影印版 A GreenSource BOOK

Green Architecture

Advanced Technologies and Materials

Osman Attmann

绿色建筑 新技术与新材料

哈爾濱工業大學出版社

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GREEN ARCHITECTURE

ADVANCED TECHNOLOGIES AND MATERIALS

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PREFACE

Global warming is emerging as an issue of international significance. The rapid growth and increasing concentration of greenhouse gases worldwide is expected to contribute to climate change at a faster rate than previously recorded in the earth's history. Governments, industries, communities, and academic fields across the globe are racing to better understand the impact(s) of these climatic changes and their implications for ecological balance. Today, it is the responsibility of every academic field to help create sustainable environments by developing solutions for reducing energy and water consumption, and our dependence on nonrenewable resources.

This is especially imperative in the architecture and construction fields, where buildings account for nearly half of all greenhouse gas emissions, energy consumption, and raw material use around the globe. According to 2006 Energy Information Administration data, commercial and residential buildings account for 48 percent of the energy consumed, 76 percent of electricity used, and 15 percent of the total water consumed. Buildings also use 50 percent of the world's raw materials—many of which are nonrenewable resources—and they are responsible for 36 percent of all waste generated worldwide. These numbers are alarming and clearly identify two distinct problems in the building sector that must be taken seriously and addressed immediately.

The first problem is the nature and use of our existing technology, which is largely inefficient, outdated, and even in some cases obsolete. In the United States alone, the building sector uses nonrenewable and environmentally hazardous energy, emits 39 percent of all energy-related carbon dioxide, lacks the ability to retain its generated energy long enough to sustain indoor air quality levels, and fails in recycling and managing water and waste.

The second problem is the materials, mostly because of their compositional attributes, manufacturing, and fabrication methods. According to recent reports published by the U.S. Environmental Protection Agency (EPA, 2001), Department of Energy (Annual Energy Review, 2003, 2006) and Department of Commerce (General Housing Characteristics, 2000; Economic Census, 2002), existing building materials show significant deficiencies in most of the performance issues, such as durability, energy efficiency, amount of waste generated, toxicity, and potential for reuse.

Given the fact that inefficient buildings are partially responsible for these environmental changes, the following questions need to be asked: What is the role of architects and what can we do to address these problems? These questions are the main focus of the book, with an emphasis on utilizing advanced technologies and materials as a means to help remedy these serious issues. According to the U.S. Energy Information Administration forecast report (U.S. Annual Energy Outlook, 2006), by the year 2035, 75 percent of the existing building stock will be either replaced or renovated. This transformation over the next two decades represents a historic opportunity for architects, engineers, and the building community to develop and use new advanced materials and technologies in order to make these future buildings efficient, environmentally friendly, and sustainable.

This book intends to contribute to this historic transformation by introducing new technologies and materials that will promote and support this change.

The book is organized into eight chapters around the following themes:

Chapter 1 introduces the subject, providing an overview of the issues within our ecosystem. It concludes with a discussion of our responsibilities as architects, and addresses the relationship between architecture and technology.

Chapter 2 compares the concepts sustainability, ecology, and the green movement. Sustainability is of one the most widely used but poorly defined terms in architecture today. While the terms "sustainable," "ecological," and "green" are often used interchangeably to describe environmentally responsive architecture, in depth each term has its own sociopolitical connotations and agenda. This chapter defines these terms separately, investigates their similarities and differences, and explores their development over the years. It concludes by focusing on green architecture as a concept that best describes technologically advanced, economical, environmentally friendly, sustainable architecture.

Chapter 3 provides a brief history of the preservation, ecological, environmental, and green movements, as well as green architecture, including a summary of current Green Building Rating Systems.

Chapters 4 and 5 present existing, emerging, and future green technologies, as they apply to residential, commercial, and institutional buildings. It provides a complete introduction to the advanced technologies used to construct high-performance buildings. This chapter focuses on three major technological issues: (1) energy generation (i.e., biological, solar, geothermal, and hybrid systems); (2) energy retention (i.e., insulation, environmental controls, skins, building envelopes, passive methods, and zero-energy technologies); and (3) water and waste management (i.e., reuse, recycle, energy recovery, and disposal). Furthermore, this chapter emphasizes and encourages the reader to realize the ecological, economical, and design benefits of using green technologies.

Chapters 6 and 7 focus on green materials that make "zero-energy" green buildings. Building materials and construction activities consume three billion tons of raw materials each year. Using green building materials and products promotes conservation of dwindling nonrenewable resources internationally, and can also help reduce environmental impacts (e.g., extraction, transportation, processing, installation, and disposal) associated with traditional building industry materials. Accordingly, these chapters focus on several categories of green materials (such as biomaterials, composites, smart and nanomaterials) with the following benefits: (1) energy exchange and conservation; (2) environmental adaptation and reversibility; (3) environmental safety, recyclability, and renewability; (4) reduced maintenance/replacement costs over the life span of a building; and (5) greater design attributes and flexibility.

Chapter 8 takes an in-depth look at a broad range of relevant case studies in green architecture that are designed, operated, renovated, or reused in an ecological, resource-efficient manner. Selected projects represent both new construction and future projects for various building types, based on the earlier defined standards of green architecture (i.e., employing alternative energies, incorporating advanced technologies and materials, using efficient water- and waste-management techniques, and reducing the overall impact to the environment). Case studies are presented and analyzed in four major categories: (1) advanced green buildings; (2) active and passive solar buildings; (3) self-sufficient, off-the-grid modular and mobile systems; and (4) solar-decathlon competition projects since 2002. The last three categories have never been covered or discussed in other publications.

It is my hope that this book will help the reader to understand that green architecture is not only good for the environment, but offers new opportunities for creativity and innovation.

ACKNOWLEDGMENTS

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CONTENTS

1

GREEN ARCHITECTURE: OVERVIEW

Introduction: Ecosystems and Natural Environments

An ecosystem is defined as a natural unit, consisting of all plants, animals, and microorganisms in an area functioning together, along with the nonliving factors of the area (Christopherson 1997). The term was first coined by A. G. Tansley in 1935 to encompass the interactions between biotic and abiotic components of the environment at a given site (Tansley 1935; Gorham 2006). The word biotic refers to the living components of an environment, where the actions of a variety of species affect the lives of fellow organisms. Abiotic factors are essentially nonliving components, such as temperature, light, moisture, air currents, etc. that equally affect the ecosystem (Lockwood and McKinney 2001; Buchs 2003; Saxena 2003; Gaston and Spicer 2004).

The term ecosystem was later redefined by Eugene Odum as any unit where this interaction between biotic and abiotic factors in a given area produces a flow of energy leading to a clearly defined trophic structure, biotic diversity, and material cycles (exchange of materials between living and nonliving parts) within the system (Odum 1971; Gorham 2006).

An ecosystem is not a single unified entity, constant in size. Our entire planet is covered with a variety of different, sometimes overlapping, and often interdependent ecosystems. A single lake, a neighborhood, or an entire region can be considered an ecosystem, while the term biome is used to refer to a major global ecosystem (Millennium Ecosystem Assessment 2005, *Ecosystems and Human Well-being: Current State and Trends*). Therefore an ecosystem can be as large as the entire globe, or as small as a city or a building (see Fig. 1.1).

While smaller ecosystems are part of the global ecosystem, the flow of energy for an ecosystem occurs on a more local level. Most ecosystems are *autotrophic*, which means that they capture sufficient energy to support their own requirements. For example, green plants convert solar energy to glucose, which is used for plant growth and other functions. In turn they provide energy to the rest of the living system. However, some ecosystems are *heterotrophic*, that is, unable to produce sufficient energy to meet the system's needs. The additional energy requirements must come from adjacent ecosystems. Thus, they can be regarded as autotrophic

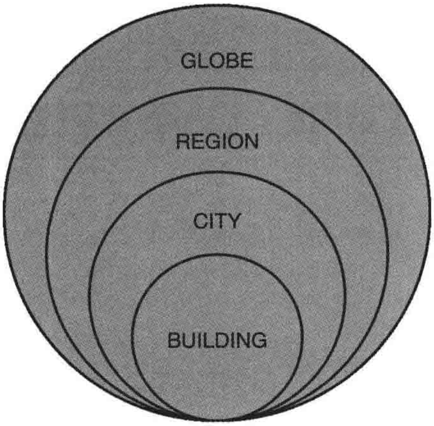

Figure 1.1 Ecosystems are a hierarchy of systems, consisting of subsystems which make up parts of supersystems.

on a bioregional level, such as a river and its watershed (Wardle 2002; Newman and Jennings 2008).

The key to an ecosystem is interconnection and relationship. All the parts of an ecosystem are interrelated through a complex set of self-regulating cycles, feedback loops, and linkages between different parts of the food chain. If one part of an ecosystem is removed or disrupted, there are ripple effects throughout the system. The extent of the disturbance varies depending on the nature, scale, and duration of the disruption; on the relative significance of the part or parts affected; and on the resilience of the ecosystem (Chapin, Mooney and Chapin 2004; ANRC 2005; Ponting 2007; Krapivin and Varotsos 2008; Ostfeld, Keesing and Eviner 2008).

This complex, unique, and fragile relationship is quite vulnerable. It can be altered, even damaged, by various factors, whether cyclical, natural, or man-made. Examples of cyclical factors are solar flares and radiations (Hoyt and Schatten 1997; Carslaw, Harrison and Kirkby 2002; Salby and Callaghan 2004; Benestad 2006), the orbital inclination of the earth with the astronomical theory of accompanying climate change (Berger 2002; Svensmark 2007), and climate variations from geology, geochemistry, and paleontology (Saltzman 2001; Lovejoy and Hannah 2005). Natural factors refer to such events as earthquakes, volcanic activities, floods, and fires (Kondratev and Galindo 1997; Cowie 2007). Most of these factors are out of our control and run their natural course, regardless of what we do.

Human Impact on the Natural Environment

Man-made factors are controllable, and our actions have a great impact on the ecosystem. Throughout history, man's interaction with nature has created disruptive and damaging effects, whether through the generation of energy, the creation of artificial landscapes, the construction of buildings, excavations, or soil cultivation. Today, our pressure on natural environments and the magnitude of the disruption of ecosystems is greater than ever. According to the 2005 Millennium Ecosystem Assessment (MEA) study, the health of the world's ecosystems is in significant decline (Millennium Ecosystem Assessment 2005, *Ecosystems and Human Well-being: Synthesis*). Whether one considers the supply of fresh water and food, or the regulation of climate and air quality, the study found that the global ecosystems showed a 62 percent decline over the course of the last four decades (see Fig. 1.2).

Just a few of the problems resulting from this decline are: 40 percent of the world's coral reefs have been lost or degraded, water withdrawals from rivers and lakes have doubled since 1960, the atmospheric concentration of carbon dioxide has jumped 19 percent since 1959, and extinction of species has increased as much as 100 times over the typical rate seen across earth's history (Millennium Ecosystem Assessment 2005, *Ecosystems and Human Well-being: Synthesis*) (see Fig. 1.3.).

So what does this mean to us? The decline of these systems brings about an increasing risk of disruptive and potentially irreversible changes, such as regional climate shifts, the emergence of new diseases, and the formation of dead zones in coastal waters (Millennium Ecosystem Assessment 2005). Another unforeseen consequence of this decline is the exacerbation of poverty among the two-thirds of the world's population who desperately rely on the resources formerly produced by collapsing local ecosystems.

Furthermore, two separate reports, published by MEA 2005 (Millennium Ecosystem Assessment 2005,) and the World Wide Fund for Nature (Living beyond

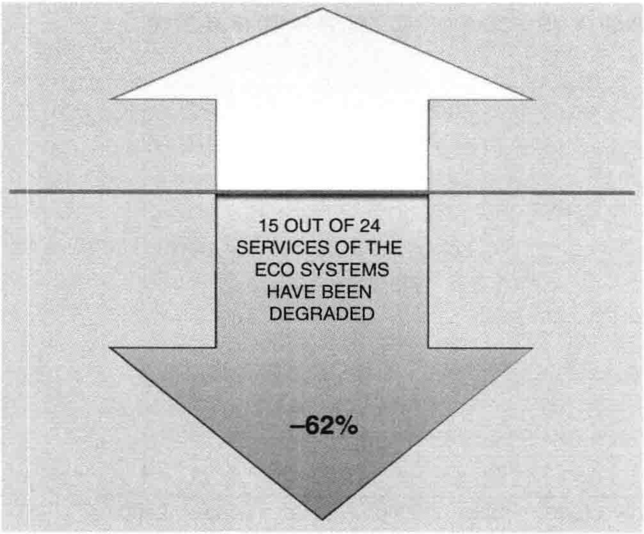

Figure 1.2 The 2005 MEA was a comprehensive analysis by 1360 scientists of 24 benefits or services derived from ecosystems. After four years of consultations and research, the results showed a 62 percent decline in 15 out of 24 services.

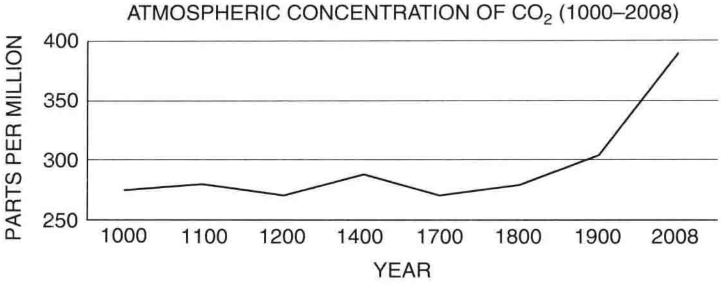

Figure 1.3 **Atmospheric CO_2 has increased from a preindustrial concentration of about 280 parts per million to about 367 parts per million today.** *(Sources: Current and long term historical data compiled by Scripps, Earth Policy Institute, ESRL/NOAA, Worldwatch)*

our means: natural assets and human well-being: statement from the board) show that human activity is putting such strain on natural resources that the ability of the global ecosystem to sustain future generations can no longer be taken for granted. The Ecological Footprint, a conservative measure of natural resource consumption, calculates the total amount of land the world's countries need to produce the resources they use to absorb the waste generated from energy used, and to provide space for infrastructure (WWF 2008). According to this source, man has exceeded the earth's ecological capacity, and we have been living beyond our means since 1987 (see Fig. 1.4).

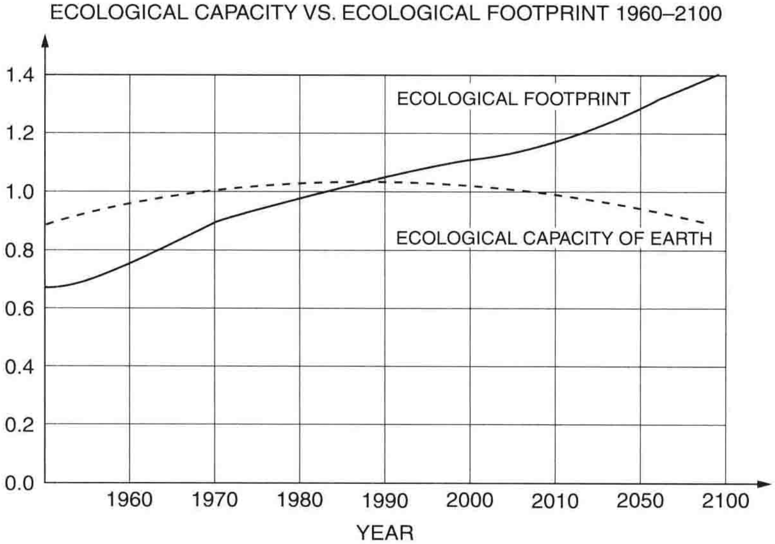

Figure 1.4 **Since 1987, Ecological Footprint has exceeded the earth's biocapacity. The United Nations estimates that by 2100 humanity's demand on nature will be more than twice the biosphere's productive capacity.** *(Source: WWF, Global Footprint Network, 2008)*

REDUCTION AND FRAGMENTATION OF HABITATS AND LANDSCAPES

The expansion of man-made activities into the natural environment, caused by urbanization, recreation, industrialization, and agriculture have resulted in increasing reduction, disappearance, fragmentation, or isolation of habitats and landscapes. With the extension of cultivation areas from preagricultural times to 1994, the changes are dramatic in terms of loss of forest, woodland, and grassland (see Table 1.1).

As a result, landscape uniformity has been altered, geomorphic processes have been affected, and the quality and the quantity of some natural waters have been changed. The nature of the entire landscape has been transformed by human-induced vegetation changes. (Hannah, Lohse, Hutchinson, Carr and Lankerani 1994; Hannah, Carr and Lankerani 1995; Goudie 2006). The spread of agriculture has transformed land cover at a global scale. Even in the past decade, the cropland areas have quadrupled.

According to the 2005 MEA report, agricultural land has been expanding in about 70 percent of the world's countries, while forest areas are decreasing in two-thirds of those same countries. While there is a slight increase in forest area in the past 30 years in industrial countries, we see a 10 percent decline in developing countries over the same time period (Millennium Ecosystem Assessment 2005). Significant deforestation in tropical forests has been documented for 1990 to 2000. The total loss of natural tropical forests is estimated for this period at 15.2 million hectares per year (FAO 2001) (see Fig. 1.5.).

MASS EXTINCTION OF SPECIES (PLANTS AND ANIMALS)

Although the extinction of plants and animals is a natural part of evolution, the number of species disappearing per year has increased dramatically since the 1800s and directly correlates to population growth and the impact of man-made activities on the environment. The 2008 Living Planet Report, co-prepared by the World Wildlife Fund

TABLE 1.1 ESTIMATED CHANGES IN THE AREAS OF THE MAJOR LAND COVER AREAS BETWEEN PREAGRICULTURAL TIMES TO 1994

LAND COVER	PREAGRICULTURE AREA	PRESENT AREA	PERCENT CHANGE
Total forest	46.8	39.3	–16.0%
Tropical forest	12.8	12.3	–3.9%
Other forest	34	27	–20.6%
Woodland	9.7	7.9	–18.6%
Grassland	34	27.4	–19.4%
Cultivation	1	17.6	1760.0%

Source: Modified from Meyer and Turner, 1994.

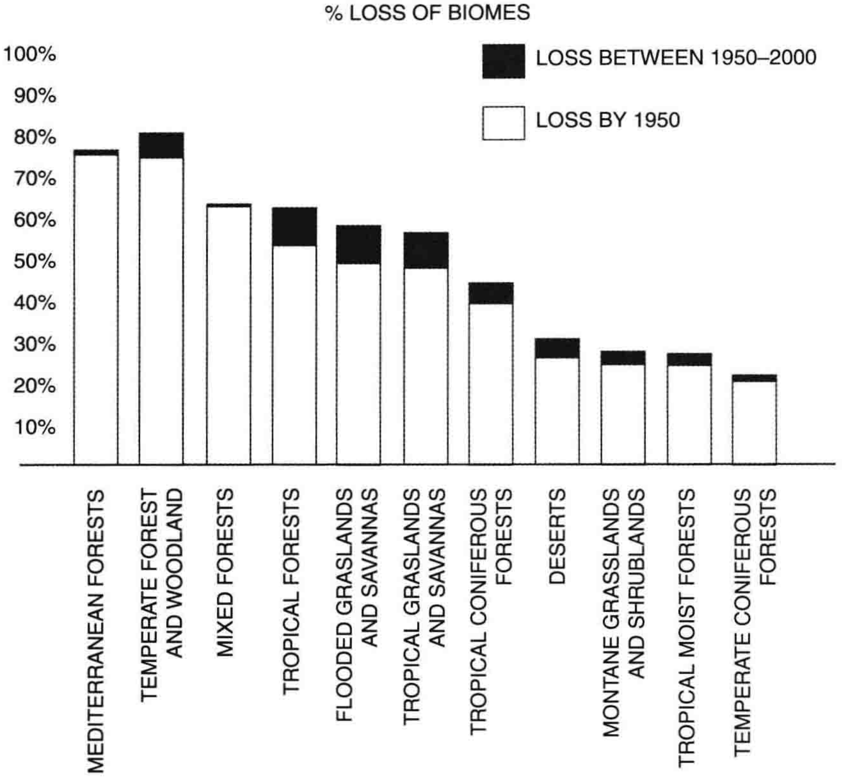

Figure 1.5 **Conversion of terrestrial biomes.** *(Sources: Millennium Ecosystem Assessment 2005, Ecosystems and Human Well-being: Current State and Trends ; UNEP/GRID-Arendal Maps and Graphics Library (2008))*

(WWF), Global Footprint Network, and the Zoological Society of London (ZSL), states that the living planet index, which charts the populations of species of animals and plants, has declined by a third over the past 35 years (WWF 2008) (see Fig. 1.6).

According to the Threatened Species Red List released by the International Union for the Conservation of Nature and Natural Resources (IUCN) in 2008, 40.1 percent of all species, approximately 19.2 percent of the animals and 20.9 percent of the plants are classified as "threatened" (see Fig. 1.7). These threats are directly linked to the loss of habitats due to destruction, modification, and fragmentation of ecosystems as well as from overuse of chemicals, intensive farming methods, hunting, and general human disturbance. The overall deterioration of global air and water quality, excavations, and deforestation, add to the detrimental influence. Looking solely at species loss resulting from tropical deforestation, extinction rate forecasts climb as high as 75 percent (Ehrlich 1985; Clark, Reading and Clarke 1994; Broswimmer 2002).

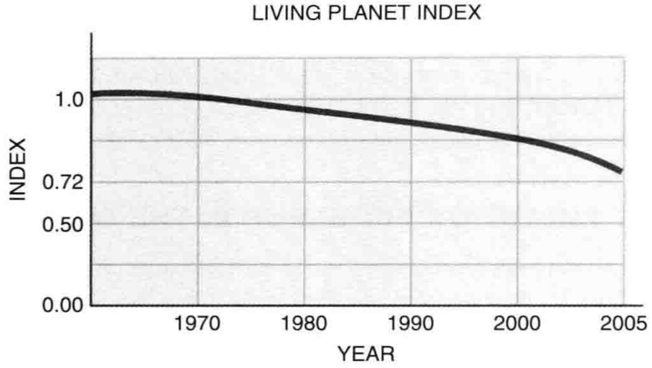

Figure 1.6 **Global Living Planet index shows 28 percent decrease in 4642 populations of 1686 species since 1970.** *(Source: Millennium Ecosystem Assessment 2005, Ecosystems and Human Well-being: Synthesis)*

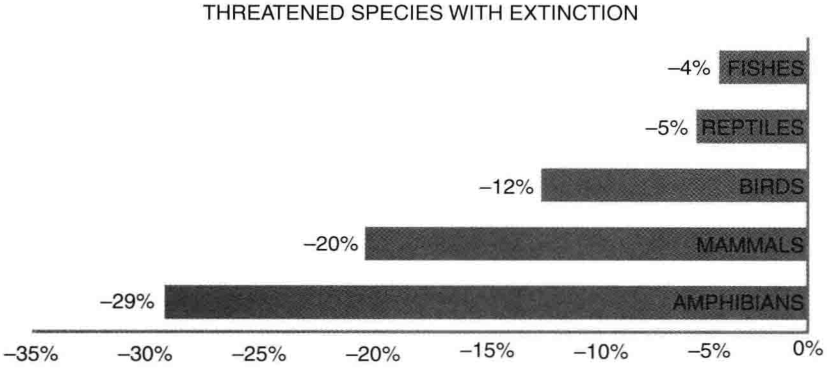

Figure 1.7 **The 2008 Red List, prepared by the IUCN World Conservation Congress shows at least 1141 of the 5487 mammals on earth are known to be threatened with extinction.** *(Source: IUCN Red List, 2008)*

POLLUTION AND CLIMATE CHANGE

Since Paleolithic times, humans have had some effect on the environment, and pollution has always been a part of human history. As summarized in the Brief History of Green Architecture, chapter 3, the rise and fall of all existing civilizations are connected to environmental pollution and its subsequent consequences. However, any type of pollution, whether of land, water, or air, before the twentieth century was more or less local. But beginning in the early 1900s, especially after World War II, globalization, increasing population, and the use of industrial processes created a new paradigm, in which our modern way of life began to have a much greater collective impact on our surroundings than ever before.

Today, harmful emissions into the air and water from urban, industrial, and agricultural sources affect over a billion people around the world by making resources either unusable or unhealthful. The World Bank estimates that about 20 percent of health concerns in developing countries can be traced to environmental factors (WB 2007). Pimentel et al. study reports the number could be higher (Pimentel, Tort, D'Anna, Krawic, Berger, Rossman, Mugo, Doon, Shriberg, Howard, Lee and Talbot 1998) with 40 percent of deaths resulting from exposure to environmental pollutants and malnutrition (WHO 1992; WHO 1995).

TOP TEN WORST POLLUTION PROBLEMS IN THE WORLD

In a joint report with Green Cross Switzerland in 2008, Blacksmith Institute produced the first list of the "World's Worst Pollution Problems: The Top Ten of the Toxic Twenty," an overview of the range of pollution threats which details the sources and effects of pollution in the most polluted places around the world (see Table 1.2). The 20 major global pollution problems are directly associated with economic and technological factors of the regions. High levels of urbanization, poor or no infrastructure, and lack of formal sector employment, as well as over leveraged governments, present very dangerous conditions for human health, as people turn to informal and often toxic sources of generating income (Blacksmith_Institute 2008).

TABLE 1.2 TOP TEN WORLD'S WORST POLLUTION PROBLEMS

Contaminated Surface Water
Groundwater Contamination
Urban Air Quality
Indoor Air Pollution
Metals Smelting and Processing
Industrial Mining Activities
Radioactive Waste and Uranium Mining
Untreated Sewage
Used Lead Acid Battery Recycling
Artisanal Gold Mining

Sources: Blacksmith_Institute and Green Cross joint report (2008).

Although each one of these issues has a devastating impact on the health of the environment and its people, contaminated surface water, groundwater contamination, urban air quality, and indoor air pollution are directly and/or indirectly related to architecture, and therefore, need to be addressed.

Contaminated surface water now affects one-third of the world, and almost five million annual deaths in the developing nations are due to water-related diseases (Prüss-Üstün, Bos, Gore and Bartram 2008).

Groundwater pollution is another major health issue connected to surface water contamination. Groundwater makes up 97 percent of the world's accessible freshwater reserves and only 0.3 percent of it is useable for drinking (WB 2008). An overwhelming