Sulfur Concrete for the Construction Industry
A Sustainable Development Approach

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SUSTAINABLE DEVELOPMENT FOR THE CONSTRUCTION INDUSTRY

1.1 INTRODUCTION

Over the last few years, a diverse number of public- and private-sector organizations around the world have given increased attention to the problems of excessive natural resource consumption, depletion, and degradation; waste generation and accumulation; and environmental impact and degradation. Since the construction industry is a major contributor to these problems, it now faces increasingly restrictive environmental conservation and protection laws and regulations, the emergence of international standards to address environmental quality and performance such as ISO 14000, and substantial pressures from civic and private environmental groups. As a result, private and public sector owners face new, complex, and rapidly changing challenges imposed by these laws, regulations, standards, and pressures at all life cycle stages of a capital project from initial planning, design, construction, and operation/maintenance to ultimate rehabilitation, decommissioning, and/or disposal. Furthermore, traditional approaches to capital projects of mere environmental regulatory compliance or reactive corrective actions such as mitigation or remediation have proven to be consistently costly, inefficient, and, many times, ineffective.

There are strong incentives for the development of a sustainable approach to capital projects. Such an approach goes beyond the traditional focus on cost, time,
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and quality performance to include the goals of minimal (1) natural resource consumption, depletion, and degradation, (2) waste generation and accumulation, and (3) environmental impact and degradation, all within the contextual satisfaction of human needs and aspirations. These goals are explicitly and systematically incorporated within the decision-making process at all stages of the life cycle of a capital project, particularly the early funding allocation and the planning and conceptual design phases. However, most stakeholders within the capital project delivery process (i.e., owners, planners, designers, vendors/suppliers, constructors, users/operators) face a complex task when attempting to implement a sustainable approach. First, they face the challenges imposed by increasingly limited resources on the effective and efficient delivery of capital projects. Second, they do not have clear incentives, the proper resources, or the mechanisms or tools to do so. Finally, there is a lack of awareness and understanding of the actual or potential impact and/or implications of environmental regulations and standards on capital projects; a lack of awareness and understanding of the opportunities and potential benefits to an organization created by a sustainable approach to its capital projects; and a lack of credible and reliable quantitative indicators, metrics, and/or data on the actual benefits and associated costs.

A sustainable approach to capital projects would allow the construction industry to take a more aggressive role in finding both short- and long-term solutions for a more effective and efficient use of its increasingly limited and tight capital resources. The anticipated beneficiaries include: owners who would directly accrue the economic benefits of the implementation of specific strategies for investment, execution, and management of capital resources within a sustainable framework; designers and constructors who could significantly enhance environmental quality and performance of capital projects as a result of the application of specific guidelines for sustainable design and construction; and vendors and suppliers who would have a strong incentive to develop and supply sustainable construction technologies, systems, products, and materials.

This chapter discusses the framework of sustainability and implication for the building design and construction industry; how the construction industry can move toward sustainable development in view of energy, material, waste, and pollution; the role of technology in sustainable development; sustainable technology characteristics; and strategies for implementing changes for a more sustainable future.

1.2 SUSTAINABLE DEVELOPMENT

Sustainable development offers a new way of thinking that reconciles the ever-present human drive to improve the quality of life with the limitations imposed
on us by our global context. It requires unique solutions for improving our welfare that do not come at the cost of degrading the environment or impinging on the well-being of other people. Sustainable development has been defined by various organizations as:

1. The 1987 World Commission on Environment and Development (WCED) defined sustainable development as:
   *Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*

2. The 1989 Tokyo Conference on Conservation of the Global Environment stated that:
   *Sustainable development calls for a review of not only the conventional framework of the world economy, such as trade, direct investment, international financing and official development aid, but each country’s domestic economic, financial and monetary policies.*

3. The 1992 Rio Conference on Environment and Development stated in Principle 3 that:
   *The right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations.*
   and in Principle 4 further stated that:
   *In order to achieve sustainable development, environmental protection shall constitute an integral part of the development process and cannot be considered in isolation from it.*

4. Weston (1995) stated that:
   *Sustainable development is a process of change in organizing and regulating human endeavors so that humans can meet their needs and exact their aspirations for current generations without foreclosing the possibilities for future generations to meet their own needs and exact their own aspirations.*

Although there is no general agreement regarding the precise meaning of sustainability, beyond respect for the quality of life for future generations, most interpretations and definitions of the term sustainable refer to the viability of natural resources and ecosystems over time and to the maintenance of human living standards and economic development (National Science and Technology Council, 1994).

Sustainable development is a relationship, or balancing act, between many factors (social, environmental, and economic realities and constraints) that are constantly changing. Because sustainable development is a dynamic concept, it requires decision makers to be flexible and willing to modify their approaches
according to the changes in the environment, human needs and desires, or technological advances. This means that actions that contribute to sustainable development today, either in perception or in reality, may be deemed detrimental tomorrow if the context has changed:

Ensuring sustainability over time means maintaining a dynamic balance among a growing human population and its demands, the changing capabilities of the physical environment to absorb the wastes of human activity, the changing possibilities revealed by new knowledge and technological changes and the values, aspirations, and institutions that channel human behavior. Thus, visions of a sustainable world must naturally change in response to shifts in any part of this dynamic relationship (Pirages, 1994).

The basic elements of sustainable development are (Mohamed and Antia, 1998):

1. Education
2. Determining environmental limits
3. Efficient use of natural resources
4. Integrated environmental management systems
5. New technologies and technology transfer
6. Perception and attitude changes
7. Population stabilization
8. Refining market economy
9. Social and cultural changes
10. Waste reduction and pollution prevention

Fundamentally, sustainable development aims for the satisfaction of human needs, the maintenance of ecological integrity, the achievement of equity and social justice, and the provision of social self-determination (Mohamed and Antia, 1998). The real challenge lies in finding ways of putting sustainable development into practice. In the following sections, the social, environmental, and economic issues that are essential to sustainable development are discussed.

1.2.1 Social Sustainability

Sustainability is inherently anthropocentric since it is the welfare of humans with which we are concerned. More than a concern for mere survival, sustainability is a desire to thrive and have the best life possible. There are many socio-cultural issues that influence sustainability. The most prominent issue is intergenerational equity in which we must insure that we leave our children with the tools and resources they need to survive and enjoy life. Therefore, we must strive to raise the standard of living of those people who today lack the most basic require-
ments such as clean water and adequate food. Other issues in this dominion are: environmental justice, population growth, human health, cultural needs, and personal preferences. These elements have a great deal to do with our quality of life and should not be ignored in favor of the more easily measurable economic elements.

Ways in which social sustainability can be promoted include:
1. Encouraging systematic community participation
2. Emphasizing full cost accounting and cradle-to-grave pricing, including social costs
3. Promoting qualitative improvement of social organization patterns and community well-being over quantitative growth of physical assets
4. Using resources in ways that increase equity and social justice while reducing social disruptions

1.2.2 Environmental Sustainability

Environmental concerns are also important for sustainable development. The natural environment is the physical context within which we live. Sustainable development requires that we recognize the limits of our environment. There are limits to the quantities of natural resources that exist on the planet. Some of these resources, including trees and wildlife, are renewable so long as we leave enough intact to regenerate. Other resources, such as minerals, are renewed at such slow rates that any use whatsoever depletes the total stock. We need to minimize our consumption of all resources, renewable and depletable.

Another key environmental issue is to minimize our impact on global ecosystems. The earth is like an organism and we must maintain it in a healthy state. Natural ecosystems can survive some impacts, but these must be small enough so that the earth can recover. In some cases, there are particular resources or elements of an ecosystem that are essential to its health. Protecting ecosystem health may involve the protection of an endangered species, the preservation of a wetland, or the promotion of biodiversity in general.

To maintain the natural resources, Goodland and Daly (1995) developed the following practical rules:

1. Input rules:
   a. **Renewable**: Harvest rates of renewable resources inputs would be within the regenerative capacity of the natural system that generates them.
   b. **Nonrenewable**: Depletion rates of nonrenewable resources inputs should be equal to the rate at which renewable substitutes are
developed by human invention and investment. Part of the proceeds from liquidating nonrenewable resources should be allocated to research in pursuit of sustainable substitutes (El Sarafy, 1991).

2. Output rule:
   a. Waste emission from a project should be within the assimilative capacity of the local environment to adsorb without unacceptable degradation of its future waste absorption capacity or other input services.

### 1.2.3 Economic Sustainability

Economics, as it pertains to sustainable development, does not simply refer to Gross National Product (GNP), exchange rates, inflation, profit, etc. Economics is important to sustainable development because of its broader meaning that explains the production, distribution, and consumption of goods and services. The exchange of goods and services has a significant impact on the environment since the environment serves as the ultimate source of raw material inputs and the repository for discarded goods.

Economic gain has been the driver for much of the unsustainable development that has occurred in the past. A shift to sustainability will only occur if it is shown not to be excessively costly and disadvantageous. Part of sustainability is changing the way things are valued to take into consideration the economic losses due to lost or degraded natural resources and expand our scope of concern from short- to long-term impacts. Once this is done, sustainable development will be revealed to be a more economically beneficial option than current development patterns.

In view of Principle 4, environmental protection is considered to be an integral part of the development process. This is different from the traditional pattern of making economic decisions and then correcting the environmental impacts which may result. This is illustrated in Figure 1.1 in which the natural system includes the ambient physical environment, ecosystem, and natural resources. The economic system refers to the factors of production of goods and services. Utilization of the natural system by the economic system results in a decrease in the natural resources and produces additional environmental problems such as solid wastes, air and water pollution, and greenhouse gases. The importance of these impacts on the natural system varies geographically, depending on the existing states of both the natural environment and the economy.

Economic sustainability involves the consumption of interest rather than capital and is defined by Goodland and Daly (1995) as:
The amount one consumes during a period and still be as well off at the end of the period.

Though this definition has focused solely on man-made capital, the principle can be broadened to include natural capital. Rather than viewing the economy as an isolated system, we must begin to see it as linked to the environmental system. Therefore, the economic sustainability can be defined as the maintenance of capital in general, both man made and natural (Mohamed and Antia, 1998).

Nowadays, the concept of environmental economics, which seeks to integrate the environmental system into a broader economic system in which current economic principles will still apply, is growing. Much research is being done on internalizing environmental values, which are external to the classic economic system, as well as finding ways of placing monetary values on intangible non-market (and nonmarketable) components of the environment.

1.2.4 Land Sustainability

Land sustainability can be achieved by integrating the ecological, economical, and social objectives (Serageldin, 1993). Figure 1.2 describes this concept. Ecologists stress the preservation of the integrity of the ecological system that is critical to the overall stability of our global ecosystem and that deal in measurement units of physical, chemical, and biological entities.

Economists seek to maximize human welfare within the existing capital stock and technologies and use economic units (i.e., money or perceived value) as a measurement standard. Sociologists emphasize that the key factors in sustainable
development are people with a range of needs and desires and use units that are often intangible such as well-being and social empowerment.

Sustainable solutions for land development fall at the intersection of the spheres, as shown in Figure 1.3, that represent the three key ingredients for sustainable development (Campbell and Heck, 1997). Sustainable development occurs only when management goals and actions are simultaneously ecologically viable, economically feasible, and socially acceptable. These imply environmental soundness and political acceptability. Imbalance among the three components, due to failure in one or more of the spheres, will likely result in failure to achieve sustainable development.

Figure 1.2. Integrated set of objectives for sustainable development (Mohamed and Antia, 1998).

Figure 1.3. Sustainable solution for the development of a sustainable land (Mohamed and Antia, 1998).
1.3 ROLE OF TECHNOLOGY

Technology plays an important role in sustainable development because it is one of the most significant ways in which we interact with our environment; we use technologies to extract natural resources, to modify them for human purposes, and to adapt our man-made living space. It is through the use of technology that we have seen drastic improvements in the quality of life for many people. Unfortunately, many of these short-term improvements in the immediate quality of life have also exacted a great toll on the environment. In order to proceed toward sustainability, we will have to be more deliberate and thoughtful in our employment of technology. We need to develop and use technologies with sustainability in mind. We need sustainable technologies.

To avoid confusion and ambiguity, it is necessary to establish a working definition of technology. In this book the term technology is taken to mean the application of knowledge to the achievement of particular goals or to the solution of particular problems (Moore, 1972). Thus, technologies include not only the physical tools we use to interact with our environment, but also symbols, processes, and other nontangible effectors such as language and economic transactions that serve as interfaces between humans and enable actions toward the solution of problems to occur.

1.3.1 Characteristics of a Sustainable Technology

A sustainable technology is one that promotes a societal move toward sustainability and one that fits well with the goals of sustainable development. Sustainable technologies are practical solutions to achieve economic development and human satisfaction in harmony with the environment. These technologies serve to contribute, support, or advance sustainable development by reducing risk; enhance cost effectiveness; improve process efficiency; and create processes, products, or services that are environmentally beneficial or benign, while benefiting humans (National Science and Technology Council, 1994). To qualify as sustainable technologies, these solutions must have the following characteristics, in addition to meeting pre-existing requirements and constraints (e.g., economic viability):

- Minimize use of nonrenewable energy and natural resources
- Satisfy human needs and aspirations with sensitivity to cultural context
- Minimize the negative impact on the earth’s ecosystems
Minimizing Consumption

The use of nonrenewable energy and natural resources should be minimized because consumption of resources inherently involves increasing the disorder of materials and energy, rendering them of lower utility for future use (Roberts, 1994; Rees, 1990). By subjecting materials and energy to consumption processes, we decrease their potential utility to current and future generations. Therefore, consuming as little matter and energy as possible, or doing more with less is a fundamental objective of sustainability.

Maintaining Human Satisfaction

A sustainable technology must fulfill the needs of the population that it is intended to serve. In fulfilling those needs, the technology must account for human preferences and cultural differences. In some cases, these preferences may conflict with environmental and economic criteria and a compromise will have to be found. This does not mean that human preferences should be ignored; fulfillment of our desires means the difference between merely surviving and truly living.

Minimizing Negative Environmental Impacts

Finally, causing minimal negative environmental impacts (as well as maximizing positive impacts) is an important objective of sustainability since the environment consists of ecosystems whose ongoing health is essential for human survival on earth (Goodland, 1994). Sustainability of the human race requires that ecosystems are protected and preserved in a reasonable state of health through maintaining biodiversity, adequate habitat, and ecosystem resilience.

1.4 A FRAMEWORK FOR A SUSTAINABLE INDUSTRY

1.4.1 Current System

In order to understand the changes that need to be made to develop sustainable technologies, it is useful to look at the paradigm that is currently being used. Despite a wide range of positions and opinions on the subject of sustainability, there is general agreement that the current paradigm that disregards constraints to material or energy consumption is unsustainable (Roberts, 1994). In Figure 1.4, a model of the unsustainable development approach that has prevailed over the last few centuries is shown. In this model, several systems are linked. It begins with both renewable and nonrenewable natural resources such as air, water, soil, mineral, or biological resources.
The basic components are:

1. **Subsystem 1**: *Exploitation and use of primary natural resources*: This system provides inputs for industrial processes. Its outputs are the principal inputs for two other systems.

2. **Subsystem 2**: *Production and use of energy*: The output of this system is a critical input to all the systems.

3. **Subsystem 3**: *Resource processing and manufacturing*: The output of this system is a set of industry-specific products or services.

4. **Subsystem 4**: *Transport and commercialize products and services*.

5. **Subsystem 5**: *Use and consume products and services*.

This process has two additional outputs from each of its systems that are at the core of many problems facing the world today: (a) increasing amounts of hazardous and nonhazardous waste and (b) increasing levels of environmental impact.

It is worth noting that during this process inputs enter at Subsystem 1 and move in one direction through the system to Subsystem 5 and then are disposed, going through the system only once with no cycling of materials. To aggravate the situation even more, this process is fueled by continuous increases in the demand for and the use and consumption of products and services, creating pressures for further exploitation of natural resources, and for continued expansion of energy production, resource processing, and manufacturing capabilities. This unrelent-
ing growth has created three serious problems: (1) natural resource depletion, (2) accumulation of waste, and (3) environmental degradation. These challenges must be addressed to achieve sustainability.

1.4.2 Modified System

A new way of thinking must be adopted to redirect our development toward sustainability. This cyclic sustainable process is a direct response to the challenges and problems posed by the unsustainable process described in Figure 1.4 and offers a mechanism to gradually overcome the problems of unsustainability.

The framework for a sustainable system presented in Figure 1.5 highlights one way of looking at this new approach (Roberts, 1994). This system shows how to implement two of the three criteria for sustainable technology: (1) economical in use of nonrenewable energy and natural resources and (2) minimal negative impact on the earth's ecosystems. The criteria regarding the satisfaction of human needs and aspirations is not represented explicitly in this figure but nonetheless remain important.

First, the framework represents a closed cyclical system. The total integrated system includes the same five systems described earlier and, in addition,
it incorporates four new subsystems, each a response to a specific sustainability challenge:

6. **Subsystem 6: Natural resource management**: Addresses the need to manage the exploitation of renewable natural resources in a way that ensures that the supply will always exceed the demand. At the same time, this management system monitors and controls the use of nonrenewable natural resources to prevent their total depletion.

7. **Subsystem 7: Resource recovery**: Addresses the need to recover and recycle selected resources and products from waste. These recovered resources would then become inputs to the five basic subsystems in the described framework. They also would contribute to reducing the amount of waste that requires disposal.

8. **Subsystem 8: Waste disposal**: Recognizes that a certain amount of waste is inevitable and, thus, will require disposal in ways that are not detrimental to the environment.

9. **Subsystem 9: Environmental technologies**: Addresses the need to incorporate proactively, in every subsystem within the framework, strategies and mechanisms that mitigate environmental impacts at the root before the impact happens, through the application of preservation, pollution prevention, avoidance, monitoring, assessment, and control strategies and mechanisms. This subsystem also takes into account that some damage already has been done to the environment and that corrective actions such as remediation or restoration are necessary.

Sustainable technologies should adopt this cyclic closed loop system that mimics natural systems. In this system, the generation of waste is avoided; instead, all byproducts are used as inputs back into production or as inputs into some other process. By minimizing waste, environmental impact is lessened. Because the scale of impact is kept low in this system, change to the environment will be gradual and the surrounding environment will be able to adapt and remain healthy.

**1.5 SUSTAINABILITY AND THE BUILDING CONSTRUCTION INDUSTRY**

Whereas traditional design and construction focus on cost, performance, and quality objectives, sustainable design and construction adds to these criteria a minimization of resource depletion and environmental degradation and, therefore, creating a healthy built environment (Kibert, 1994). Figure 1.6 illustrates the
primary paradigm shift to sustainability within the building design and construction industry. This model of the new sustainability paradigm shows issues that must be considered for design making at all stages of the life cycle of the facility.

Sustainable designers and constructors will approach each project with the entire life cycle of the facility in mind, not just the initial capital investment. Instead of thinking of the built environment as an object separate from the natural environment, it should be viewed as part of the flow and exchange of matter and energy that occurs naturally within the biosphere. In addition to the non-living components that make up the built environment, sustainable designers and constructors must also consider the living components of the built environment (flora, fauna, and people) that operate together as a whole system in the context of other ecosystems in the biosphere (Yeang, 1995).

Life cycle considerations are particularly important with respect to the design and construction of built facilities because the life cycle of a facility involves more than just constructing the facility itself. Operation, maintenance, and decommissioning or disposal of the facility also consume matter and energy and are largely constrained by the design and construction decisions made in the early phases of the facility’s life. Not only are changes easier to make during the design of the facility, but the costs of the changes are lower also, since the facility exists only on paper as opposed to being a physical artifact that exists in reality after construction begins and ends. Additionally, choices of more costly design features
made during facility and design construction may be offset by costs, resources, and energy savings realized over the life cycle of the facility. Thus, the primary responsibility for creating sustainable built facilities falls to the designers and constructors of such facilities.

People who make project decisions with sustainability as an objective will need to evaluate the long-term as well as short-term impacts to the local and global environments. And those who take a sustainability approach to design and construction will be rewarded with reduced liability, new markets, and an earth-friendly construction process that will help future and current generations to achieve a better quality of life (Kinlaw, 1992; Liddle, 1994).

1.6 STRATEGIES FOR IMPLEMENTING SUSTAINABLE DESIGN AND CONSTRUCTION

In the creation of built facilities, there are many opportunities to improve how design and construction are currently accomplished to make them more sustainable. Three general objectives should shape the implementation of sustainable design and construction while keeping in mind the three categories of sustainability issues discussed earlier (social, environmental, and economics). These objectives are:

1. Minimizing consumption of matter and energy over the whole life cycle of consumption
2. Satisfying human needs and aspirations with sensitivity to cultural context
3. Avoiding negative environmental impact

In the following subsections, we present specific strategies for approaching each of the three objectives, along with examples of technologies and opportunities related to each of the strategies.

1.6.1 Minimizing Consumption

Consumption of natural resources is at the heart of sustainability. With its large scale use of materials and energy and the displacement of natural ecosystems, the built environment greatly influences the sustainability of human systems as well as the natural ecosystems of which we are a part. Minimizing consumption of matter and energy is essential to achieve sustainability in creating, operating, and decommissioning built facilities. The following sections highlight several strategies for minimizing consumption of natural resources over the life of the built facilities.
Improving Technological Efficiency: Doing More with Less

One strategy for minimizing consumption in creating the built environment is improving the technological efficiency of our materials and processes. For materials, we need to improve the efficiency with which they meet the needs for which they are used. An example of this is improving the technology of windows to reduce unwanted thermal losses and air leakage in climate-controlled applications. With respect to processes, technological efficiency means reducing the amounts of input matter and energy required to generate the desired outcome of the process. In construction, improving the site layout to reduce the travel distance of excavating equipment is an example of improving process efficiency, resulting in fewer equipment hours, less fuel used, and lower maintenance costs.

Reuse, Rehabilitation, and Retrofitting

Reusing buildings, materials, and equipment is a second strategy for making design and construction more sustainable. By reusing what already exists, we save the cost, material, and energy input that would be required to create new facilities from scratch. The primary reason for disposal of facilities and materials is that those artifacts do not meet the present needs of humans. By using techniques such as adaptive reuse, rehabilitation, or retrofitting, old facilities can be modified or improved to meet new use criteria, at a much lower consumptive cost than building a new facility. An example of adaptively reusing existing facilities are loft apartments developed in the structures formerly used for factories. Materials and equipment can also be reused or rehabilitated to varying degrees. The greatest impediments to this strategy are artifacts that are designed for obsolescence, with short life cycles, or where economic constraints have forced sub-quality construction or manufacturing.

Creating New Technologies

Many opportunities exist to increase the sustainability of human activity by creating new technologies. Consumption of matter and energy can be reduced by developing new technologies that do not rely on traditional types or amounts of materials and energy to meet human needs. Photovoltaic (PV) panels, which generate electricity from solar radiation, are one example of such a technology. Instead of using finite reserves of coal or oil to make the electricity used by humans, PV panels use the essentially infinite resource of solar energy. Opportunities for new technologies can be found by observing natural ecosystems: what sources of energy and matter are used by these systems? Particularly promising opportunities exist in the area of waste recovery and reuse. Examples of taking artificially-generated waste that would otherwise have been disposed in
the natural environment, and using it as input back into the building process are: (a) using waste masonry and concrete from demolished structures as aggregate in new concrete and (b) using sulfur, from the oil industry, fly ash, and aggregates for production of sulfur cement and concrete.

**Modifying Historical Technologies**

Technologies have been used over the course of human history to meet the needs of people. Many of these technologies have been forgotten or abandoned as new technologies were developed to replace them. Whereas most of these technologies may appear to be obsolete, some may prove to be useful in and of themselves, or to suggest ideas for new technologies. Traditional construction techniques such as rammed earth have found new applications in structures constructed from waste automobile tires filled with compacted earth. By combining a knowledge of historical building techniques with consideration of the dangerous problem of waste tire disposal, builders have developed a low-cost system that helps to deal with waste disposal while creating a useful and durable structure.

**Reshaping Human Desires**

A more fundamental strategy for minimizing consumption is to attempt to change human desires and tastes. Whereas fundamental human needs such as food, shelter, and water are not greatly adaptable, other human wants are often significantly responsive to external influences. The obvious architectural trends in built facilities from decade to decade are an example of how designers can influence consumer demand and thus the consumption of matter and energy. Other mechanisms for changing human consumptive patterns are education and awareness. If people are aware of the impacts of their choices on the ecosystems of which they are a part, they may make more enlightened choices.

**1.6.2 Satisfying Human Needs and Aspirations**

The quality of the facility as a man-made environment for people is determined by how well it meets human needs and aspirations for such things as security, nontoxicity, shelter, aesthetics, and other functional requirements. Other human needs that are indirectly met by built facilities include economic profitability for those who participate in the design and construction of the facility. Since sustainability is meaningless without reference to humans and their continued survival, the second objective of applied sustainability is satisfaction of human needs and aspirations.
**Improving Economic Viability**

In today’s world, economic viability is an important consideration for any building project. Indeed, a facility design that is sustainable but too expensive to construct has little value in and of itself. Thus, increasing cost effectiveness of facilities is a critical strategy for creating sustainable built facilities. Economic viability often follows from achieving the objectives of minimizing cost and negative environmental impacts, since less consumption means less cost, and reduced environmental impact means lower liability and remediation costs. However, tradeoffs usually exist with respect to economic viability. While sustainable choices save money in the long-term, they are often more expensive initially, making these choices seem unattractive from a short-term perspective. To accurately identify the economic viability of sustainability choices, we need technologies that assist in cost-benefit analysis, financial forecasting, and long-term predictions. In addition, revised economic valuation schemes that assign meaningful values to reserves of natural resources and ecological habitats are essential in assessing the economic viability of construction projects.

**Matching User Needs with Facility Design**

In creating a facility that is sustainable based on the human satisfaction criteria, the first step must be to identify the needs of the people who will use the facility. These needs shape the basic functional requirements of the facility and must be met in order for the facility to be considered sustainable. The facility design process has been described by one architect as “establishing a fit between the pattern of needs and use: the patterns of built form, servicing systems, technological factors, and environmental factors” (Yeang, 1995). Opportunities exist in the area of systematic human needs assessment, and adapting those needs as input to the design process. Additionally, technologies such as decision support systems can help designers and project decision makers to match user needs with appropriate building functionalities within the design.

**Creating a Healthy Built Environment**

In addition to the basic functional requirements of users that must be met by the facility, designers, and constructors must also strive to include factors that create a healthy environment both inside and outside of the facility. Nontoxic materials are an essential component of a healthy built environment, as well as design features that convey aesthetic or spiritual values conducive to the tasks and activities that occur within the facility. Besides the requirements for creating a healthy indoor environment, sustainable design also requires consideration of the interfaces between the built environment and the natural environment. Nontoxic
materials and processes are essential technologies for achieving sustainability throughout the facility life cycle.

**Empowering People to Meet their Own Needs**

A final strategy for satisfying human needs in the built environment is empowerment. By including users in decision making for the planning and design of facilities, the final facility will be more likely to meet the needs of those users. Allowing user participation at all phases of the facility life cycle creates an awareness among the users of the interfaces of the facility with its environmental context and a respect for the flows of energy and material through the built system over time. Strategies such as owner/builder programs in which people are taught techniques for constructing their own homes that invite a respect for the final outcome that might not exist for manufactured or contractor-built houses. This respect and understanding can only lead to more sustainable design and construction.

### 1.6.3 Avoiding Negative Environmental Impacts

Built facilities impact the natural environment in many ways over their entire life cycles. Yeang (1995) lists four categories of impacts that built facilities have on the earth’s ecological systems and resources:

1. Spatial displacement of natural ecosystems, and modification of surrounding ecosystems as a result
2. Impacts resulting from human use of the built environment, and the tendency for that use to encourage further human development of the surrounding ecosystems
3. Depletion of matter and energy resources from natural ecosystems during the construction and use of the facility
4. Generation of large amounts of waste output over the whole life cycle of the facility, which is deposited in and must be absorbed by natural ecosystems

Given their large scale and long life cycles, built facilities have particularly large and long-lasting effects on the environment as a whole. The following strategies are examples of approaches that can be taken to improve the sustainability of built facilities by avoiding negative environmental impacts over their life cycle.

**Recovering Waste: Reduce, Reuse and Recycle**

Various approaches exist to help recover waste from building construction and operation processes. Pollution prevention, for example, is a strategy that advocates anticipating and eliminating pollution before it is produced and has been
used successfully in factory fabrication applications. Material recycling is also commonly used in prefabrication processes where careful planning can eliminate waste or enable it to be directly recycled back into the manufacturing process or to other complementary processes. Construction and demolition waste recycling is also becoming increasingly popular as disposal options become more expensive. Promising applications include recycling construction and demolition waste into new composite materials for construction such as the concrete aggregate.

**Reusing Existing Development**

Another way of minimizing impacts on the natural environment is by making better use of sites and facilities that have already been used. Rehabilitation of existing structures for similar or adaptive uses, as well as using retrofitted existing sites rather than green field sites for new development, are examples of strategies that reduce negative impacts on the natural environment. By reusing existing sites and/or facilities, we save costs and avoid negative impacts by avoiding the need to *start from scratch*. Additionally, peripheral costs such as extending utility and transportation systems to green field facilities, as well as travel savings for users, are reduced or eliminated. Thus, not only is reuse of existing development more sustainable because of its reduced environmental impact, it can also be economically beneficial. Finally, redeveloping unsavory components of built systems can lead to improvements in the human system, as well, by providing better environments for living and by encouraging further development.

**Integrating the Built Environment into Ecological Systems**

Sustainability must occur within the context of natural ecological systems because these systems provide the resources for all human activity. The built environment can be integrated into the natural environmental context of its site and bioregion by designing material and energy flows into and out of the built system to fit within the yield and assimilative capacities of that context. Grey water systems are an example of a technology that has been successfully used to facilitate the processing and absorption of human wastewater back into the natural environment. Rather than collecting the wastewater and using artificial chemical treatment processes to eliminate contaminants, grey water systems take advantage of the naturally purifying processes of ecosystems in their operation. As an added bonus, the grey water relationship is symbiotic since the plants, which purify the wastewater, use the contaminants as a nutrient. Thus, integration of built systems into the surrounding ecological context can be mutually beneficial to humans and nature provided that humans do not exceed the assimilative capacity of natural systems.
1.7 SUSTAINABILITY AND PROJECT PROCUREMENT LIFE CYCLE

Construction project procurement life cycle encompasses the following critical phases:

a. Business justification
b. Project brief and procurement process
c. Design brief
d. Construction process
e. Operation and management
f. Disposal and reuse

1.7.1 Sustainable Business Justification

Defining a business case establishes the need for the project. An effective business case sets out the range of solutions that would meet the business objectives and justify the proposed project. This includes whether the delivery of a construction project, or of a service, is the most appropriate way to meet the business need. Questions around sustainability must be an integral part of this process. Examining these issues will help the project team identify the range of options and deliver the best value, whole-life solution—one that not only meets the business need but also makes informed decisions about the feasibility and nature of the project.

The key issues that should be considered in the development of the business case are: (a) whether construction is the best solution to meet a recognized business need, (b) the impact that alternative service, delivery, and construction options have on the effectiveness and efficiency of the business operation, (c) the impact that options (in delivering and operating the facility) will have on the stakeholders, and (d) including staff and the local community, as well as the social, economic, and environmental impacts of the various options.

The key areas of sustainability that should be considered during the development of the business case are:

A. Economic Aspects:

- *Whole-Life Costing (WLC) and Value for Money*: Assessment should be carried out on a whole-life cost basis. (a) Is construction the best choice? (b) Can the business need be delivered in a different way? (c) Have the options and cost assessment been undertaken for refurbishment versus new build?
- *Economic Regeneration*: How will it affect the local economy?
• **Function:** The project should offer flexibility and have the ability to adapt to future changes.

• **Investment and Project Delivery:** WLC must be assessed against the benefits that will be delivered; higher WLC may deliver greater business benefits.

### B. Environmental Aspects:

• **Location:** (a) Does the construction utilize previously developed land and buildings? (b) If so are there any issues of contamination? (c) are there any planning issues? (d) Has an environmental impact assessment (EIA)/site appraisal been carried out?

• **Transport Infrastructure:** (a) How is the area currently serviced? (b) Are public services readily available? (c) Is the development reliant on energy-intensive forms of transport? (d) Is there an infrastructure in place to support the community? (e) How would the project impact on current infrastructure? (f) Has a transport impact assessment (TIA) been carried out?

• **Biodiversity:** (a) Has a detailed survey and EIA been undertaken? (b) Does the development create opportunities to enhance green spaces and nature conservation? (c) Are there planning conditions relating to biodiversity?

• **Energy and Water:** (a) Will the development actively contribute to the government targets to reduce emissions of CO₂? (b) Will the development use energy efficiently? (c) How will the development impact on local gas and distribution networks? (d) How will the development impact on the local sewage system? (e) Can the local water supply cope with additional demand from the development? (f) Will the development pose risks to water pollution?

### C. Social Aspects:

• **Stakeholders:** The local community should be consulted during the decision-making process. Have their needs been identified and taken into consideration?

• **Culture/Heritage:** The project should enhance or preserve the existing culture and heritage and should address any negative visual impact. Issues to be considered are: (a) Will the project be sympathetic to the local styles of architecture? (b) Is there a possibility of uncovering archaeological remains? (c) Are there planning constraints in place?
Table 1.1. Sustainability and the project procurement lifecycle

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<tr>
<th>Project activity</th>
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<td>• Life cycle assessment</td>
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<td>• Economic regeneration</td>
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• **Health and Safety:** Appropriate resources should be allowed for within the business case to comply with government policy of health and safety.

### 1.7.2 Sustainable Procurement Process

The procurement process consists of: (a) the establishment of the procurement route, (b) finalizing tender documents, including the project brief and the output based specification, and (c) the tender selection process for an integrated supply team.

The project brief sets out the vision, strategy, and requirements of the project. It must clearly highlight the importance of sustainability considerations to the client to ensure that all parties involved in the project are conscious of the client’s needs and requirements.

Before beginning the tender process, the client must develop the project brief into an output-based specification that defines the objectives that they wish to achieve but not how these should be met. Within this, the client must set out those objectives that are considered essential and those that are desirable. This specification must include the sustainable performance objectives for the project, covering both the construction and operation of the facility so that prospective companies who are submitting tenders can fully respond to these requirements. Equally, it is vital to assess which risks are more appropriately managed by the client and which should be managed by the supply team and to develop the detail of the specification taking this analysis into account.

Companies submitting tenders should also be asked to provide full details of how they will respond to the required sustainability objectives. The importance of this element in the tender appraisal process should be made clear. This will encourage them to suggest innovative approaches and alternatives that offer better value for money and/or whole-life cost performance. As part of the tender evaluation process, the client should explicitly appraise the responses to the sustainability criteria defined within the tender documentation. This appraisal should also consider the supply team’s knowledge and experience of sustainable projects.

The key areas of sustainability that should be considered during the development of the project brief and the output-based specification are:

#### A. Economic Aspects:

• **Whole Life Costing/Value for the Money:** Tender documents should emphasize the importance of life-cycle-assessment costs (LCAC) in delivering a value for money, sustainable project. Project briefs should clearly set out the benefits the facility is intended to deliver
and should seek to link their delivery to supply team rewards. In a long-term concession, does the contract ensure that the residual assets value at the end of the concession reflects life cycle assessment costing constraints?

B. Environmental Aspects:

- **Biodiversity**: A requirement for a biodiversity management plan (BMP) for current development and long-term management should be included in the brief. The BMP should encompass the following: (a) consultation and scoping study, (b) detailed surveys and impact assessment, (c) design of development to incorporate biodiversity objectives, (d) enhancement, mitigation, and compensation, and (e) management and after care. We have to make sure that biodiversity interest has been identified on the site.

- **Energy**: The brief should define targets for energy consumption during construction and operation, and how they will be monitored. The brief should identify minimum requirements for energy performance for both new facilities and major renovations. Will the brief include the requirement to procure only buildings in the top quartile of energy performance for the government estate?

- **Water**: The brief should include targets and how they will be monitored for water consumption both during construction and when the facility is in operation.

- **Waste Minimization and Management**: A requirement for suppliers/contractors to provide a waste management plan should be included in the brief. Targets should be specified for reuse/recycling during construction and in operation and how they will be monitored.

- **Materials**: The brief should include a requirement to use materials that contribute to the sustainability goals the project is aiming to achieve. Examples are: (a) use of preferred standards, (b) reuse of materials that can be recycled or reclaimed on-site, (c) avoidance of environmentally damaging materials, (d) use of natural materials, and (e) avoidance of materials that are potentially harmful to humans.

The brief should include an outcome-based requirement for overall material efficiency such as a minimum requirement for recycled content in the project. For example, one may state that a minimum requirement such as 10% of the materials value of the project should derive from recycled or reused content.
• *Pollution (Air, Noise, Land, and Water):* The brief should define targets to minimize or reduce pollution where possible. Risks should be identified and a plan to mitigate potential sources of pollution should be stated in the brief. Targets for minimizing the pollution should be set out by the client and key performance indicators (KPIs) should be used to benchmark performance.

• *Environmental Performance Standards:* The brief should include a requirement for the use of a performance measurement target set by various professional agencies. The brief should take account of governmental or departmental strategy and targets.

**C. Social Aspects:**

• *Respect for People:* The respect for people toolkit addresses the following six action themes: (a) equality and diversity in the workplace, (b) working environment, (c) health, (d) safety, (e) career development and lifelong learning, and (f) worker satisfaction.

• *Health and Safety:* The brief should take full account of government policies.

• *Stakeholders/Local Community:* The views, interests, and requirements of stakeholders should be addressed within the brief. The brief should include a provision for future consultations on design, construction, and operating issues.

• *Culture/Heritage:* Does the brief identify the client’s commitment to preserving and maintaining the culture and heritage of the local community?

• *Project Team and Contractor Selection:* The brief should identify clearly the sustainability criteria those tendering will be measured against. Does the tender documentation encourage supplies to innovate and offer higher sustainability solutions?

• *Supply Team:* The supply team should have the following characteristics:

1. *Knowledge and Competence:* (a) Can the integrated supply team provide examples of successful sustainable projects they have completed? (b) Does the integrated team have the relevant experience?

2. *Commitment and Motivation:* (a) Is the integrated supply team enthusiastic and interested in sustainability issues? (b) Does the integrated supply team actively promote sustainability?

3. *Resources:* Does the integrated supply team have suitably experienced resources to implement a sustainable project?
4. **Training:** (a) Is the integrated supply team willing to educate all stakeholders? (b) Is the integrated supply team able to provide handover training?

5. **Team Building and Communication:** Will the integrated supply team share knowledge and best practice?

### 1.7.3 Sustainable Design

**Developing the Sustainable Design**

The design brief should be developed in partnership with the integrated project team. It should expand on the project brief by providing greater detail but still be flexible enough to allow for alternative solutions. This can then be used as the base for developing the scheme and for detailed design proposals. During the design phase, the client and the supply team continue to have an opportunity to influence the sustainability performance of a development. A key focus is to identify those construction materials that best meet sustainability targets. These sustainability considerations, such as the requirement for energy efficiency or accessibility, will have a significant influence on how the final design is reached.

The key areas of sustainability that should be considered during the development of both the outline and detailed design briefs are:

#### A. Economic Aspects:
- **Function:** Does the design encompass adaptability and reuse?

#### B. Environmental Aspects:
- **Location:** The design should take account of a facility's orientation, solar radiation levels, wind speed, and wind direction.
- **Enhancing Biodiversity:** Biodiversity objectives should be drawn up to reflect both opportunities and constraints for conservation within the design. Will the building materials utilized in the design be benign to local species?
- **Energy Efficiency:** The design should incorporate energy-saving features. (a) Does the design make use of renewable energy sources? (b) Does the design make use of alternative means of heating/cooling? (c) Does the design utilize products or apply processes that allow the facility to utilize energy efficiently?
- **Materials:** (a) Have considerations been given to using materials with low-embodied energy? (b) Can the material be sourced locally reducing the energy used in delivery to site? (c) Does the specified materials comply with government policy? (d) Does the design maximize the
cost-effective use of recycled products? (e) Does the design incorporate materials with a long life and low-maintenance requirements? (f) Does the design include specifications for low-energy use materials?

**Examples:**

Crop-based materials are increasingly being used by the construction industry as an alternative to more traditional materials. A number of crop-derived materials are available that provide significant benefits through reduced environmental impact and cost savings during disposal. In many cases, the additional cost of renewable material is offset over the whole life of the product.

a. **Insulation Materials:** Have the benefits of low-embodied energy in manufacture, naturally good performance when damp, and renewable feedstock been identified?

b. **Paints:** Have the benefits of low-embodied energy in manufacture, reduced toxicity and disposal issues, and renewable feedstock been identified?

c. **Floor Covering:** Have the benefits of reduced health and allergy issues, disposal benefits, and renewable feedstock been identified?

d. **Biomass Heat Boilers:** Have the benefits of renewable energy and efficient and carbon neutral been identified?

e. **Geotextiles for Landscaping and Roadside Use:** Have the benefits of much lower-embodied energy, degrades naturally at end of life, and renewable feedstock been identified?

- **Waste Minimization and Management:** (a) Has thought been given to a design that minimizes waste both during construction, operation, refit, and demolition? (b) Does the design make use of prefabricated components? (c) Can waste off-cuts be returned to suppliers for recycling? (d) Can standard components be used? (e) Does the design take account of the segregation and storage of waste during operation of the facility? (f) Does the design facilitate both routine maintenance and component life cycle replacement?

- **Transport and Travel:** Does the design promote the use of public transport?

- **Water:** (a) Does the design incorporate water-saving features both for consumption and discharge of waste? (b) Has a sustainable urban drainage system been considered? (c) Does the design incorporate grey water recycling and rain water harvesting?
• Pollution (Air, Noise, Land, and Water): Does the design mitigate against any possible risks to pollution?
• Climate Change: The facility should be robust enough to cope with future climate change. (a) What practical measures can be adopted within the design?

C. Social Aspects:

• Internal Environment and Accessibility: Does the design provide for a healthy and comfortable environment? i.e., the design should be accessible to the young, elderly, or disabled.
• Culture/Heritage: Does the design enhance the historic or local environment?
• Health and Safety: The design should consider the health and safety requirements of the end user. (a) Will the materials, products, and furniture be assessed for safety? (b) Does the design minimize the risk of crime?
• Local Communities: (a) Has the local and wider community been consulted on the design? (b) Have design quality indicators been used to help stakeholders evaluate the design quality?

1.7.4 Sustainable Construction Process

Before Construction Begins

Before the construction process begins the client must be satisfied that the proposals meet or exceed the original project and design brief.

During Construction

Construction sites often have a negative impact on the local environment and community through noise, air, water and land pollution. The client and the integrated supply team should make provisions to minimize pollution and disruption and to ensure the health and safety of local residents as well as construction site staff. However, during the construction process there are opportunities to make cost savings and reduce the environmental impact through waste recycling and recovery. For example, the client can cut the costs of disposal and reduce the pressure on the landfill by utilizing reclaimed materials and recycled aggregates.

After Construction: The Handover

The client should see the commissioning and handover of a project as an important and final phase of the construction process. As part of the handover, it is
essential to provide the client with training, facility operations and maintenance information, health and safety files, and procedures for reporting defects.

Key areas of sustainability that should be considered both before and during the construction process are:

A. Economic Aspects:
   - Performance Monitoring: Is economic, social, and environmental performance being monitored, recorded, and reported on site?
   - Cost Management: Have whole-life costs been reassessed?
   - Logistics: Has the use of a central delivery-handling center been considered?

B. Environmental Aspects:
   - Biodiversity: (a) Has a biodiversity management plan been implemented? (b) Are construction techniques sympathetic to the local habitat and species?
   - Energy Efficiency: Are there plans in place to minimize energy use during construction?
   - Waste Minimization and Management: Hazardous waste on-site should be disposed of in the correct manner. (a) Has a site waste management plan been implemented? (b) Is there a provision for waste segregation and auditing? (c) Have steps been taken to minimize construction waste? (d) Can any construction waste be recycled or sold? (e) Who is responsible for disposing of the waste and are they licensed to do so?
   - Pollution (Air, Noise, Land, and Water): (a) Are there plans to minimize and monitor pollution? (b) Are there plans to conserve and minimize water usage on-site?

C. Social Aspects:
   - Respect for People: (a) Are the contractors, suppliers and designers committed to their workforce? (b) Are they committed to achieving the respect for people standard? (c) Are the site staff and subcontractors educated and trained in environmental awareness?
   - Health and Safety: The site should be secure from theft and vandalism. (a) Are the contractors registered to and committed to the considerate contractors scheme or something similar? (b) Are the contractors registered to and committed to the construction skills certification scheme or something similar?
   - Local Communities: Are the relevant stakeholders being kept informed of the progress?
1.7.5 Sustainable Management and Operation of the Facility

It is essential that, as far as possible, the facility is monitored and maintained according to the predefined sustainability criteria set out in the project and design brief. Following the handover of the completed facility, the client must ensure that its end-users are educated and trained in how to use the facility efficiently. This is not only an ideal opportunity to promote the sustainability aims (and achievements) of the facility itself, but it will encourage end-users to play their part in meeting those goals as well as instilling a sense of belonging. Once the end-users have had time to adjust to their surroundings, a post-occupancy evaluation should be carried out to identify not only how satisfied people are with the building, but to examine how the facility is meeting its environmental objectives.

This feedback is extremely useful. It can help iron out any problems with the facility and the information gathered could be used to inform on future projects. Those key performance indicators that were identified for the site in-operation should be assessed and verified appropriately throughout the operational life of the facility. All major facilities should operate under an environmental management system that provides a framework for setting, implementing, and monitoring environmental targets. This will help deliver cost savings and demonstrates, through verification, an organization’s positive environmental achievement.

Key areas of sustainability that should be considered throughout the management and operation of a facility are:

A. Economic Aspects:
   • Cost Management: Is there a process in place to validate whole-life costing?

B. Environmental Aspects:
   • Water: Plans should be in place to monitor and reduce water usage during operation.
   • Energy: Plans should be in place to monitor and reduce energy usage during operation. Are there plans in place to undertake regular inspections of boilers and air conditioning systems (in buildings)?
   • Biodiversity: Plans should be in place to manage and care for areas of conservation both on-site and within the facility.
   • Waste Minimization and Management: There should be guidance on waste minimization and recycling for users and facility management. Are recycling facilities provided?
   • Environmental Performance Standard: Has a performance measurement been carried out?
• *Environmental Management System:* Has an environmental management system been put in place? Many organizations are now compliant with ISO 14000 that provides a framework for the development of an environmental management system and the supporting audit program.

C. Social Aspects:

• *Post Occupancy Evaluation:* Feedback should be obtained from the occupants on user satisfaction. Has feedback been obtained on the performance of the facility?

• *Health and Safety:* (a) Is there a health and safety file? (b) Are risk assessments carried out regularly?

• *Education:* End-user training should be completed as part of the handover. (a) Has environmental training been given? (b) Are end-users aware of the sustainability aims and achievements of the facility? (c) Have procurement advisors been trained in the need for securing sustainable procurement contracts, e.g., buying recycled, buying energy efficient, etc.

1.7.6 Sustainable Disposal and Re-Use of the Site

There are two distinct areas a client must be aware of at this phase of the construction project life cycle. These are: (a) disposal of a surplus facility and (b) reuse of an existing facility. Each area has its own set of considerations that will apply, depending on the individual circumstance of the facility in question.

**Disposal**

Where a facility is identified as surplus to requirements, it is important to dispose of it on best terms bearing in mind the sitting tenants, biodiversity, and historical context.

**Reuse**

Occasionally facilities reach the end of their life or no longer fulfill the function for which they were built. There are a number of options a client can choose to adopt. However, it is important that the solution represents an efficient, affordable, and sustainable use of an existing built asset. The options for re-use are: (a) adapt for a small change in use, (b) refurbish and alter for a major change in use, and (c) demolish and recycle if the facility cannot be reused.

It is always preferable to adapt or refurbish an existing facility rather than choosing to construct anew. However, there will be circumstances in which a
facility has come to the end of its life. Demolition of an existing facility can create a large and complex waste stream that covers a wide array of materials. This waste stream, if managed carefully, can provide materials for re-use in new structures, can lessen the associated environmental impacts, and deliver cost savings through avoided waste disposal fees (for example, design for deconstruction).

Key areas of sustainability that should be considered before commencing disposal or re-use are:

A. Economic aspects:
   • *Adaptation for New Use*: Can the facility be adapted to meet future needs?

B. Environmental Aspects:
   • *Waste Minimization and Management*: (a) Has a waste management plan been put in place? (b) Can any demolition waste be recycled or sold?
   • *Materials*: Have existing building materials been identified for re-use?
   • *Pollution (Air, Noise, Land, and Water)*: Plans should be in place (a) to control and minimize emissions to air, noise and vibration, and (b) to avoid contaminating land and water.

C. Social Aspects:
   • The demolition process should be fully planned in order to minimize risk to health and safety. Is there a need to remove any hazardous materials such as asbestos?

### 1.8 SUMMARY AND CONCLUDING REMARKS

The recent global attention to the issues and challenges of sustainable development is forcing industries to conduct self-assessments to identify where they stand within the framework for sustainability and, more importantly, to identify drivers, opportunities, strategies, and technologies that support achieving this goal. However, in order to understand the changes that need to be made to achieve sustainability, it is useful to look at the paradigm that is currently being employed. Despite a wide range of positions and opinions on the subject, there is general agreement that the current paradigm of development that disregards constraints to material resources and/or energy consumption is unsustainable. This paradigm, which has prevailed over the last few centuries, is based on an unsustainable approach to development that begins with the extraction and use of primary natu-
eral resources, both renewable and nonrenewable such as air, water, soil, mineral, or biological resources. These resources are then utilized for energy production and use and as inputs to resource processing and manufacturing processes. The results of these processes are industry-specific products or services that are eventually transported and commercialized, and ultimately used and consumed across all segments of society. In the process, all inputs and outputs move in one direction until disposed, going through the system only once with no recovery of materials. Aggravating this situation even more is a continuous increase in the demand, use, and consumption of products and services that creates pressures for further extraction of natural resources and for continued expansion of energy production, resource processing, and manufacturing capabilities. This unrelenting growth has created three serious problems: (1) excessive natural resource consumption, depletion, and degradation (both renewable and nonrenewable); (2) waste generation and accumulation (including organic and inorganic; hazardous and nonhazardous); and (3) environmental impact and degradation (on the air, water, land, biota). These are the challenges that must be overcome to achieve sustainability.

In striving to achieve sustainability in the built environment, three themes emerge. First, awareness of the impacts that built facilities have on both human and natural systems is essential and should be considered as early as possible in the planning and design of any built facility. Second, the ecological, social, and economic contexts of the facility must be taken into account for all project decision making. Finally, sustainable designers and constructors must be aware of the connectivity of human systems to the natural environment. No human action can take place without affecting the ecological context in which it occurs. All human activity must be undertaken with an awareness of the potential consequences to other humans and nature, especially the construction of built facilities because of its large scale.

The principal conclusion is that the area of sustainable technologies is one of increasing interest that has many levels and complex dimensions. In this chapter we have tried to provide a brief overview of the wide range of technological issues at an industry level while emphasizing the need for an integrated approach and understanding of the various components of a sustainable system. We have stressed the importance of adopting a new paradigm that considers industry as a total system rather than focusing on individual components of processes and operations. In order to achieve sustainability for society as a whole, and for construction in particular, intelligent decision making is required that includes full consideration and knowledge of the many trade-offs and impacts associated with each alternative available as an option. Sustainability is a desirable state toward which to strive, but the journey is not easy.