Principles and practice of ecological design

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Principles and practice of ecological design

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Abstract: The history of development of the concept of ecological design (or eco-design) is described, and key influences and antecedents are introduced. Seven principles of ecological design are advanced: (1) the need to meet the inherent needs of humans and their economy; (2) the requirement to sustain the integrity of the structure and function of both natural and managed ecosystems; (3) the appropriateness of emulating the inherent designs of nature in anthropogenic management systems; (4) the need to make progress to a sustainable economy through greater reliance on renewable resources and more focus on recycling, reusing, and efficient use of materials and energy; (5) the use of ecological economics (or full-cost accounting) to comprehensively take resource depletion and environmental damage into consideration and thereby address issues of natural debt; (6) the need to conserve natural ecosystems and indigenous biodiversity at viable levels; and (7) the desirability of increasing environmental literacy to build social support for sustainable development, resource conservation, and protection of the natural world. Examples are presented of the recent application of the principles of eco-design to the planning and management of human communities, industrial parks and networks, architectural practice, and products. The principles and practices of eco-design have much to contribute to the urgent need to make rapid and tangible progress towards a sustainable human economy.

Key words: ecological design, eco-design, sustainable development, community planning, architecture, industrial park, green products, biological conservation.

Résumé : Les auteurs présentent l'historique du développement du concept de design écologique (ou éco-design), ainsi que ses principales influences et antécédents. On propose sept principes de design écologique : (1) le nécessité de rencontrer les besoins inhérents aux humains et à leur économie; (2) le besoins d'assurer la durabilité et l'intégrité de la structure et de la fonction des écosystèmes naturels aussi bien qu'aménagés; (3) l'à-propos de suivre les designs inhérents à la nature dans les systèmes d'aménagement anthropogènes; (4) le besoin de progresser vers une économie durable via une utilisation plus poussée des ressources renouvelables, avec une plus grande préoccupation pour le recyclage, la réutilisation et une efficacité accrue dans l'utilisation des matériaux et de l'énergie; (5) l'utilisation de l'économie écologique (comptabilité intégrale) afin de prendre en compte globalement l'épuisement des ressources et les dommages écologiques, et conséquemment

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d'inclure les problèmes de dette environnementale; (6) le besoin de conserver les écosystèmes naturels et la biodiversité indigène à des niveaux viables; (7) l'importance d'augmenter l'éducation, afin d'augmenter le support social au développement durable, à la conservation des ressources, et à la protection de l'univers naturel. Les auteurs présentent des exemples d'applications récentes des principes d'éco-design dans la planification et l'aménagement des communautés humaines, de parc industriels et de réseaux, ainsi que dans la pratique de l'architecture et l'utilisation des produits. Les principes et la pratique de l'éco-design peuvent contribuer énormément au besoin urgent de faire des progrès rapides et tangibles vers une économie humaine durable.

Mots clés : design écologique, éco-design, développement durable, planification des communautés, architecture, parc industriel, produits verts, conservation biologique.

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Introduction

It is well known that planet Earth is experiencing a so-called environmental crisis. This crisis is characterized by three major themes:

- rapid growth of the human population and its associated economic activity;
- the depletion of both non-renewable and renewable resources; and
- extensive and intensive damage caused to ecosystems and biodiversity.

The dimensions of this crisis are clearly established. The key issues have been explored and are summarized in state-of-the-environment reports presented by a widely divergent group of interests, including Environment Canada (1996), the Organization for Economic Cooperation and Development (2001), the United Nations Environment Programme (2002), the World Wildlife Fund (2002), and the WorldWatch Institute (2002).

In part, the environmental crisis is a predicament of inappropriate design — it is a consequence of how cities have been developed, industrialization undertaken, and ecoscapes used. Fundamentally, the problem has been one of inadequate integration of ecological concerns into planning. This is evidenced by the comments of McDonough and Braungart (2002), who suggest that the dominant system of industrial production and mass consumption in the "developed" world operates as if it is designed to achieve the following results:

- the generation of gigantic amounts of discarded materials (much of which could potentially be recycled) that are disposed into landfills;
- even while enormous quantities of toxic chemicals are emitted to air, water, and soil;
- and certain materials are produced that are so dangerous they will require constant vigilance by many future generations;
- all governed by a plethora of complex regulations — designed not to keep people and natural systems safe, but rather to keep them from being poisoned or degraded too quickly;
- and achieving economic growth and wealth through the mining and degrading of the natural capital of both non-renewable and potentially renewable resources;
- while causing a severe erosion of the diversity of other species and of human cultures.

Although the current economic system is clearly non-sustainable over the longer term, environmentally literate readers will see the above characterization of its design as an oversimplification. Nevertheless, there is some merit to interpreting developed economies as having a pathological relationship with their base of natural resources and with the biosphere. Resolution of this problem is an enormous challenge to human civilization.

One concept that is increasingly being used to address the non-sustainability of the human enterprise is known as “ecological design”, or “eco-design” (Fuller 1975; Olkowski et al. 1979; Todd and Todd 1994; Scott 1999). Eco-design provides a framework for uniting conventional perspectives on design and management with environmental ones, by incorporating the consideration of ecological concerns at relevant spatial and temporal scales. If the principles of eco-design are rigorously applied, important progress will be made towards ecologically sustainable economic development.

History of the development of the concept

Some of the ideas of eco-design have ancient roots, and have been expressed in various ways. For example, in traditional subsistence agriculture, many cultures have grown crops using systems in which numerous species are cultivated in diverse mixtures, allowing the development of a relatively stable agroecosystem with a predictable yield. The Yanomamö of Amazonia, for instance, cultivate or wild-harvest hundreds of plants as sources of foods, medicines, and materials, using their intimate knowledge of local ecosystems and biodiversity to guide their enterprise (Van der Ryn and Cowan 1995). In China, traditional small-plot farmers have long practiced a highly integrated agriculture, growing a diversity of crops in complex rotations, while closely managing compost to maintain the quality of farmland and the output of crops; this was a forerunner of what is now called “organic” agriculture. In much of the Americas, Amerindian farmers grew as staples the “three sisters” (maize, *Zea mays*; beans, *Phaseolus vulgaris*; and squash, *Cucurbita pepo*) in a closely integrated system of organic cultivation.

Eco-design is also reflected in many traditional building designs that use local materials in their construction and are situated and designed to achieve optimalities of heating and cooling. Examples include traditional buildings constructed using adobe, animal hides, or living spaces excavated from soft rock (Van der Ryn and Cowan 1995).

Another antecedent of ecological design, which is an extension of the previous examples, involves the achievement of comprehensive livelihoods at the level of individual habitations or in small villages. In many rural contexts, the homestead and its integrated house and outbuildings have been the core of a largely self-sufficient enterprise that produced a livelihood for a nuclear or extended family by providing it with food, fiber, energy, and some surplus commodities for external trade. This locally sufficient economic system also commonly extended to the level of village or tribe. It might also extend more broadly, but only if there was enough surplus production and adequate transportation to engage in trade at a broader scale. This kind of locally sufficient system persists in many “less-developed” countries or regions, but it has been replaced in “developed” ones by more expansive corporate enterprises.

There have also been historical proponents of ecologically sound urban planning, building design, and green products and technologies. One early influence was Ebenezer Howard, an Englishman who in 1898 wrote about “garden cities”, which would be designed to include a “decency of surroundings” and “ample space, well built clean healthy housing, abundant garden space, [and] preservation of natural landscape” and to be “pollution and litter free” (Letchworth Museum 2003). These ideas were extended by Jane Jacobs (1961, 1969), who emerged in the 1960s as a champion of the incorporation of “neighborhood” elements into planning. This involved urban areas in which housing, shopping, employment, schools, and recreation are all developed in an integrated manner, fostering a sense of community among the residents, while decreasing the use of materials and energy for commuting and other kinds of longer-distance transportation.

Another important influence was the American architect Frank Lloyd Wright, who began to work at the beginning of the twentieth century (Fancher 2002). His ideas about “organic architecture” included the design of long, low-slung houses constructed of local stone and wood, with a fireplace to anchor the building to the earth, wide roof overhangs, inconspicuous entrances, slab construction instead of a dug-out basement, indirect and passive heating and lighting, the use of clear sealers on wood rather than paint, external drainage systems that do not require gutters and downspouts, and other naturalistic and minimalist elements.

Particularly since the 1960s, additional influences were blending into the historical ideas about ecological design. In part, the new ideas were emerging from small-scale experiments in architectural design, which were intended to lighten the intensity of ecological footprints. Many of the technologies and ideas, such as alternative building materials, renewable energy sources, organic means of agricultural production, and conservation and recycling of materials have subsequently been to some degree adopted. Interestingly, many of these "new" ideas involved the re-emergence of older ones in a more technologically advanced form, for instance: the use of wind power, small-scale hydro, and traditional building materials and methods (such as straw-bale, adobe, and wooden construction).

In the 1970s, John Todd began to experiment with artificially constructed wetlands as treatment systems for municipal sewage. He and his team conceived of living "machines" that would replicate some of what nature accomplishes in natural wetlands. The concept has evolved into "solar aquatic" treatment systems that have been constructed in such places as the Body Shop (Canada) headquarters in Toronto and the village of Bear River in Nova Scotia. Todd has gone on to explore natural models for mitigating other kinds of pollution.

Partly with this in mind, Benyus (1997) proposed a new science-based management model referred to as biomimicry, which "studies nature's models and then imitates or takes inspiration from these designs and processes to solve human problems." Benyus suggests that humans should use nature as a mentor for adaptive designs and functions: "doing it nature's way has the potential to change the way we grow food, make materials, harness energy, heal ourselves, store information, and conduct business."

This is similar to an idea advocated in a seminal article published in *Scientific American* by Frosch and Gallopoulos (1989), two executives at General Motors. They argued that: "the traditional model of industrial activity — in which individual manufacturing processes take in raw materials and generate products to be sold plus waste to be disposed of — should be transformed into a more integrated model ... In an industrial ecosystem, the consumption of energy and material is optimized, waste generation is minimized, and effluents of one process are used as resources in another process."

The ideas of Frosch and Gallopoulos (1989), supported by work undertaken by Ayres and others as early as the 1970s, has now evolved into the field of industrial ecology. Lowe, Warren and Moran (1997) have proposed the following vision for this new field, and for the design of the industrial system:

- industry operates within the limits of global, regional, and local carrying capacities, and in a mode preventative of environmental and ecological damage;
- industry reflects ecological principles in the design and operation of its activities, from the factory floor to the executive suite;
- materials are cycled through the economy to an optimal degree, approaching a closed-loop system to the degree possible;
- major energy sources are, to the degree possible, based on renewable sources, and are preferably solar-based;
- the use of renewable resources is in balance with their production and renewal;
- non-renewable resources are conserved and their actual or potential diminishment is appropriately valuated;

- the diversity of life is maintained as a foundation for the stability and viability of the ecological and economic systems;
- efficiency and productivity are in a dynamic balance with resiliency, assuring continued capacity to adapt to change;
- societies make the transition to an ecologically balanced economy while maintaining quality of life.

Arguably, this vision is a prescription for the design of ecologically sustainable industrial development.

At the larger spatial scale, concepts and knowledge from ecology have been central to developing the attributes of eco-designed habitat used for urban, industrial, and commercial purposes, or for integrations of these. In fact, McHarg (1967) became well known for advocating that ecological systems reflected in natural landscapes should be the basis for decisions on the means of human appropriation of land for development. He promoted a field called “ecological design”, which we might now call ecological planning. These designs would incorporate elements intended to provide space for native species and their habitats, thereby moving towards an integration of the legitimate needs of humans, other species, and natural ecosystems.

Rethinking the metabolism of homesteads and commercial enterprises became a central mission of the first generation of ecological designers (Van der Ryn and Cowan 1995). In the 1980s, the environmental movement developed into a broad-based political- and social-action endeavor that was seeking progress towards both sustainability of the human enterprise and the protection of nature. Great technical advances were made in the harnessing of solar and wind energies as renewable sources of power, and many environmentally friendly demonstration projects were undertaken.

These ideas were extended in the 1990s into larger-scale, integrated schemes, resulting in the emergence of the international eco-cities movement, constructed service ecosystems (e.g., to treat sewage), and ecologically integrated industrial parks (Schlarb 2001; Cote and Cohen-Rosenthal 1997). These, along with the use of life-cycle analysis of manufactured products and their means of production, have become key tools for conserving natural resources and for decreasing pollution.

At about that time, an integration of the concepts of ecology and economics also began to occur, and the field of ecological economics emerged (Costanza 1991, 1997; Daly and Townsend 1993; Jansson et al. 1993). This resulted in the emergence of the notion of full-cost accounting, which requires that resource depletion and environmental damage be valuated as costs and used in the determination of “profit”. As a result, damage caused to the environment was no longer considered a “free” externalized factor, and greater legitimacy was given to actions that avoided or repaired such damage.

By the beginning of the 21st century, eco-design had emerged as an expression of a sustainability world-view, which seeks to integrate the human enterprise with a sustainable harvest of resources, while ensuring that stresses caused to natural ecosystems are within the bounds of viability. If this can be achieved, the integrity of both the human economy and of natural ecosystems can be maintained. As such, eco-design is an all-encompassing concept, as it deals with the sustainability of:

- the enterprises of families, neighborhoods, and cities;
- the construction of buildings in a manner that decreases resource use and environmental damage to the degree possible;
- the manufacturing of certifiably green products;
- the organic production of foods and other renewable resources;

- the integration of these various activities within ecologically planned mutualisms, such as industrial and business parks, which are designed to maintain high production while reducing the use of resources and minimizing waste; and

- the maintenance of indigenous biodiversity.

Understanding the concept

In essence, any form of design that minimizes environmentally destructive impacts by emulating and integrating with natural ecosystems can be referred to as eco-design. As such, eco-design seeks to provide a framework for an environmentally appropriate system of design and management by incorporating both anthropogenic and ecological values, at relevant spatial and temporal scales. The concept of eco-design involves several key aspects, which are explained below:

- **Meet the inherent needs of humans:** Humans and their economies cannot exist without using natural resources as sources of food, materials, manufactured products, and energy. Humans must also have opportunities to engage in livelihoods, and to have an acceptable standard of living. Inevitably, however, some degree of environmental damage is caused by the human economy. The key to sustainability of the human enterprise is to ensure that resources are not depleted and that damage caused to the natural world does not exceed the limits of tolerance and viability of species and natural ecosystems. A goal of eco-design is to help meet this vision of ecological sustainability, by finding ways of manufacturing goods, constructing buildings, and planning more complex enterprises, such as business and industrial parks, while reducing resource consumption and avoiding ecological damage to the degree possible.

- **Move toward resource sustainability:** Strictly interpreted, a human economy that is sustainable over the longer term must be based on the wise use of renewable resources, which are capable of regenerating after harvesting and can potentially be available for many generations. In contrast, non-renewable resources are diminished by use; although they can contribute to economic growth, they cannot be used as the primary basis of a sustainable economy. Eco-design strives to achieve an increasing reliance on renewable sources of energy and materials, while maintaining standards of quality of goods and services and reducing overall resource consumption, waste generation, and ecological damage through efficiencies of use, re-use, and recycling. These principles can be applied to the design and operation of buildings and cities, the manufacturing of goods, and other economic activities.

- **Maintain ecological integrity:** Ecosystems are life systems — they are environments that support biodiversity and natural communities, while also providing critical support for the human enterprise. Maintenance of the integrity of ecosystems must be considered a key element of economic sustainability. As such, a purpose of eco-design is to integrate human activities with the structure and dynamics of natural flows and cycles of materials, organisms, and energy. This begins with development of an understanding of the ecological context of particular design problems, and then developing solutions consistent with that circumstance. To achieve this, the eco-designer must have a clear idea of both (*a*) the economic activity being contemplated and (*b*) the limitations of nature to support that enterprise. What, for instance, are the implications of a proposed anthropogenic activity for the viability of populations of native species, for maintaining representatives of all natural ecosystems, and for essential ecological services (such as clean water and air, and carbon storage in ecosystems)? To understand how alternative designs would affect these natural values, the designer needs a detailed understanding of local ecosystems and environments, including climate, topography, soil, water, flows of energy and materials, biotic communities, and critical habitat of at-risk species. This information can be used to define the carrying capacity of the study region for the proposed economic activity, allowing the eco-design to be accommodated within the identified ecological limits. This planning process is similar to that used in conventional environmental impact assessment, but eco-design places a stronger and limiting emphasis on maintaining or enhancing natural ecological values. When the eco-design and project implementation are finished, the result should be a sustainable economic activity that still maintains viable levels of native biodiversity and ecosystem services over the longer term, at levels considered appropriate to local and regional climate, soil, and other environmental conditions.

- **Emulate natural ecosystems:** Natural ecosystems are characterized by complex patterns and dynamics of biodiversity, materials, and energy, occurring at various spatial and temporal scales. These patterns reflect the long- and short-term influences of biological evolution (including speciation and extinction), disturbance and successional regimes, environmental change (i.e., in climate), species introductions, and anthropogenic influences associated with pollution and other stressors. Biodiversity plays a critical role in ecosystems, in part by forming a globally integrated web of producers and consumers, the healthy functioning of which is related to symbiotic relationships, resource availability, nutrient and biomass cycling and retention, and the intensity of environmental stressors. The biosphere represents the largest ecological scale — within it the waste oxygen of blue-green bacteria may be absorbed by blue whales, whose own emission of carbon dioxide may fertilize spruce or oak trees, and so on. Such cycling also occurs at much smaller scales, for example, within a particular stand of forest. A central goal of eco-design is to emulate these natural ecological qualities when planning for anthropogenic activities, so the resulting effects will be relatively "natural". Emulation of the structure and function of natural ecosystems can be expressed in various ways. For example, to the degree possible, it is necessary to:

  — **design towards an integrated web of economic and ecological activities,** to develop a diversity of industries and businesses whose use of energy and materials is, to some degree, symbiotic, while also being within the capacity of natural systems to absorb the resulting impacts. The tools of ecological footprint and life-cycle analysis are particularly useful in identifying linkages and understanding the web of integrations of economic activities and the natural world. For instance, in the design of an industrial park, the cluster of enterprises should be designed to incorporate a degree of interdependence of energy and material use — the discarded materials of one process becomes a resource for another, integrated process. This allows the consumption of energy and materials to be reduced, and the generation of wastes to be minimized.

  — **accommodate the natural regime of ecological stressors and disturbances,** thereby maintaining a relatively high degree of support for environmental services and indigenous biodiversity. Horticultural landscaping, for instance, should be designed to mimic the ecological dynamics appropriate to the region, including the use of native species to develop facsimiles of natural communities. This takes advantage of local adaptations and avoids the grievous damage potentially associated with non-native plants, animals, and pathogens.

- **Eliminate natural debt:** Many economic activities cause environmental damage that is not routinely repaired or offset. Consequently, the calculated "profit" of the enterprise does not account for all of the environmental costs of production, resulting in an accumulation of so-called "natural debt". For instance, if a building relies on electricity purchased from a coal-fired utility, that energy is associated with: toxic ash that may cause soil and water pollution; emissions of sulfur dioxide and oxides of nitrogen that contribute to acidifying deposition; and of carbon dioxide, an important greenhouse gas. In conventional economics, the cost of the coal-fired electricity does not fully account for the fact that its generation causes environmental damage, which is considered a "free" good in the marketplace. Although the utility is making money in the conventional marketplace, from the perspective of environmental economics there is an accumulating debt to nature associated with pollution, disturbance, and resource depletion. In the same sense, the global economy has been rapidly growing for centuries, but this increase has been achieved at the expense of massive resource depletion and extensive ecological damage — these environmental externalities are key components of natural debt. Environmental economics is an alternative way of looking at these complex systems, involving the full costing of resource depletion and environmental damage. As such, eco-design seeks to comprehensively account for all of the costs and environmental implications of alternative choices of design. It considers a wide range of environmental impacts in a holistic manner, over the entire life-cycle of the project, from the extraction of natural resources, through manufacturing of components, to construction and operation, and finally deconstruction, re-use, recycling, and disposal of components. Eco-designers consider whether these comprehensive aspects of project design contribute to meeting the needs of a proposed development, as well as the possibility that there might be unfavorable environmental impacts. If the latter are identified, steps are taken to eliminate or minimize them to avoid the externalities of natural debt, so as to realize true, fully costed, economic profit.

- **Protect natural habitat:** Even while earnest attempts are made to avoid ecological damage through eco-design, it is inevitable that changes will result from implementation of any project. In particular, some elements of native biodiversity may be threatened by economic activities. For this reason, it is important to consider whether the ecological risks should be offset by designating protected areas that are not used intensively by humans, and are intended to sustain species and natural ecosystems that are incompatible with the proposed project or with the human economy in general.

- **Increase environmental literacy:** Environmental protection is a broad societal responsibility. Eco-design is the work not only of experts, but of entire communities — it entails deep cooperation among designers, government, businesses, and citizens. Designers must listen to the public voice in the design process, and heed advice about local conditions and special places. However, if citizens are not literate about the causes and consequences of ecological damage, some of their choices and advice may not be environmentally appropriate. This can influence the kinds of architecture and community that they prefer and advocate to politicians and businesses. As such, when eco-designers begin to design a community, they must first establish the degree of environmental protection that is achievable — there must then be agreement among government, businesses, and the populace on such key questions as the degree of protection of natural habitat, and the amount of investment in pollution control. It must be recognized that environmental literacy is part of the context of environmental protection, because it influences how much people are willing to "pay" for sustainable development.

The application of eco-design

The principles of ecological design can be applied within a continuum of spatial scales, ranging from individual homes, to neighborhoods and industrial parks, as well as to particular manufactured products.

Urban planning

Eco-design can be applied to both the improvement of existing urban areas and communities, as well as planning for new ones. Improvements of existing areas begin with the identification of such environmental problems as inefficiencies of use of materials and energy (associated, i.e., with excessive transportation distances, or inadequate coordination among businesses in the use and disuse of resources), environmental pollution, and conflicts with indigenous biodiversity, followed by efforts at mitigation and restoration ecology. Related socioeconomic issues must also be considered and dealt with, including commuting distances, the development of economically integrated neighborhoods, and equity issues. These improvements can be retrofitted onto the existing infrastructure and functions of an urban area, or implemented when it is being re-developed. To the degree possible, eco-design will utilize planning improvements that are intended to:

- minimize the use of energy and materials, i.e., by encouraging the use of renewable sources, by recycling, by decreasing transportation distances, by encouraging the consumption of locally grown food, and by promoting public transit, bicycles, and walking;
- provide high levels of ecosystem function, by avoiding the pollution of air, water, and soil and by maintaining carbon storage in vegetation;
- naturalize urban ecosystems by increasing or maintaining the dominance of native species and their communities. For instance, an urban forest dominated by native trees can provide environmental services related to cooling, heat retention, pollution mitigation, carbon storage, and aesthetics, while also providing habitat for many indigenous species. Various instruments can be used to encourage these environmental improvements, including planning by-laws and regulations, as well as taxation that adjusts prices to account for the true cost of using natural resources and any resulting damages. For instance, energy-inefficient private motor vehicles might be heavily taxed, while walking, bicycles, and public transit are subsidized.

In a new development, however, there is a particular opportunity to integrate the principles and practices of eco-design into the planning of an eco-community. This would begin with an investigation of local ecosystems and native species, allowing ecologically sensitive areas to be identified and conserved. This helps provide for appropriate levels of environmental services while conserving natural areas for indigenous biodiversity, but at the same time providing people with recreational opportunities and natural aesthetics. The amount of natural area to be conserved varies with the ecological circumstances, but it would be substantial and perhaps not be less than one-third of the total area. In areas where infrastructure for residences, businesses, industry, institutions, transportation, waste management, and communications are to be developed, the planning should strive to minimize the use of space, materials, and energy to the degree possible, while also incorporating natural elements (such as the use of native species in horticulture). There should be organizational structures (whether private, governmental, or non-governmental) to encourage the efficient recycling and reuse of disused materials among integrated commercial and industrial enterprises, and the environmentally safe processing and discarding of wastes. Environmental quality would be maintained using certification procedures, technological innovation, and by monitoring ecological integrity to identify any problems that might arise.

Industrial parks and networks

Eco-design has the potential for developing environmental synergies through the coordination of economic activities among commercial or industrial enterprises. A key aspect of this design is the development of a web of enterprises connected to form an efficient and inter-dependent system, in which discarded materials and (or) heat of processes are used as inputs to others. In this sense, “wastes” have value to other modes of production, allowing them to be reclaimed, reused, or recycled as “resources”, thereby achieving progress towards a zero-emission ideal. Achieving such a complex economic and manufacturing system requires that businesses, the public sector, and the community all integrate their activities to manage their use and emissions of energy and materials, so as to minimize the net environmental impact. This includes the development of essential environmental services to serve an integrated development (i.e., park-wide rather than by individual company), such as water and sewage management, hazardous waste treatment and disposal, and environmental health and safety training for employees. There is also scope for the fostering of native biodiversity values to some degree, even within the spatial context of industrial parks.

Architecture

Although much progress has been made, it is still necessary to pay more attention to energy and resource efficiency in the construction and operation of buildings. This can be achieved by designing to: minimize the use of land, conserve heat in winter and cool in summer, reduce emissions of pollutants, and naturalize the landscaping. For instance:

- the use of land can be optimized by designing multi-storied buildings instead of sprawling ones, and by efficiently allocating internal space to various needs;
- energy use can be decreased by using passive and (or) active solar heating technologies in winter, shading and reflecting surfaces in summer, and efficient insulation, windows, lights, and appliances; externally, trees can be positioned to provide shade in summer and wind-shielding in winter; in some cases, low-grade "waste" heat from thermal power plants can be used in nearby buildings;
- building materials and furniture can be selected to be efficiently manufactured (in terms of the consumption of energy and material) from renewable resources, to be long-lasting yet readily reused or recycled, and to not emit indoor pollutants;
- locally traditional (or vernacular) design elements can be incorporated into buildings to improve their energy and material efficiency, aesthetics, and comfort, while also respecting cultural heritage. For example, adding adobe or other thermal mass to buildings constructed in desert regions makes it easier to keep their interior cool;
- emissions of wastes can be reduced in many ways, such as designing to:
    - — replace in-house fossil-fueled systems for heating and cooling, with their attendant emissions of SO_2, NO_x, and CO_2, with centrally generated electricity, which because of economies of scale can have smaller emissions of these pollutants (in the case of non-fossil-fueled generating systems, there are no emissions of these gases);
    - — install low-flow faucets and toilets to conserve water, while ensuring that sewage and gray water are effectively treated;
    - — have comprehensive systems to reduce, reuse, and recycle disused materials, such as paper and other materials;
- landscaping can be naturalized by utilizing only native plants in horticulture, and by designing to simulate natural communities appropriate to local conditions, while respecting the need for pleasant aesthetics and low-impact recreational use.

Products

Eco-design has been applied extensively to the development and manufacturing of certain products, especially in western Europe. With continuing increases in the human population and in industrial production and consumption, concerns have been raised about the environmental burdens associated with the extraction and harvesting of materials, the manufacturing of products, the use of the products, and finally their recycling or disposal. Within this context, eco-design is recognized as a strategy that can be applied to reduce the impacts associated with the production and consumption of products. Management tools have been developed that permit product designers to assess the benefits that may be realized by modifying products to reduce their overall environmental impacts. For example, the Life Cycle Design Wheel (LiDs Wheel; UNEP 1997) allows a designer to compare an existing product to an environmentally modified one in terms of:

- selecting low-impact materials
- reducing material use
- optimizing production techniques
- optimizing distribution systems
- reducing impact during use
- enhancing durability
- optimizing recovery, reuse, and recyclability

There are now many examples of the application of eco-design to products. Xerox Corporation, for example, has set "zero waste" as a corporate goal and has established an Asset Recovery programme. It leases photocopiers, and recovers and remanufactures components for use in replacement copiers with like-new guarantees. Similarly, the Interface Corporation has introduced a "green lease" programme in which it will lease modular carpets to clients, while retaining ownership, and monitoring product service and replacing worn modules as necessary. Recovered carpet modules are returned to the factory where their material will be recycled into new carpet.

The adoption of closed-loop and life-cycle thinking by large companies, and its integration into the design and production of their products, is being fostered by various influences. These include environmental concerns associated with land-filling and incineration of waste materials, as well as an increasing realization that resource stocks must be conserved. It is also being driven by consumer choice that is becoming increasing reflective of environmental concerns. This latter context is reflected in the establishment of various eco-labeling programmes, such as Canada's Environmental Choice, which is designed to inform consumers of the environmental features of products.

Selected examples of the application of eco-design

An eco-community

Many communities are developing action plans for sustainable development. One Canadian example is Hamilton-Wentworth, a regional municipality located in the country's manufacturing and commercial heartland of southern Ontario. In 1990, its Regional Council organized a Citizens' Task Force on Sustainable Development that met with more than 1000 citizens and developed a three-part community vision: (1) *Vision 2020: The Sustainable Region*; (2) *Directions for Creating a Sustainable Region*; and (3) *Detailed Strategies and Actions for Creating a Sustainable Region*. These initiatives were adopted by the Regional Council as a guide to decision-making, and in following years a number of projects and programs were implemented, including the building of community awareness. Eleven key areas were highlighted, as follows (Regional Municipality of Hamilton-Wentworth 1995, 2003):

- Protecting a system of interconnected natural areas by identifying suitable sites and corridors; to date, about 3500 ha (3% of the regional municipality) have been protected;
- Improving the quality of surface waters by: implementing a user-pay system for use of municipal water, selling 12 000 conservation kits to residents (including low-flow faucets), and constructing four combined storm-sanitary overflow storage tanks for the sewage handling system; these and other key actions resulted in people being able to swim in the western end of Hamilton Harbour for the first time in more than 50 years;

- Enhancing urban vegetation to improve air quality, while achieving many additional environmental benefits. This was largely done by developing a standard for the amount of vegetation required on residential lots, and by the local Conservation Authority planting more than 300 000 trees in the regional municipality;
- Reducing solid waste by establishing an exchange depot, by recycling materials, and by instituting a composting programme for organics. More than 30 000 t of "waste" have been annually diverted through the recycling and waste-reduction programs, and over 40 000 households now engage in backyard composting;
- Reducing energy consumption by converting public vehicles to lower polluting fuels (primarily natural gas), and by enhancing bicycle use by constructing more than 20 km of lanes and installing 150 parking racks in a community where none existed prior to 1994. In addition, the Hamilton-Wentworth Green Venture will audit about 5000 homes and businesses annually for energy and water consumption and waste production;
- Creating a more compact and diverse urban footprint by designating and enforcing firm land-use boundaries consistent with the urban development plan;
- Encouraging a better model of public transit by improved routing and progressively converting buses to run on natural gas;
- Ensuring good health and well-being of citizens through efforts to improve the accessibility of an affordable and nutritious food supply, safe drinking water, and acceptable housing;
- Enhancing the local economy by creating a resource centre to support local businesses, including those with an environmental focus; the region has a relatively low unemployment rate;
- Empowering the community by holding regular town-hall meetings and other forums to facilitate citizen input. More than 2000 people attended the second VISION 2020 Sustainable Community Day in 1995, and over 75% of the cost of the event was provided by grants from local businesses;
- Supporting the local agricultural sector by encouraging the direct sale of farm produce to the public.

An eco-industrial park

As defined by the President's Council on Sustainable Development (1996), an eco-industrial park is a "community of businesses that cooperate with each other and with the local community to efficiently share resources (information, materials, energy, infrastructure, and natural habitat), leading to economic gains, improvements in environmental quality, and equitable enhancement of human resources for business and the local community." Burnside Industrial Park in Dartmouth, Nova Scotia is one example of a park being transformed to achieve those characteristics. As a result of coordinated initiatives taken by the federal, provincial, and municipal governments and Dalhousie University's Eco-Efficiency Centre, Burnside now exhibits various design features and guidelines to foster environmental goals (Cote and Crawford 2003), including:

- improved material-use efficiency through the cycling and cascading of materials among local businesses;
- an increase in the number and diversity of local "scavengers" (i.e., businesses that collect disused material for reuse, remanufacturing, and recycling) and "decomposers" (i.e., businesses that perform these functions); in 2003, about 15% of the companies in the Park filled niches categorized as reuse, rental, repair, remanufacture and recycling;

- an on-site center to catalyze integrated actions and to disseminate environmental information (as of 2004, 164 environmental reviews of companies had been undertaken);

- economic instruments to promote recovery, reuse, repair and recycling of resources (including tipping fees, water-use fees, and sewer-use fees); and

- bans on landfill disposal and sewer use for certain purposes (paper, cardboard, glass and organic waste are banned from regional landfills; corrosive chemicals are prohibited from sewer disposal and most metals and many organic chemicals are restricted).

A building

One of the most environmentally appropriate or "green" buildings in Canada is operated by Mountain Equipment Co-op Ltd (MEC) in Winnipeg, Manitoba (MEC 2003). Although all MEC facilities have adopted a philosophy emphasizing the need to reduce, reuse, recycle and rethink, the Winnipeg store is regarded as its most advanced demonstration. The store was re-developed from three former buildings, which were carefully dismantled and renovated to facilitate reuse of 75% of the original materials. The MEC facility was also designed and built to maximize energy efficiency and reduce wastes. For example, a criterion for the selection of new materials to use in construction set a limit of 500 km over which they could be transported from their site of manufacture. In addition, the materials used had to emit no ozone-depleting substances, have low embodied energy, have low inherent toxicity, and minimal environmental impact. Energy consumption is projected to be 60% below the model National Energy Code for buildings.

Chemicals, processes, and products

Various substances, processes, and products are being developed and used to replace more damaging alternatives, such as the following examples:

- Rohm and Haas Company, a chemical manufacturer headquartered in Philadelphia, Pa, has developed a marine anti-foulant to replace the use of tributyltin oxide (or TBTO; this compound is widely considered a toxic threat to the marine environment). Their substitute is based on 4,5-dichloro-2-octyl-4-isothiazolin-3-one, and it degrades rapidly in seawater without bioaccumulation and has a much smaller acute toxicity to marine organisms than TBTO (Jensen 2001). This chemical won the 1996 Designing Safer Chemicals Award of the European Environmental Agency.

- The Dow Chemical Company has developed and is using commercially 100% carbon dioxide as a blowing agent to manufacture polystyrene foam packaging, replacing a previous use of ozone-layer depleting chlorofluorocarbons and hydrochlorofluorocarbons (Jensen 2001).

- Imation, an information technology company, has developed a photo thermographic imaging system that uses no wet chemistry, generates no effluent, and requires no drying steps that emit contaminants to the atmosphere (Jensen 2001).

- McDonough and Braungart (2002) were contracted to develop a fabric that would breathe and be strong; there were also criteria relevant to the potential for causing acute toxicity, mutagenicity, carcinogenicity, endocrine disruption, environmental persistence, and bioaccumulation. The resulting fabric is called Climatex, which resulted from an exhaustive study of more than 8000 chemicals, from which 38 were identified as potentially suitable (see Climatex 2003).

Societal and ecological benefits of eco-design

The principles and practice of eco-design are focused on the planning of environmentally friendly architecture, communities, industries, and products. However, there is always a need to import supporting commodities from other regions, including food, timber, metals, water, fossil fuels, and other kinds of energy and materials. To the degree possible, reliance should be placed on renewable sources of these essential resources (because renewable resources are the ultimate foundation of a sustainable economy), and environmental damage should be minimized during their extraction and processing. For instance, the provision of food supplies should not involve unacceptable environmental damage associated with long-distance transport or with the use of pesticides, fertilizers, or water — the practices of organic agriculture are especially useful in these regards.

Compared with conventional modes of planning and economic development, the practice of eco-design could potentially yield great social and environmental benefits. Esty and Chertow (1997) have suggested that we need to think ecologically, moving from an environmentalism largely driven by sectoral issues involving pollution, resources, and biodiversity, to a more integrated "ecologicalism that recognizes the inherent interdependence of all life systems." This approach would acknowledge the need for co-sustainability of the economies of present and future generations of humans, in concert with the needs of other species and natural ecosystems. Eco-design is intended to conserve ecological integrity, while allowing ecosystems to provide sustainable flows of resources and to maintain critical services required by the human economy. Potentially, eco-design can contribute to the wise use of natural resources and the conservation of natural habitats, while still allowing people to engage in livelihoods that provide manufactured products and economic services. The ecologically sustainable development that results will accumulate little in the way of "natural debt", while allowing people to have a comfortable and equitable lifestyle.

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