ECOLOGICAL ENGINEERING IN THE URBAN ENVIRONMENT

John Hadjinicolaou
Department of Building, Civil, and Environmental Engineering, Concordia University, Montreal,Canada.

Keywords: Ecological Engineering, Ecotechnology, Sustainable development, Ecocity, Ecological Concepts, Ecological Principles, Scenario Techniques, Remote Sensing, Ecological Integration.

Contents

Summary

Ecotechnology and Ecological Engineering are based on ecological considerations and attempts to optimize ecosystems and man-made systems for the benefit of both. To find the optimal solution for the entire system the necessity for a holistic view of environmental systems becomes apparent. Ecological Engineering should not only be able to solve many of the society’s traditional environmental problems but should understand well the ecosystem science and work towards the successful integration of

the two. In the past two decades concepts, principles, methods and techniques have been developed in the area of Ecological Engineering without yet their complete integration into a sophisticated framework. The Ecological Engineering of the urban environment under different names and labels (urban ecology, urban ecotechnology, etc.) grew out of the principal concept of sustainable urban development and the extra emphasis placed by the agenda 21 proposal of the United Nations towards the improvement of the city's quality of life. Unified strategies have been developed together with methods, techniques, and scenarios for general and particular applications. A number of very successful case studies have been reported. A more generalized methodical framework needs to be established which will integrate the many elements and processes into a complete environmental accounting scheme for the urban level towards future improvements.

1. Introduction

We are approaching an age of diminishing resources, the growth of the human population is continuing, and we have not yet found means to solve local, regional, and global pollution problems properly. About two decades ago, ambitious goals such as "zero discharge," defined as the complete elimination of pollution from entering the environment, were seriously discussed. There was a strong belief in the possibilities that environmental technology offered. Today we have finally recognized that we cannot achieve the complete elimination of, pollutants owing to a number of factors. *First*, we have a finite quantity of resources to address to the problems of pollution control. This is particularly true for developing countries. *Second*, when we offer a technological alternative we are usually transferring the material from one medium (e.g., air) to another (e.g., water). We must seek additional means to reduce the adverse effects of pollution, while at the same time preserving our natural ecosystems and conserving our nonrenewable energy resources. Ecotechnology and ecological engineering offer such additional means to cope with pollution problems, by recognition of the self-designing properties of natural ecosystems.

Pollution problems became widely recognized during the 1960s. Although many billions of dollars have been invested all over the world on solutions of these problems we are still far from an acceptable solution to many serious problems, which threaten the survival of *Homo sapiens.* Some even claim that we are further from a total solution of our environmental problems today than we were 10 to 20 years ago, owing to the continuous growth of population and continuous disappearance of natural resources. We must acknowledge that there are 2 billion more people on earth and that the non-renewable resources are more limited today than 20 years ago.

We therefore need to find new ways. We have attempted to solve the problem by use of available technology. It has partially failed. Therefore we must think more ecologically and consider additional means. Ecotechnology and Ecological engineering is based on ecological considerations and attempts to optimize ecosystems (including limited resources) and man-made systems for the benefit of both. It should therefore afford additional opportunities to solve the crisis. The limited resources and the high and increasing human population force us to find a trade-off between the two extremes of pollution and totally unaffected ecosystems. We cannot and we must not accept a situation of no environmental control, but we cannot afford zero-discharge policies either, knowing that we do not provide one-third of the world's population with sufficient food and housing.

All applications of technologies, whether of biotechnology, chemical technology, or ecotechnology, require quantification. Because ecosystems are complex systems, the quantification of their reactions becomes complex. However, ecological modeling represents a well-developed tool to survey ecosystems, their reactions, and the linkage of their components. Ecological modeling is able to synthesize the pieces of ecological knowledge, which must be put together to solve a certain environmental problem.

The application of ecological modeling in engineering emphasizes the need for a holistic view of environmental systems. Optimization of subsystems does not necessarily lead to an optimal solution of the entire system. There are many examples in environmental management where optimal management of several aspects of a resource separately does not optimize management of the resource; for example, in some governments, water quality is controlled by one agency and water quantity by another, often leading to conflicting policies and regulations.

Ecological engineers should not only focus on solving many of society's traditional environmental problems, including wastewater treatment, hazardous waste cleanup, by-product resource recovery and air quality management, but they should also be capable of ensuring the viability and increasing the sustainability of agricultural production. Additionally, ecological engineers should be applied ecologists, able to interact with theoretical scientists in designing, creating and managing solutions to complex ecological problems. Ecological engineers should be able to address issues such as terrestrial, aquatic and wetland restoration, sustainable development, biodiversity conservation planning, watershed sustainability analysis and ecological risk assessment.

Ecological engineers should not only be able to solve many of society's traditional environmental problems:

- Wastewater treatment
- Hazardous waste cleanup
- By-product resource recovery
- Air quality management.

But ecological engineers should understand ecosystem science well enough to:

- Create and manage solutions to complex ecological problems
- Restore terrestrial, aquatic and wetland ecosystems
- Encourage sustainable development
- Conserve biodiversity
- Design sustainable watershed management plans
- Perform ecological risk assessment
- Increasing the sustainability of agricultural production.

2. Ecological Engineering or Ecotechnology

2.1 Definitions

Ecological engineering or E*cotechnology* is defined as the design of human society with its natural environment for the benefit of both. It is engineering in the sense that it involves the design of this natural environment using quantitative approaches and basing our approaches on basic science. It is a technology with the primary tool being self-designing ecosystems. The components are all of the biological species of the world.

In 1962, H. T. Odum was among the first to define ecological engineering as "environmental manipulation by man using small amounts of supplementary energy to control systems in which the main energy drives are still coming from natural sources. Formulas for ecological engineering may begin with natural ecosystems as a point of departure, but the new ecosystems, which develop, may differ somewhat. ..." Then, in 1971 he developed the concept of ecological engineering in his book *Environment, Power and Society* as follows: "The management of nature is ecological engineering, an endeavor with singular aspects supplementary to those of traditional engineering. A partnership with nature is a better term." He later states in his comprehensive work *Systems Ecology* that "the engineering of new ecosystem designs is a field that uses systems that are mainly self-organizing."

Uhlmann, Straskraba and Gnauck have defined ecotechnology as the use of technological means for ecosystem management, based on deep ecological understanding, to minimize the costs of measures and their harm to the environment.

Over the last four decades, others have amended the original definition as “the design of ecosystems for the mutual benefit of humans and nature”, and “the design of sustainable systems consistent with ecological principles that integrate human society with its natural environment for the benefit of both”. Throughout this same period the field has evolved, through countless investigative endeavors worldwide and diligent academic planning at select institutions, from a simple idea into a widely demanded and well practiced specialty of engineering, albeit informally.

2.2 Terminology

It may also be useful in discussing what ecological engineering and ecotechnology are first to define what they are not. Ecological engineering is not the same as *environmental engineering*. The environmental engineer is certainly involved in the application of scientific principles (*unit processes)* to clean up or prevent pollution problems, and the field is a well-honored one. Environmental engineers are taught and use valuable environmental technologies called Unit operations.

Ecological engineering, by contrast, is involved in identifying those ecosystems that are most adaptable to human needs and in recognizing the multiple values of these systems. Ecological engineering and ecotechnology use the basic principles of science mainly to design a better living for human society. However, unlike other forms of engineering and technology, ecological engineering has as its reasons to be the design of human society with its natural environment, instead of trying to conquer it. And unlike conventional engineering, ecological engineering has in its toolbox all of the ecosystems, communities, organisms, that the world has to offer.

Ecological engineering and ecotechnology should also not be confused with *bioengineering* and *biotechnology*. Biotechnology, by its very design, involves the manipulation of the genetic structure of the cell to produce new, strains and organisms capable of carrying out certain functions. Ecotechnology does not manipulate at the genetic level, but considers an assemblage of species and their abiotic environment as a self-designing system that can adapt to changes brought about by outside forces like the changes introduced by humans or the natural forcing functions.

Biotechnology has begun with enthousiasm but now is beginning to realize the enormous costs and concerns arising from manipulation at this micro level. In contrast, ecotechnology introduces neither new species that nature has not dealt with before, nor does it involve major laboratory development costs except for microcosm studies of new combinations of organisms.

2.3 Concepts of Ecological Engineering

Misch and Jorgensen in their pioneering work on Ecological Engineering (1989) view Ecotechnology based on the following concepts;

Concept 1: Self-Design
Ecotechnology involves an acceptance of the concept of the self-designing capability of ecosystems and nature. We may even go so far as to say that the concept of a polluted ecosystem is an anthropogenic view, one that may not recognize the beauty of natural systems shifting, substituting species, reorganizing food chains, adapting as individual species, and ultimately designing a system that is ideally suited to the environment that is superimposed on it. The ecosystem also does another wonderful thing; it begins to manipulate its physical and chemical environment to make it a little more palatable! It is this self-designing capability of ecosystems that ecological engineering recognizes as a significant feature, because it allows nature to do some of the “engineering." We participate as the choice generator and as a facilitator of matching environments with ecosystems, but nature does the rest.

Concept 2: Ecosystem Conservation:
Just as an engineer depends on an abundance of tools and raw materials to design and build products and processes, so too does the ecological engineer depend on an abundance of species and ecosystems. Therefore it would be counterproductive to eliminate, drain, or even disturb natural ecosystems unless absolutely necessary. These are the environments that protect the biological diversity that the ecological engineer may call on one day. This means that the ecotechnology approach will lead to a greater environmental conservation ethic than has up to now been realized. It has been noted, for example, that when wetlands were recognized for their abiotic values of flood control and water quality enhancement in addition to the long understood values as habitat for fish and wildlife, then wetland protection efforts gained a much wider degree of acceptance and enthusiasm. Recognition of ecosystem values leads to conservation of ecosystems.

Concept 3: Solar Basis:
Because ecosystems are solar-based systems, either directly or indirectly (with the possible exception of biological communities that have developed along vents in the abyss of the oceans), the concept of self-sustaining systems is basic to ecotechnology. Once a system is designed and put in place, it should be able to sustain itself indefinitely with only a modest amount of intervention. This means that an ecosystem, running on solar energy or the products of solar energy, does not have to depend on technological energies as much as would high tech solutions. If the system does not sustain itself, it does not mean that the ecosystem has failed us (its behavior is ultimately predictable). It means that we have not designed the proper interface between nature and the environment.

The management of ecosystems is not an easy task, but complex problems of complex systems should not be expected to have easy solutions. Most environmental problems require the application of environmental technology as well as ecotechnology to find an optimal solution. This again will require a deep ecological knowledge to understand the processes and reactions of ecosystems to possible management strategies. Recognition of nature's ability to self-design to its forcing function is also necessary to find the right ecotechnological methods. Thus ecology becomes the basis of ecotechnology just as genetics is for biotechnology, as chemistry is for chemical engineering, and so on.

All new technologies have grown from their basic science. When the basis in science was sufficiently strong, the technology emerged. During the past two decades, the fields of ecology and environmental science have grown very rapidly. So the time is mature for ecotechnology to appear on the stage after waiting in the wings for several years. Ecological engineering must be based on sound ecological methods and a thorough understanding of ecosystems, their reactions, and their information subsystems (species), just as biotechnology requires understanding the cell and its information (genetic) subsystems.

3. Ecological Engineering Methods, principles, and Applications

3.1 Ecological Engineering Methods

Table 1, shows some of the ecotechnological methods and their examples that are classified according to the engineering approach used.

Ecological Eng. approach	Terrestrial Examples	Aquatic Examples
Nutrient recycling	Sludge disposal on agriculture land	Recycling in wetlands
Hydrologic modification	Artificial ponds and wetlands	Control of retention time of reservoirs
Ecosystem recovery	Coal mine reclamation	Restoration of lakes
Enhancement of ecological diversity	Tropical forest management	Bio-manipulation in lakes

Ecological sound biotic harvest	Good forestry practices	Multi-species fisheries

Table 1. Examples of ecological Engineering Approaches for terrestrial and aquatic systems (Misch and Jorgensen, 1989)

The various approaches are based upon one or more of the following considerations:

1. Ecosystems are used to reduce or solve a pollution problem that otherwise would be very harmful to other, or other types of ecosystems. Examples are sludge disposal and wastewater recycling in terrestrial ecosystems or wetlands.
2. Ecosystems are imitated or "copied" to reduce or solve a pollution problem, leading to artificial ecosystems that can cope “on behalf of”, natural ecosystems. Examples are integrated fishponds and created wetlands.
3. The recovery of ecosystems is supported after significant disturbances. Examples are coal mine reclamation, methods for restoration of lakes and rivers, and biomanipulation (such as the use of grass carp to reduce eutrophication).
4. Ecosystems are used for the benefit of humankind *without* destroying the ecological balance, that is, utilization of the ecosystem on an ecologically sound basis. Typical examples are the use of agroecosystems and a sound ecological basis for the harvest of renewable resources.

3.2 Ecological Engineering Principles

- Ecosystem structure and function are determined by the forcing functions of the system. Alterations of the forcing functions cause the most drastic changes in ecosystems.
- Ecosystems are self-designing. The more one works with the self-designing ability of nature, the lower the costs of energy to maintain that system.
- Elements are recycled in ecosystem. Matching humanity and ecosystems in recycling pathways will ultimately reduce the effects of pollution.
- Homeostasis of ecosystem requires accordance between biological function and chemical composition.
- Processes in ecosystems have characteristic time scales that may vary over several orders of magnitude. Manipulation of ecosystem must be adapted to the ecosystem dynamics.
- Ecosystem components have characteristic space scales. Manipulation of ecosystems should take into account the appropriate size necessary to achieve the desired result.
- Chemical and biological diversity contributes to the buffering capacities of ecosystems. When designing ecosystems, one should introduce a wide variety of parts for the ecosystem’s self-designing ability to choose from.
- Ecosystems are most vulnerable at their geographical edges. Ecological management should take advantage of ecosystems and their biota in their optimal geographical range.

- Ecotones are formed at the transition zones between ecosystems. The interfaces between human settlement and nature should be designed as gradual transition, not as sharp boundaries.
- Ecosystems are coupled with other ecosystems. This coupling should be maintained wherever possible and ecosystems should not be isolated from their surroundings.
- Ecosystems with pulsing patterns are often highly productive. The importance of pulsing subsides should be recognized and taken advantage of where possible.
- Everything is linked to everything else in the ecosystem. It is impossible to manage one components of an ecosystem without affecting other parts.
- Ecosystems have feedback mechanisms, resilience, and buffer capacities in accordance with their preceding evolution. Existing ecosystems do not match wee with man-made synthetic chemicals, although new emerging ecosystems can develop to deal with them in some cases.

-
-
-

Bibliography

Breuste, J., Feldmann, H., Uhlmann, O.(1998) *Urban Ecology*. Center for Environmental Research, Leipzig – Germany. Published by Springer, New York. [A book summarizing recent articles and developments in Urban Ecology].

Celecia J., (1991) UNESCO and Science- From Ideals and to Action. In: Deelstra T, vanEmden HM, de Hoop WH, Jongman RHG (eds*) The resourceful City-Management approaches to efficient cities fit to live in*. Royal Netherlands Academy of Arts and sciences Amesterdam. [Very general but basic text on city management].

Deelstra T., (1993) The Quest for Sustainability in Urban Development and Design. In: Rantsi J. (ed). *The European city today – The Helsinki round table on Urban Improvement Strategies*. Ministry of Environment, Helsinki, Finland.

"*Ecological Engineering Journal*". Elsevier Science B.V. [Major complementary source].

EPA Science Advisory Board (1990). *Reducing risks: Setting priorities and strategies for environmental protection*. Report SAB-EC-90-021 and 021a. Washington DC: United States Environmental Protection Agency. [Excellent handbook of priorities and Strategies].

European Commission, (1994). *City and Environment*. Office of the European Communities, Luxembourg. [Basic source].

Ispen D., Chichorowski G., Schramm E. (1998). "Wasserkultur – Urbanitat, Technik, Okologie. Analytica Verlag, Germany.

Keoleian, Gregory A., Jonathan E. Koch, and Dan Menerey (1995). "*Life Cycle Design Framework and Demonstration Projects: Profiles of AT&T and Allied Signal"*. EPA/600/R-95/107, Office of Research and Development, Washington, DC. [A demonstration Project].

Kressler F.P., Steinnorchez K.T. (1996). Change detection in Urban Areas using satellite images and spectral mixture analysis. *International Archives of Photogrammetry and Remote Sensing*. Vol. 31, Part B7, pp. 379-383.

Landsberg H., (1981) *The urban climate*. International Geophysics Series 28. New York [Basic monograph].

Levin H. (1995) Emissions Testing Data and Indoor Air Quality in, Haghighat, F. (ed.), *Indoor Air Quality, Ventilation, and Energy Conservation in Buildings, Proceedings of the Second International Conference*, Volume 1, 465-482. [Basic reference in Indoor Air Quality].

Levin, H., A. Boerstra, and S. Ray, (1995), Scoping U.S. Buildings Inventory Flows and Environmental Impacts in Life Cycle Assessment Presented at *Society for Environmental Toxicology and Chemistry (SETAC), Impacts assessmnet work group meeting*, Alexandria, VA, April 19. [Review of the Environmental Impacts in Life Cycle Assessment in Buildings].

Lippiatt, Barbara C., and Gregory A. Norris, (1995). "*Selecting Environmentally and Economically Balanced Building Materials*". In, Fanny, A.H., K.M. Whitter, and T.B. Cohn, Eds., Second International Green Building Conference and exposition (1995). NIST Special Publication 888.pp. 37-46 [Development of Building for Environmental and Economic Sustainability (BEES)].

Ma S., Wang R-S., (1984) Social-economic-natural complex ecosystem. *Acta Ecological Sinica*, 4(1): 1-9.

Mitch W.J., Jorgensen S.E., (1989) *Ecological Engineering-An Introduction to Ecotechnology*. John Wiley and Sons, New York. [Excellent textbook on the topics of Ecological Engineering].

Musinszki A., Simon KH., John Wileg (1996). *Die stadt der vielen wasser im jahr 2023- Ein kontrastszenario mit Beispielen aur Frankfurt am main*. Wasserkultur texte Nr. 18, Kassel, Germany.

Norberg-Bohm, Vicki, William C. Clark, Bhavik Bakshi, JoAnne Berkenkamp, Sherry A. Bishko, Mark D. Koehler, Jennifer A.Marrs, Chris P. Nielsen, Ambuj Sagar (1992). *International Comparisons of environmental Hazards: Development and evaluation of a method for linking environmental data with the strategic debate management priorities for risk management*" Center for Science and International Affairs, Publications, Cambridge, MA. [Very important contribution on Systematic Evaluation and Assessment of Building Environmental Performance (SEABEP)].

Odum, H. T. (1962). *Man in the Ecosystem*. In Proceedings Lockwood Conference on the Suburban Forest and Ecology. Bull Conn. Agr. Station 652. Storrs, CT, pp.57-75. [Background reference on the role of man in the ecosystem.]

Odum, H.T. (1971). *Environment, Power and Society*. Wiley, New York, 331 pp. [An informative article, with emphasis on global phenomena].

Odum, H.T. (1983). *Systems Ecology: An Introduction*. Wiley, New York, 644 pp. [Fundamental textbook on systems ecology].

Straskraba, M. (1985). *Simulation Models as Tools in Ecotechnology Systems*. Analysis and Simulation, Vol.II. Academic Verlag, Berlin. [Useful overview on ecosystem management].

World Commission in Environment and Development (1987) *Our Common Future*. Oxford University Press Oxford, New York. [One of the most comprehensive references on the topic of environment and development].

Wang R., (ed) (1991). *Human System Ecology*. Science and Technology Press. Beijing-China.

Biographical Sketch

Dr. John Hadjinicolaou has been working in the field of environmental engineering since he received his Ph.D. degree in 1983. He was a visiting research fellow for two years in Environment Canada and for eight years a senior Research Associate at the Geo-environmental section of the Geotechnical Research Centre of McGill University. Since 1983 he is teaching at McGill University in the area of Environmental Engineering and since 1999 also at Concordia University at the Department of Building, Civil and Environmental Engineering as an Adjunct Associate Professor.