Construction Ecology

Nature as the basis for green buildings

Edited by
Charles J. Kibert, Jan Sendzimir,
and G. Bradley Guy

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Charles J. Kibert is the Director of the Rinker School of Building Construction and former Director of the Center for Construction and Environment at the University of Florida. He is also a CSR/Rinker Professor in the M.E. Rinker School of Building Construction and a University of Florida Research Foundation Professor. He founded the Cross Creek Initiative, a non-profit organization for transferring sustainable building methods and technologies to construction industry. He organized and coordinates Task Group 39 of Conseil International du Batiment (CIB), an international research body that promotes building disassembly (deconstruction) and materials reuse as a high-priority strategy for sustainable construction. He is the editor of *Reshaping the Built Environment: Ecology, Ethics, and Economics* (Washington, DC: Island Press, 1999) and is the primary author of *Turning Brownfields into Vital Community Assets* (Washington, DC: Neighborhood Training Institute, 1999), *Greening Federal Facilities* (Washington, DC: Federal Energy Management Program, 1997), and over ninety papers on the sustainable built environment.

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Jan Sendzimir is a systems ecologist at the International Institute for Applied Systems Analysis in Laxenburg, Austria, and sits on the board of directors of the CEIBA Foundation and the Soils of Tomorrow Foundation. His research addresses environmental issues at global, regional, and ecosystem levels, particularly the resilience of human and natural communities in response to disturbances at different time and space scales. Of particular concern in addressing the interface between the human and natural worlds is the evolution of environmental management systems and policies which flexibly adapt to emerging conditions. He has taught ecology courses at Santa Fe Community College (1985), the Ecological Summer School of Central European University in Budapest (Soros Foundation) (1991), and the Academy of Mining and Metallurgy in Krakow (1998) and has published five papers. He holds a PhD and a MSc in systems and landscape ecology from the University of Florida, and an MA in teaching biology. He also was a member of the board of directors of the Kosciuszko Foundation from 1985 to 1996.

Sim Van der Ryn is President of the Ecological Design Institute and Van Der Ryn Architects in Sausalito, California, and is renowned as a leader in ecological design. For over thirty years, his design, planning, teaching, and public leadership has advanced the viability and acceptance of ecological principles and practice in architecture and planning. He is the author of over 100 articles, monographs, and book contributions, including *Ecological Design* (Washington, DC: Island Press, 1995), *The Toilet Papers: Recycling Waste and Conserving Water* (White River Junction, VT: Chelsea Green, 2000), *Sustainable Communities* (Sierra Club Books, 1986), and *The Integral Urban House* (San Francisco: Sierra Club Books, 1978).

Malcolm Wells is a pioneer of underground building and natural design. For 34 of his 45 years as an architect he has been an advocate of underground buildings as the answer to the paving over of America with asphalt and concrete. He is widely known for many books, including *How to Build an Underground House* (New York: Malcolm Wells, 1991) and *Gentle Architecture* (New York: McGraw Hill, 1981). His cartoons are featured in Rob Roy's *Mortgage Free! Radical Strategies for Home Ownership* (White River Junction, VT: Chelsea Green, 1998). He lives in the Underground Art Gallery in Brewster, Massachusetts.

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Preface

Through the efforts of a wide array of public and private organizations around the globe, a strong and growing movement is beginning the process of transforming the systems that create the built environment from ones that pay no attention to resources and the environment to a new variety in which these considerations are the pre-eminent criteria for "good" construction. Although dating back only to the early 1990s, there is already ample evidence that the "green building" movement is affecting the design, construction, operation, and disposal of the built environment. It utilizes many of the same efforts used in the mid-1970s to reduce building energy consumption and promote a shift to renewable energy resources. Green buildings are designed and built with a sharp focus on the overall environmental and resource impacts of human habitation. In addition to significantly reducing energy use, the green building movement also attempts to reduce water consumption, minimize construction and operational waste, select materials that are recyclable and/or with recycled content and renewable resource content, optimize the siting of buildings, and insure healthy interior environments for the occupants.

In spite of the early success of this movement, much work needs to be done, particularly in deepening the understanding of the connections and interplay between the built environment and natural systems. At present, green building movements rely on a virtual smorgasbord of options that are no more than the best judgment of the designers and builders who are seeking to explore new practices. Building professionals are using a largely intuitive approach to creating a green built environment that, although fairly effective in decelerating the destruction of environmental and resource capacity, lacks an adequate understanding of the very systems it purports to protect. A strong philosophical and technical basis for the wide array of decisions that must be made in the selection of sites, materials, or energy systems does not currently exist. This is the purpose of a new discipline called construction ecology involving the development of an understanding of how the structures and behavior of natural systems, their organization, metamorphosis, resource utilization, pulsing, complexity, and other important aspects can be examined both as heuristic metaphors and for providing information for the life cycle of the built environment. This volume is the first attempt to develop an ecology of the built environment that explores how the built environment affects the human–natural system interface. This development must be an important part of the research agenda of the green building movement as it proceeds over the next few decades. The ecologists, industrial ecologists, and architects who wrote the chapters of this volume describe their thoughts on how nature can inform the built environment and lead to an era in which these significant human artifacts are integrated with, rather than made apart from, Nature.

Outside the building industry, similar struggles to link human and natural systems behavior have been taking place. One result has been the emergence of the field of industrial ecology, which, since 1989, has been investigating, with some degree of success, the application of the behavior of natural ecological systems to manufacturing and other industrial activities such as power generation and wastewater management. The initial efforts of industrial ecology have focused on closing materials loops by integrating industries in what has been called *industrial symbiosis*. Several eco-industrial parks have been designed and are achieving varying degrees of success around the world. The study of economics is also undergoing a transformation as a result of examining how the behavior of the economy has much in common with the ebb and flow of nature. Michael Rotschild, in his 1992 book *Bionomics*, described many of these similarities. The emergence of complexity theory has opened many new avenues for exploration of these connections and similarities. M. Mitchell Waldorp describes the application of complexity theory to economics in *Complexity: The Emerging Science at the Edge of Order and Chaos* (New York: Simon & Schuster, 1992). Michael Byrne, in his book *Complexity Theory and the Social Sciences: An Introduction* (New York: Simon & Schuster, 1998) explores how human systems behave in a chaotic/complex fashion. Meanwhile, ecologists are beginning to tease out the complex behavior of natural systems. The remarkable outcome of these disparate efforts is that Nature and the built environment seem to exhibit much the same types of behaviors. The growth, maturation, and decline of natural systems mirror the development, aging, and decay of cities. The resources and population of human settlements exhibit the same pulsing character as natural systems. The questions begging to be answered are: Does human habitat, its planning, content, and functioning behave in a complex/chaotic manner analogous to natural systems? What are the lessons that can be learned from the behavior and functioning of natural systems that the green building movement should adopt as its philosophical basis and incorporate into both its foundation philosophy and its design principles?

These questions stimulated the organization of a collaborative effort at the University of Florida in 1999 among architects, ecologists, industrial ecologists, and materials manufacturers. The Rinker Eminent Scholar Workshop on Construction Ecology and Metabolism brought together a group of the world's foremost authorities and practitioners from academia and the public and private sectors. This volume is a result of their post-workshop thoughts on, and responses to, these questions and others that were stimulated during the workshop. It is organized into three main parts. Part 1 contains the reflections of the ecologists who attended the workshop, and in each case they illuminate the current state of thinking about ecological systems as well as their notions about how the built environment may benefit from considering the behavior of natural systems. Part 2 provides the insights of leading thinkers in the field of industrial ecology, which for the past decade has been attempting to determine how industrial systems can adopt the elegant functioning of natural systems into their processes. Part 3 is a compilation of the responses of leading architects to the possibility of considering natural systems as both metaphor and model for the built environment. The final chapter, Conclusions, provides some initial thoughts on new directions for green building using construction ecology as its basis.

In organizing and carrying off the truly complex effort of bringing together a group of people representing the leading edge of thinking on the human–natural system interface, many acknowledgements are in order.

First, our gratitude must be expressed to the Marshall E. Rinker, Sr. Foundation and the Marshall and Vera Lea Rinker Foundation for their continuous support of the Rinker School of Building Construction. The endowments created in memory of "Doc" Rinker

continue to provide opportunities to the faculty of the school to create a world-class construction program. The faculty of the Rinker School of Building Construction responded positively to a proposal for the workshop and provided the financial resources from the Rinker endowment necessary to support the expense of bringing this group to Gainesville and organizing their thoughts into a hopefully coherent volume. The then Dean of the College of Architecture, Wayne Drummond, fully supported this concept and provided much moral support in its execution. Thanks also to Jimmie Hinze, former Director of the Rinker School, for his support of this program and his efforts in bringing it to fruition.

I would also like to acknowledge the efforts of the Center for Construction and Environment in the Rinker School for their energy and enthusiasm in performing all the detailed tasks of making the workshop a reality. Gisela Bosch led the group which organized the workshop, and it is largely through her tireless work and dedication that it was a great success. G. Bradley Guy assisted in both the selection of the eminent attendees and the editing of this volume. Jan Sendzimir was responsible for selection of leading ecologists to attend the workshop and also assisted in editing the volume. Dottie Beaupied worked diligently to insure the details of travel and accommodation were thoroughly attended to and continued to assist the editors throughout the entire process of bringing this resulting book to press. Finally, we are grateful to Spon Press for deciding to publish this volume and for the efforts of Sarah Kramer in making it a reality.

Charles J. Kibert
Gainesville, Florida

Foreword

My first direct experience of the need for adding significantly to the built environment was in the 1960s, when I interviewed farm workers in their shanty towns in California. Often, a dozen family members would be crowded into a two- or three-room tarpaper shack with corrugated iron roof and no running water. Then in 1997–98 my perception of this challenge became much more acute when I visited townships such as Alexandra and the Cape Flats in South Africa. For families there to be able to afford housing sufficient to their very deep needs, they also needed work places and training facilities – further additions to the built environment.

In the Philippines in 1999 I saw another version of this situation in the strip residential and commercial developments strung out between a freeway and factory walls. Ironically, people from these poverty-stricken neighborhoods would dress up in their finest to visit Glorietta Mall or MegaMall and enjoy the fantastic luxury of air conditioning! The multiplicity of such malls, filled with global identity shops such as Pierre Cardin and fast food chains such as Pizza Hut, are another indicator of a huge increase in construction activity, even in developing countries.

China plans twenty new towns a year in the west to accommodate the hundreds of thousands of farm families unable to compete with global prices when this country enters the World Trade Organization. The large cities in the east could not withstand even more migration into their overcrowded neighborhoods.

This escalating demand for built space makes dramatically clear that we cannot afford to continue designing and building our homes, commercial centers, and industrial and public facilities in the old unsustainable models. Chapter 1 in this volume gives detailed evidence of the enormous environmental costs of construction, operation, and deconstruction of our buildings. While green design has many success stories, such as the Herman Miller Phoenix Designs plant in Michigan, we must go beyond incremental and fragmented improvements in design and construction of the built environment. The disciplines of design and construction must go to a basic level of rethinking to achieve the level of change the challenges of sustainability demands. This publication is a powerful beginning of that process.

Construction ecology is a breakthrough in two fields of research and application – the design and construction of our built environment and the relatively new discipline of industrial ecology. The buildings in which we live and work and the infrastructure that supports our lives demand an amazing share of the natural resources we humans consume. As populations continue to grow and expectations rise, it is essential that we learn to design and build with a much higher level of efficiency and a much lower level of pollution and waste.

Industrial ecology has emerged in the last 15 years as a systems approach to design, development, and operation of human systems, both public and private. It aims to create the transition to a sustainable world in which our economic activities respect the limits of global and local carrying capacity. The construction ecology conference that was the source of this book was a very significant effort to use the concepts and methods of industrial ecology to begin charting the path to sustainable design and construction.

One of the most attractive concepts industrial ecologists have suggested is that we can learn how to design human systems from the dynamics of ecosystem behavior. While there is potentially great value in this approach, most of the efforts before this book have been naive and full of clichés. Relatively few industrial ecologists have written of "industrial ecosystems" with much insight into how ecosystems actually function. We hear repeatedly that the waste of one organism becomes the food for another and little more.

Construction ecology, and the conference that produced it, is the first large-scale attempt to learn about major human energy and materials flows by comparing them to the dynamics of natural systems. Ecologists, industrial ecologists, architects, construction researchers, and representatives of building products manufacturing have used the ecological metaphor in a profound way that other industry and academic clusters could learn from.

Ecosystems in Nature demonstrate many strategies beyond consumption of life's by-products (what we still call 'waste') that are relevant to design and construction. For instance:

- The sole source of power for ecosystems is solar energy.
- Concentrated toxic materials are generated and used locally.
- Efficiency and productivity are in dynamic balance with resiliency. Emphasis on the first two qualities over the third creates brittle systems, likely to crash.
- Ecosystems remain resilient in the face of change through high biodiversity of species, organized in complex webs of relationships. The many relationships are maintained through self-organizing processes, not top-down control.
- In an ecosystem, each individual in a species acts independently, yet its activity patterns cooperatively mesh with the patterns of other species. Cooperation and competition are interlinked and held in balance.

By exploring the implications of these and other ecological principles for design and construction the authors of the papers in *Construction Ecology* have created a context for the holistic rethinking required for a sustainable approach to the built environment.

As an industrial ecologist, I am pleased to see that we can apply the basic strategy of the ecological metaphor with real depth, not just as a cliché. As someone whose career focuses on supporting developing countries in their often daunting task of housing their poor and giving them employment to rise out of poverty, I feel that this volume may help them achieve these goals while preserving their environments.

Ernest Lowe

Introduction

Charles J. Kibert

Construction ecology articulates the philosophical and technical foundations for the international movement most commonly referred to as *green building*. Linking the words "construction" and "ecology" into a single description may be a difficult concept for many people, and some may contend that it is an oxymoron. However, in attempting to respond to the need to connect human activities to Nature, many disciplines are beginning to explore their existing "ecology" and are trying to understand how it is related to the behavior of natural systems. Thus, one can now find references to urban ecology, social ecology, industrial ecology, and political ecology, to name a few.

The construction industry has much in common with the overall industrial subsystem of the economy. This industry is in fact tightly coupled to the industrial subsystem because modern buildings largely comprise products made in factories of materials extracted from the Earth's biological or mineral resources. It could be argued that the built environment is merely a portion of industrial output and that its so-called ecology could be studied wholly within the framework of industrial ecology, itself a relatively new discipline.

The built environment, however, is not merely an industrial product. Buildings are perhaps the most significant artifacts of human culture and can have historic meaning across millennia, something that can be said of few other human artifacts. The scale of the built environment is enormous, and it occupies a significant fraction of the Earth's surface. It replaces, at long time scales (typically 50–100 years), once productive natural systems with non-productive (in a natural ecological sense) structures. The alteration of existing natural systems is a primary effect of the built environment, and these systems are usually replaced in part by human-designed landscaping that may not bear any resemblance to the ecological systems that once occupied the site. In addition to the industrial products that constitute it, the built environment incorporates significant quantities of raw materials such as earth and gravel to create a structural boundary layer between buildings or infrastructure and the ground. During its operation, the built environment consumes energy, water, and materials and emits solid, liquid, and gas contaminants. At the end of their useful life, these structures contribute vast quantities of waste to the environment, on the order of 0.4–0.5 tons per capita per year in industrialized countries.

In spite of the differences between the built environment and other products of an industrial society, the construction industry can use the lessons learned from industrial ecology as a jumping off point to discover its existing metabolism of energy matter and its interactions with ecological systems. Examination of natural systems has revealed structures and behaviors, and their metaphors, that mutually reinforce the natural and built environments, and these lessons can benefit both industrial and construction ecology.

Although the international green building movement has enjoyed success during the 1990s, its initial decade, much work needs to be done, particularly in the area of understanding the connections between buildings and Nature and the effects of the built environment on natural systems. At present, green building movements rely on a wide array of options based on the intuition and judgment of professional planners, architects, engineers, and facility managers. Optimal approaches, techniques, and methods for producing green buildings do not currently exist because, although one of the stated purposes of green buildings is to protect the environment, the effects of specific design and operational decisions on the natural world are virtually unknown and clearly not able to be quantified in any meaningful way. Consequently, the professionals associated with the creation of the built environment are literally guessing at how best to reduce the effects on Nature of building construction, operation, and demolition. Although effective tools have been developed to examine financial trade-offs associated with shifting to low environmental impact options, methods to assess the direct effects of decisions on ecological systems are presently lacking. Understanding the effects of building decisions on the health of natural systems is absolutely essential to the long-term success of efforts to advance the state of ecological design and the construction of green buildings. Integrating natural systems function with the operation of buildings is another largely untapped source. For example, the possibility of buildings providing nutrients to natural systems while Nature does the work once performed by energy-intensive mechanical systems is a field of study ripe for both intellectual and commercial exploitation. A fundamental rethinking of green building strategies will be required for this to occur, and the integration of the study of both ecology and industrial ecology with architecture will be needed to begin this process of deep change.

Current state of green building

A description of the current state of the movements to green the built environment would be useful in establishing a context for understanding the need to develop a sound basis for its future development. Many terms are used to describe these movements and, in addition to green building, terms such as sustainable construction, sustainable architecture, ecological architecture, ecologically sustainable design, and ecologically sustainable development have been used. The term "sustainable construction" seems to be the most comprehensive description of all the activities involved in trying to better integrate the built environment with its natural counterpart. Begun as an international movement in 1993, sustainable construction can be defined as "creating a healthy built environment based on ecologically sound principles." It looks at the entire life cycle of the built environment: planning, design, construction, operation, renovation and retrofit, and the end-of-life fate of its materials. It considers the resources of construction to be materials, land, energy, and water and has an established a set of principles to guide this new direction:

1. reduce resource consumption;
2. reuse resources to the maximum extent possible;
3. recycle built environment end-of-life resources and use recyclable resources;
4. protect natural systems and their function in all activities;
5. eliminate toxic materials and by-products in all phases of the built environment;
6. incorporate full-cost accounting in all economic decisions;
7. emphasize quality in all phases of the life cycle of the built environment.

Similar principles have been set out by many of the organizations involved in the greening of the built environment, all of them having much in common with the principles of sustainable construction. Progress in implementing these principles has been impressive. A comprehensive overview of programs in countries around the world would be lengthy and, for the sake of brevity, a review of progress in the USA will be used as indicative of how rapidly change is taking place worldwide. In the USA, there are several major entities driving the emergence of green buildings: the US Green Building Council, the National Association of Home Builders, and the federal and local governments.

The US Green Building Council

The US Green Building Council (USGBC), established in 1993, represents a wide range of actors who concluded that construction industry must change course to be sustainable: architects, engineers, product manufacturers, academics, and public institutions. In the USA, the construction industry clearly has disproportionate impacts on the environment compared with other sectors of the economy. At present, although it represents just 8% of the country's gross domestic product, this industry is responsible for over 40% of total materials extraction to produce and alter buildings and infrastructure, and the operation of buildings consumes over 30% of the nation's primary energy. In a fashion similar to its counterparts in other major industrial countries, as its response to changing the playing field, the USGBC organized a system of rating buildings that would add new criteria for the siting, design, construction, and operation of new and renovated buildings in the USA. This rating system, known more commonly by its acronym of LEED (Leadership in Energy and Environmental Design), proposed to classify buildings into four categories depending on their level of performance with respect to energy and environmental issues: platinum (highest), gold, silver, and LEED-rated. In the short time since its proposal and subsequent piloting, the LEED standard must be declared to be a major success. Scores of buildings have been designed and built using its criteria, and many are more queuing up to employ it as perhaps the key focus for building design, ranking only behind the client's requirements for the building's function. The LEED standard is being expanded into other sectors of building construction, including residential housing. The beta testing of the standard started in 1998, and over thirty buildings received ratings based on version 1.0. In April 2000, the final standard, version 2.0, was issued and is now being used to rate commercial and institutional buildings.

The National Association of Home Builders

The National Association of Home Builders (NAHB) is generally considered to be the most powerful construction industry organization in the USA, with over 200,000 members organized into 800 local chapters. According to the NAHB, in 1999 there were over 1.6 million single- and multi-family housing starts. In 1998, over $214 billion dollars of family housing was produced by the private sector, about one-third the value of total construction in the USA. Home ownership is a significant aspect of American culture. Home ownership is highly valued, and homes represent a significant portion of wealth. Home ownership accounted for approximately 44% of the nation's total net worth in 1993. The high level of home building also represents a significant proportion of the environmental impacts of construction, especially in terms of its land consumption. Fortunately, several homebuilder associations have actively engaged in determining how to build homes in an environmentally friendly manner. At least six of these associations, often in cooperation with local jurisdictions, have established a variety of green builder programs, and the NAHB now has an annual national conference devoted to green home building.

Federal and local government

Of all the organizations involved in green building efforts in the USA, the federal government is both the largest customer and arguably its greatest proponent. A wide array of federal agencies have demanded better environmental and health performance for new buildings, among them the US Post Office, the National Park Service, and many of the military services. Many of the buildings that were rated by the first version of the LEED standard in the beta testing effort were federal buildings. The US Department of Energy has been a major supporter of the development and implementation of the LEED standard. Presidential executive orders have directed a variety of actions on the part of federal agencies that directly or indirectly support the construction of green buildings. Several highly visible federal building efforts, such as the "Greening to the White House" and the "Greening of the Pentagon," have been effective in publicizing green buildings in the USA.

Local government has also been a major force in the green building movement in the USA. The municipal government of Austin, Texas, initiated a green building program in the early 1990s. The Austin effort was initially directed at the procurement of city buildings and produced the first guidelines for municipal building, the *Sustainable Building Sourcebook*. The efforts of the city soon produced a parallel effort in the local homebuilding industry, and the Austin homebuilders association formed the first NAHB green residential construction program. The city of Seattle, Washington, now requires conformance to the LEED standard for all municipal buildings, and similar requirements for the use of the LEED standard are emerging from local government across the USA. The city of Boulder, Colorado, was the first municipality to require some level of green building measures for all housing constructed within city limits and enforces this requirement through the building permitting process.

Organization

The purpose of this book, the investigation of how to base green buildings on the structure, behavior, and metaphor of natural systems, necessitated the collaboration of four groups of participants: ecologists, industrial ecologists, architects, and building product manufacturers. The workshop that was conducted to create the interaction of the selected individuals representing these fields occurred over a two-day period. Prior to the workshop the participants were provided with a notebook of information and papers to tutor them on the most recent developments in ecology and industrial ecology, as well as the state of the art in green building. The purpose was to cross-inform the participants about the others' disciplines. In the initial phase of the workshop all participants gave a presentation on their own work and provided some initial responses with respect to the goals of the workshop. The participants were then divided into two groups, with all disciplines represented in each group. The groups collaborated for several sessions to begin the process of applying ecology and industrial ecology to the built environment. The chapters in this book are the reflections of the participants on their work and its application to construction as affected by their interactions with colleagues in the other disciplines. In many cases, the authors provide background on their work in their chapters for two reasons. First, because this is a cross-disciplinary effort, there is the need to provide the reader with the vocabulary and state of the art in each discipline. Second, this background is needed to understand the conclusions reached by the authors with respect to the development of an ecology of construction. The chapters were written after the collaboration and interaction of the participants in the workshop and need to be understood in this context.

Chapter 1, an introduction to the concept of construction ecology and metabolism, was written by Charles Kibert in collaboration with Jan Sendzimir, an ecologist, and G. Bradley Guy, an architect. It presents some initial thoughts on the interplay of the built environment, ecology, and industrial ecology and is meant to lay the groundwork for the reader to understand the rationale for the development of construction ecology and metabolism. It discusses some of the specific difficulties facing the green building movement due to the lack of a coherent philosophy and design principles. Some additional thoughts on how buildings will have to change to more closely resemble nature are provided.

Part 1, The Ecologists (Chapters 2–5), contains the thoughts of four eminent ecologists: H.T. Odum, James Kay, Tim Allen, and Garry Peterson. It is introduced by Jan Sendzimir, who reviews the work of these contributors and provides the reader with insights into both current ecological theory and its application to the built environment.

In Chapter 2, H.T. Odum discusses the application of systems theory to the built environment. James Kay develops a powerful overview of how to consider the interface between human and natural systems in Chapter 3. The issues of surprise and emergence are discussed by Tim Allen in Chapter 4. In Chapter 5, Garry Peterson discusses ecological resilience, ecological change, and ecological scales and their relevance to the human built environment.

Developments in industrial ecology that may apply to the built environment are the subject of Part 2 (Chapters 6–9), which is introduced by Charles J. Kibert and contains the contributions of four eminent industrial ecologists: Robert Ayres, Iddo Wernick, Stefan Bringezu, and Fritz Balkau. In Chapter 6, Robert Ayres focuses the reader on the problem of creating a zero-emissions built environment from an industrial ecology point of view and suggests several materials and energy strategies to achieve this end. Iddo Wernick, in Chapter 7, suggests several strategies for the built environment that would reduce resource consumption and impacts on natural systems. In Chapter 8, Stefan Bringezu suggests that the key issue for the built environment, as for other industrial sectors, is maximizing resource efficiency. Fritz Balkau addresses how to manage the implementation of industrial ecology concepts in Chapter 9.

Part 3 (Chapters 10–12) is introduced by G. Bradley Guy and provides the thoughts of the architecture collaborators: Sim Van Der Ryn, Robert Peña, Jürgen Bisch, and Malcolm Wells. Sim Van Der Ryn and Robert Peña address the well-developed concepts of ecological design in Chapter 10. In Chapter 11, Jürgen Bisch describes a personal and historical journey toward architecture grounded in ecology and the evolution of a design process that is sensitive to nature and both respectful of and informative for his clients. His efforts to dematerialize buildings and couple them to the natural systems on the building site portray what may in fact be the cutting edge of applying ecology to construction. Malcolm Wells describes the total systems approach he has evolved over 40 years of architectural practice in Chapter 12. His conclusion is that the built environment should in fact impinge as little as possible on the planet's surface, and his fundamental strategy for achieving this is to place buildings underground, where ground contact and beneficial interaction with natural systems is maximized.

The final chapter, Conclusions, provides an overview of the outcomes of this initial collaboration of ecologists, Industrial Ecologists, and architects. This overview is organized into three major sections: (1) recommendations and agreements; (2) critical issues requiring further investigation; and (3) additional observations.

Summary and conclusions

Developing an ecology of construction is an important step in the evolution of green building movements around the world. In almost every case, national and international movements indicate ecological design and the adoption of ecological principles as key elements of green building or sustainable construction. However, theory and practice developed in ecology have had little or no actual connection to green building and, as a consequence, the green building movement, although highly successful, stands a fair chance of ultimate failure because of the lack coherent underpinnings. This book suggests that for the green building movement to emerge successfully as standard practice, it must rely on ecology and industrial ecology to provide the coherent structure and science needed to serve as the basis for developing new theory, practices, and experiments; for decision making; and to serve as its general compass.

In addition to providing a badly needed basis for green building, construction ecology will require built environment professionals to dramatically increase their understanding of ecology. Because it could be said that the *raison d'être* for green building is the protection of natural systems, the re-education of planners, architects, builders, and policy-makers in ecological theory can only result in more sharply focused attention on the important issues of green building. The introduction of ecological education as a requirement for a professional design or construction license to impact natural systems in the dramatic fashion characteristic of the built environment would seem to be a highly beneficial and worthwhile outcome for society.

1 Defining an ecology of construction

Charles J. Kibert, Jan Sendzimir, and G. Bradley Guy

The construction and operation of the built environment has disproportionate impacts on the natural environment relative to its role in the economy. Although it represents about 8% of gross domestic product (GDP) in the USA, the construction sector consumes 40% of all extracted materials, produces one-third of the total landfill waste stream, and accounts for 30% of national energy consumption for its operation. The sustainability of this industrial sector is dependent on a fundamental shift in the way in which resources are used, from non-renewables to renewables, from high levels of waste to high levels of reuse and recycling, and from products based on lowest first cost to those based on life cycle costs and full cost accounting, especially as applied to waste and emissions from the industrial processes that support construction activity. Construction, like other industries, would benefit from observing the metabolic behavior of natural systems, in which sustainability is a property of a complex web of niche elements. The emerging field of industrial ecology, which is examining Nature for its lessons for industry, provides some insights into sustainability in the built environment or sustainable construction. This book proposes and outlines the concept of construction ecology, a view of construction industry based on natural ecology and industrial ecology for the purpose of shifting construction industry and the materials and manufacturing industries supporting it onto a path much closer to the ideals of sustainability. Additionally, construction ecology would embrace a wide range of symbiotic, synergistic, built environment–natural environment relationships to include large-scale, bioregional, "green infrastructure" in which natural systems provide energy and materials flows for cities and towns and the human occupants provide nutrients for the supporting ecological systems.

Introduction

Ecosystems are the source of important lessons and models for transitioning human activities onto a sustainable path. Natural processes are predominantly cyclic rather than linear; operate off solar energy flux and organic storages; promote resilience within each range of scales by diversifying the execution of functions into arrays of narrow niches; maintain resilience across all scales by operating functions redundantly over different ranges of scale; promote efficient use of materials by developing cooperative webs of interactions between members of complex communities; and sustain sufficient diversity of information and function to adapt and evolve in response to changes in their external environment. A variety of approaches to considering the application of natural system design principles to the industrial subsystem of human activities is emerging to help redesign the conduct of a linear economy based largely on the consumption of non-renewable resources.

Industrial ecology is an emerging discipline that is laying the groundwork for adapting ecosystem models to the design of industrial systems. In more recent thinking, industrial ecology is being redefined and extended to include industrial symbiosis, design for the environment (DFE), industrial metabolism, cleaner production, eco-efficiency, and a host of other emerging terms describing properties of a so-called "eco-industrial system." Industrial symbiosis refers to the use of lessons learned from the observation of ecosystem behavior to make better use of resources by using existing industrial waste streams as resources for other industrial processes. An emerging discipline, DFE is altering the design process of human artifacts to enhance the reuse and recycling of material components of products. Industrial metabolism examines the inputs, processes, and outputs of industry to gain insights into resource utilization and waste production of industry, with an eye toward improving resource efficiency. Cleaner production is the systematic reduction in material use and the control and prevention of pollution throughout the chain of industrial processes from raw material use through product end of life (Business and the Environment 1998). Eco-efficiency calls on companies to reduce the material and energy output of goods and services, reduce toxic waste, make materials recyclable, maximize sustainable use of resources, increase product durability, and increase the service intensity of goods and services (Fiksel 1994).

Construction and operation of the built environment in the countries in the Organization for Economic Cooperation and Development (OECD), i.e. the major industrial countries, accounts for the greatest consumption of material and energy resources of all economic sectors and could benefit the most from employing natural systems models. Within the framework being defined by industrial ecology, construction industry would be well served by the definition of a subset, construction ecology, that spells out how this industry could achieve sustainability, both in the segment that manufactures the products that constitute the bulk of modern buildings and in the segment that demolishes existing buildings and assembles manufactured products into new or renovated buildings. As is the case with other industrial systems, construction would be aided in this effort by an examination of its throughput of resource, i.e. its "metabolism."

This chapter examines the potential for construction industry to incorporate the lessons learned from both natural systems and the emerging field of industrial ecology, primarily in its materials cycles, but also at larger scale for regional energy and materials flows. It also explores the issue of dematerialization and its relevance to the built environment. In many respects, the construction industry is no different from other industrial sectors. However, there are enough differences, especially the long lifetime and enormous diversity of products and components constituting the built environment, that it requires special attention and treatment. Consequently, attempts to apply ecology to this industry and to understand its metabolism present some unique problems not encountered in other industrial sectors.

Construction industry compared with other industrial sectors

Buildings, the most significant components of the built environment, are complex systems that are perhaps the most significant embodiment of human culture, often lasting over time measured in centuries. Architecture can be a form of high art, and great buildings receive much the same attention and adoration as sculpture and painting. Their designers are revered and criticized in much the same manner as artists. This character of buildings as more than mere industrial products differentiates them from most other artifacts.