. Good design everywhere has certain common characteristics including the following:

- right scale,
- simplicity,
- efficient use of resources,
- a close fit between means and ends,
- durability,
- redundance, and
- resilience.

Good design also solves more than one problem at a time. They are often place specific or, in John Todd's words, 'elegant solutions predicated on the uniqueness of place'. Good design promotes:

- human competence instead of addiction and dependence;
- efficient and frugal use of resources;
- sound regional economies;
- social resilience.

Therefore, designers must take into account the entire range of consequences that result from each design feature or step. This is especially crucial in a predominantly service economy that separates most, if not all, means of production and distribution from consumption. Typical examples abound in retailing.

Retailers wield immense power by generating and/or catering to demands for products that are often manufactured in developing economies. A retailer such as Wal-Mart, which is the largest of its kind, and often cited as the example for efficiencies and cost effectiveness of their operations (especially in their supply chains), operates in a manner that the ultimate consumer or even people working for the retailer are far removed from the places and hence the modes of production. Manufacturing is performed with little consideration for the ecological, health, or social costs. Transactions are processed through intermediaries who are not accountable for standards or guidelines followed by any civilized society.

Educating consumers and, more importantly, raising the awareness of designers and others responsible for production, in the life cycle of products has the potential to improve this situation. A plan for accomplishing this is discussed next.

A PLAN FOR EDUCATION

Teaching design plays a key role in engineering curricula. Increased emphasis on service systems, especially in industrial engineering, implies that it may even be possible to redesign each step in a 'supply chain,' as well as the entire process. Since about a half of the graduates of industrial engineering programs currently take up jobs in service industries, including logistics, there is a great opportunity, as well as a need to improve design practice by emphasizing the importance of environmental and ethical considerations and values deriving from cultural, ecological, and social diversity.

Concerned mostly with the reduction of wastes and material reuse, most efforts to deal with these issues over the past decade or so have concentrated on life cycle manufacturing and 'environmentally conscious manufacturing.' However, such efforts do not address the fundamental issues of resource consumption. In any case, they have not had a significant impact on the teaching of design, or practice, in industrial and systems engineering. This is because one of the most fundamental issues, that of lifestyles, has been ignored. What is needed is a cultural change and a willingness to question the most basic assumption of production, that of maximizing profit as if it were isolated and decoupled from the global society. By suitably modifying the performance measures, 'optimal' production and distribution, typical of service systems, can still be achieved while maximizing *benefits*. But first it is necessary to make apparent the total costs and benefits, using the traditional as well as sustainability measures dealing with ecology, cultures, and other societal needs. We have been attempting to develop such measures.

A necessary first step is to study the means for influencing the culture of design. Design cannot be considered as an isolated activity, as it is taught in typical engineering curricula, for instance in machine design, where purely 'objective' considerations suffice. In a multi-tiered approach, the process can start with illustrating the connections between the peoples, the environment, and the sustainability of ecosystems, including an understanding of nature's services. Much of this is already part of the ecological design movement. The next tier above must deal with the development of design requirements and approaches that incorporate these considerations into formal models and approaches to design. Perhaps the most difficult problem that remains is that of educating the faculty, especially those in traditional disciplines such as industrial and systems engineering. The importance of ecological literacy and the urgency with which this needs to be done is discussed in a set of essays in [17]. Educating the faculty can be quite a challenge, but it has great potential for leading to significant changes in the way we live our personal and professional lives.

One way to effect these changes is by developing design programs derived from actual case studies that can illustrate the 'connections' in the 'global village.' This should be followed by the development of quantitative and qualitative measures related to ethics and values in a manner that can be incorporated into the traditional approaches to teaching design. Committed faculty in highly regarded institutions can make a significant impact by taking the lead and developing an awareness among their colleagues in their own institutions and elsewhere. While I have attempted to do this informally for many years, primarily in graduate courses, I have also begun to explore ways of doing this formally in an undergraduate course on human-integrated systems design, and the capstone design course where student groups must work on real-life problems. I am assembling a portfolio of cases, problems of design leading to unforeseen consequences, and analyzing them to illustrate the connectedness and the need to consider many factors comprehensively. I am also exploring means of integrating ideas from ecological economics with the more traditional approach to evaluating costs and benefits via engineering economics in the solution of real-world design problems. The 'political' climate appears to be conducive for doing this, at least in my institution, due the realization that ecological design is a legitimate endeavor. The active involvement of an influential, committed, and wealthy, alumnus from the ecological design community may have something to do with this. (However, I have learned that this commitment, passion, and enthusiasm may not be sufficient to overcome the resistance from some of the tradition-bound, and powerful, academics.)

In what follows, I discuss the design problem in context, and explore the means for developing an integrated design program for systems engineering.

SYSTEMS DESIGN IN CONTEXT

Design of systems, in contrast to isolated components or artifacts, can potentially have a large impact on the ecological and social considerations discussed above, while helping make explicit the connectedness between the various entities. Engineering design, concerned primarily with artifacts or simple systems within the traditional engineering disciplines, for example, civil, electrical, mechanical, etc., deal with structure, function, and behavior governed by appropriate physical and chemical (or material) principles and laws, both basic and derived. In contrast, system design must take into account other factors, including cultural, social, and political considerations.

Execution of systems design, for instance, a building, a power plant, a computer, or a transmission system, also requires coordination and cooperation within design teams. Members of the teams have specific responsibilities that may include the design of individual components as well as overall coordination to realize the larger system. In traditional design teams, opportunities seldom present themselves for considering the environmental and social factors.

The reasons for the absence of social and environmental considerations are many. One is that the culture of 'objectivity' precludes conscious efforts to consider issues outside of engineering. Also, in many design problems, the impact is generally local, even though some of these designs can have wider impacts that are generally not recognized at the outset, or at best not explicitly considered during design. A particularly common example is the incorporation of circuitry for instant response in common household audio-visual appliances. Even though the power consumption is miniscule for a particular device, the proliferation and ubiquity of consumer electronic devices imposes a large cumulative electrical load on the overall power grid. To this we must add the idling computers and monitors, once again considered negligible in isolation. While improved designs with instant-on capabilities have begun to be designed and sold, a greater potential for reducing the impact on the environment and on society is possible when systems of much larger scope are considered. Transportation, industrial, and service systems offer such possibilities. Design of warehousing and distribution systems offers an illustrative example.

Industrial and service systems: warehouse design as an example

Warehousing and distribution systems play a major role in the 'service economy'. Whether one buys an item via mail order, over the Internet, by telephone, or in a store, typically the item goes from the place of production or manufacture to a warehouse, and then travels to one or more warehouses and distribution centers before reaching the consumer. Their design, therefore, is important to optimize the 'supply chain'. With the emergence of grocery stores and businesses that take orders over the Internet and deliver food, one can order almost anything, even though apparel, books, computers and other electronics, and other consumer goods dominate this industry.

While warehouses are necessary to fulfill the need for essential items, often clever marketing creates the need for luxury items by manipulating the 'wants' into 'needs' that one cannot live without. At least this is the premise in some of the up-scale mail-order operations. These fast changing 'consumer trends' and the continued globalization of manufacturing and production have resulted in the need for designing warehouses and distribution centers that are flexible in scope and capable of adapting to changing needs.

During the past decade or two, we have seen apparel manufacturing relocate from the US to the Caribbean, Mexico, and other central American countries, as well as many countries in Asia. The economic, environmental and social costs, and the disruptions it has caused, both in the US and elsewhere have been considerable. The relocations have also had an important effect on many engineering functions, especially in logistics and transportation, since they are key functions in the design and operation of service systems.

We recently completed an ethnographic study of experts redesigning an apparel warehouse and distribution facility. Due to the traditional emphasis on the 'bottom line', there was no place for considering the ecological and human costs, except in a very limited sense. While this is rather shortsighted, it is quite typical. In fact, there appears to be an unwritten taboo against discussing such issues.

As pointed out by [7, 10] a clever designer or an operator is expected to single-mindedly 'focus' on one thing: the bottom line. Often, the overall design problem is decomposed into smaller subproblems for which 'optimal' designs can be developed, and the individual solutions are combined to produce the complete design. However, the overall system is not optimal in most cases. In the context of the warehouse design mentioned above, one expert designer was surprised by learning that a traditional warehouse had a return on investment (ROI) of 80 to 90%. He had expected only about 10–20%, instantly dismissing the higher return as the possible result of 'off-shore' operations. ('Offshore' often means south-of-the-border or in the Caribbean in many situations discussed in this context.) Even though the designer recognized the proximate cause for this high ROI, i.e., cheap labor (to the exclusion of everything else), no further discussion ensued because doing so would involve questioning the fundamental assumptions concerning the means of production, which is beyond the scope of warehousing. (This is not strictly true, since location of warehousing and certain distribution operations *are* directly influenced by these factors. In the warehouse design project mentioned here, the client in fact stipulated that the redesign should attempt to keep the jobs locally, to the extent possible.)

The greatest difficulty in incorporating the wider issues into design education is likely to be in convincing the (industrial) engineering faculty of the need to consider these factors explicitly. Unfortunately, the academic environment is not much different from the business world in one respect. The single measure of success is the bottom line, where the costs and benefits are computed along customary lines. Any awareness or consideration of ecological or other environmental effects is decidely absent. What is needed is perhaps a major cultural change, and, in the words of David Orr [18], the deprofessionalization of the professoriate:

> Why have so few of the tenured joined the effort to preserve biological diversity and a habitable earth? Why are so few of the tenured willing to confront the large and portentous issues of human survival looming ahead [18, p. 99]? . . . I believe the reason is that the professorate professionalized itself, and professionalization has done what even the most flagrant college administrator would not dream of doing. The professionally induced fear of making a mistake or being thought to lack rigor has rendered much of the professorate toothless and confined to quibbles of great insignificance. One sure way for a young professor to risk being denied tenure by his peers is to practice what philosopher Mary Midgley called the 'the virtue of controversial courage', the very reason for which tenure was created. For the consummate professional scholar, the rule of thumb is that if it has no obvious and quick professional payoff, don't do it [18, p. 100] . . . I offer, accordingly, two ideas to curtail professionalism run amuck. The first is to suggest that all candidates for tenure appear before an institution-wide forum to answer questions such as the following [18, p. 102]:
>
> - Where does your field of knowledge fit in the larger landscape of learning?
> - Why is your particular expertise important? For what and for whom is it important?
> - What are its wider ecological implications and how do these affect the long-term human prospect?
> - Explain the ethical, social, and political implications of your scholarship.

I have plenty of company here. For instance, the distinguished biologist Lynn Margulis [13, p. 259] observes 'Our culture measures scientific activity in the workplace by the rate of cash flow per square foot. Investigators are rewarded when we bring in students or grants, build buildings, buy chemicals—all of which increase the rate of cash flow.'

Since a radical change in culture is unlikely, at least in the near future, other approaches are needed. The identification and quantification of the costs along traditional lines can be helpful. However, it can be difficult to quantify the costs and benefits. What is missing the realization of the (lack of) connectedness among the entities. Everything looks isolated and hence the overall context is lost, and most often invisible. The potential exists for incorporating these factors, if the connections can be made explicit(e.g., [10]). Information systems capable of being integrated into the design process are needed to make the connections (and the interrelatedness) clear, transparent, and explicit. Measure of worth or value (of fundamental information) must be made available along many different dimensions (e.g., nature's contributions[6], pollution control costs, loss of biodiversity, social costs in dislocation, unemployment etc.). Means for comparing the various costs and information measures must be identified and built into the analysis and design framework. (Such issues are no longer considered unthinkable. For instance, the allocation and trading of carbon credits is an active research area within operations research.)

AN INTEGRATED APPROACH TO (TEACHING) DESIGN

To reiterate the key issues underlying this paper, my objective is to integrate ecological and social considerations into the engineering design process comprehensively. This can be done by making explicit the 'connectedness' of all things when one undertakes a design, either of an isolated artifact, or a large system comprised of many subsystems and components in multiple hierarchies. This will be done by compiling a rich set of cases and problems that provide a variety of examples where the overall context is explicit and clear. The design problems will provide opportunities to practice many of the methodologies and skills that students learn during their course of studies. This approach is likely to be viewed as subversive by some, since the context could bring up issues that often make explicit issues that are generally not discussed. For instance, one cannot ignore the less than desirable wages and living conditions or the steady deterioration in the environmental conditions in and around the maquiladora factories in Mexico [22]. However, such case studies also offer the means to illustrate the application of various analytical and modeling tools and techniques.

An integrated approach throughout the curriculum would require the adoption and use of examples and cases at different levels of detail throughout the curriculum. Ideally, the same example would be used, emphasizing different facets to suit the methodological areas central to a course, e.g., mechanical design of components, databases, interfaces, layout design, etc., at different levels of depth. Analysis and design can often be carried out in student groups at the undergraduate levels, with larger, more complex, problems forming the basis for thesis and dissertation research. A portfolio of cases (or problems) is needed for variety, to bring out different perspectives and to hold students' interest. In our undergraduate curriculum in industrial and systems engineering, such possibilities exist in the very first introductory course that provides an overview of the field, and in the two-term capstone senior design sequence. It is encouraging to see efforts to integrate the social dimension in design in several academic institutions. Reference [8] provides a brief survey of courses and describes a first-year engineering design course that they have developed. Whereas their course is concerned mostly with the design of 'traditional' engineering artifacts, ours looks at the other end of the spectrum, at the level of systems design.

A case-oriented approach

Design problems will be developed by adapting real-world cases in engineering and technology (for instance, from [20, 25, 26]; except for Wiener, these authors are rarely concerned about the ecological or social consequences). To ensure variety, possible domains can include construction, manufacturing, aviation and aerospace, semiconductors, software development, command and control, logistics, petroleum refining, and apparel and textiles. (Often ignored, aviation is heavily polluting and contributes disproportionately, in passenger-miles traveled, to global warming and the destruction of the ozone layer; see www.ipcc.ch) Among service systems, air lines, banking, insurance, and consulting in supply chain and logistics offer possibilities. Once the domain and cases are identified, it is necessary to develop the problems in a form suitable for instruction. Computer-based instructional systems can be of help to organize and present the information. Relevant problems include:

- development of historical cases and stories at a sufficient level of detail, e.g., everyday things (shoes), a modern airplane;
- indexing concepts, themes, and fundamental principles to contexts within the stories;
- identification of suitable computational tools and integrating them into the stories;
- interfaces for visualizing the information and connections clearly;
- organizing knowledge based on sound pedagogical principles;
- preparation of modules that encapsulate key concepts;
- development of processes and procedures for evaluation.

While computers will be used, the key element is the traditional, human-centered (student and teacher) instruction. The initial effort will involve the development of the cases at various levels of detail, and organizing the case information in appropriate databases. For a specific course, the supplemental curricular material will then be identified, together with key concepts, algorithms, assignments, and computational tools necessary for assisting in the solution of problems and visualizing the results.

We are well-placed to perform this 'experiment,' not only because of our prior research experience in related areas, but also since our undergraduate and graduate programs are considered to be among the top programs in the country. (High rating does not necessarily mean that these 'experiments' are possible, or even considered acceptable. See [19] for a frank appraisal of such rankings.) Therefore, we have the flexibility to experiment and evaluate new and innovative methods and techniques and compare new programs with the traditional approaches.

A side benefit and a 'selling point' of the case-oriented approach described here is the possibility to modularize course material. For instance, a curriculum can be designed so that a student can follow a selected number of cases or stories 'linearly', picking up the concepts and techniques along the way. This approach may benefit self-study programs. Organized around key concepts and principles, this course can be used as a supplement to regular courses by providing real-life contexts that can motivate the learner better.

Outlines for a plan of instruction

Teaching design in context, with social and environmental considerations integrated into the cases and the curriculum, calls for a radical change in the way we teach. Even though team teaching is not uncommon in design courses, the approach discussed here requires expertise not only in the technical aspects, for instance in both theoretical and applied aspects of operations research and systems engineering, but also in ecology, sociology, political science, and other human sciences. Engineering faculty with multidisciplinary backgrounds working closely with others in the sciences, humanities, and the social sciences must form teams. A tentative syllabus would incorporate ideas from (1) ecological design, (2) ethics and values, and (3) history and political economy into the appropriate engineering framework. Instead of teaching these other subjects separately, they should be discussed when the issues relevant to these areas become salient during the discussion of the cases. An example case is being developed based on the report from Northwest Environment Watch [21] summarized in Table 1.

SUMMARY AND DISCUSSION

I have attempted to develop a case for a radical change in teaching the design of systems so that environmental and social consequences are made explicit in all phases of design. One of the key goals is to start a discussion and raise awareness. Since many issues not generally considered in design are involved, touching on several disciplines in which I cannot claim expertise, putting together a coherent argument has been difficult. This is only a beginning, and considerable work remains to be done.

Among others, there are several important questions remain, for which answers must be worked out and articulated in detail. These include:

Table 1. How an athletic shoe is made, adapted from [21]

Steps in the sequence	Where and by whom	Design opportunities
Specify design and materials, and relays plans by satellite; Plans faxed to engineers	Shoe company in Oregon to computer-aided design firm in Taiwan to Design firm to Korea	Networked information systems; CAD
Cow hides cured, stacked, and carried by freight train	From Amarillo to Los Angeles port	Processing, packaging, warehousing, and transportation; localizing manufacturing
Shipped for tanning	From LA to Pusan, Korea	Transportation, energy use, emissions
Tanned leather loaded on an airplane for shipment to factory	From Pusan to Jakarta	Transportation, emissions
Saudi petroleum shipped by tanker	From the Middle East to Korean refinery	Energy use, transportation
Ethylene vinyl acetate made	Korea (from the cracked petroleum)	Energy use, emissions
Synthetic rubber manufactured	Saudi petroleum combined with benzene made from local coal in Taiwan	Energy use, emissions, transportation
Rubber made into large sheets and flown	From Taiwan to Jakarta	Energy use, transportation
Shoes assembled from leather, rubber, and synthetics	By people in Tangerang, paid Indonesian minimum wage; Toxic and non-toxic solvents used	Local or distributed manufacturing (at the point of consumption), environmental effects
Light weight tissue paper	Made from Sumatran rain forest trees	Rain forest destruction, loss of biodiversity
Box made and shipped as folded stacks of empty boxes	In a 'closed loop' paper mill in New Mexico; shipped from LA to Indonesia	Energy use, transportation
Shoes stuffed with tissue paper and shipped	From the factory to the US	Energy use, transportation

- Why is systems design more important than the design of artifacts, in terms of contributions to the economy, both positive and negative? Can this be shown with hard data, at least for an important class of problems in supply chains, warehousing, and distribution?
- What are suitable examples of systems and domains that have the potential to illustrate the interconnectedness and impact? Examples from manufacturing (biotechnology, semiconductor fabrication), construction, waste management and recycling, transportation etc. must be developed.
- How are nature's services computed and incorporated into more traditional designs and computations? These include unaccounted expenses (cleanup costs, health, erosion and soil loss, habitat/species destruction) and opportunities lost, etc.
- Will awareness (and knowledge) result in better overall designs? What are the measures for assessing the goodness of designs?
- What makes it difficult, or nearly impossible, to make use of the accumulated scientific and cultural knowledge about ecology and the environment, for example, greenhouse effect and ozone depletion, population growth, etc.? Why is this knowledge not being used?
- What are the cultural and political barriers that might prevent or delay the development of courses incorporating this design perspective? Is it necessary to 'camouflage' the courses, at least until their benefits are well understood and accepted?
- Do methodologies exist for casting problems in cases so that the conceptual issues, scientific disciplines, relationships and effects, etc. can be made explicit? How should real data and relationships be organized to make the issues stand out?
- What would students design? How can specifications and constraints be developed to introduce secondary and tertiary effects such as ecological footprints?

Many issues must still be clarified, and much remains to be done to convince our colleagues that the approach described here should be tried. Based on the slow and steady progress in introducing many of the concepts, I remain optimistic that it is possible to make a serious beginning.

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