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Sustainable Technologies for the Building Construction Industry

Jorge A. Vanegas[†], Jennifer R. DuBose[††], and Annie R. Pearce[†††]

INTRODUCTION

As the dawn of the twenty-first century approaches, the current pattern of unsustainable, inequitable and unstable asymmetric demographic and economic growth has forced many segments of society to come together in facing a critical challenge: how can societies across the world meet their current basic human needs, aspirations and desires, without compromising the ability of future generations to meet their own needs? At the core of this challenge is the question: how can the human race maintain in perpetuity a healthy, physically attractive and biologically productive environment (Malone 1994).

The development path that we have been taking, in the past few centuries, has been ultimately detrimental to the health of our surrounding ecological context. We are consuming an increasing share of the natural resources available to us on this planet, and we are creating sufficiently large amounts of waste and pollution such that the earth can no longer assimilate our wastes and recover from the negative impacts. This is a result of a growing population as well as new technologies which make it easier for us to access natural resources and also require the consumption of more resources. Unsustainable technology has been the result of linear rather than cyclic thinking. The paradigm shift from linear to cyclic thinking in technological design is the crux of the shift from unsustainability to sustainability.

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. The principal objectives of this paper are to present a brief overview of an overall framework for sustainability and then to discuss the implications for the building design and construction industries. Strategies, technologies, and opportunities are presented to improve the sustainability of the built environment. This summary has been compiled as part of an on-going research, education and curriculum development effort lead by the Center for Sustainable Technology (CST) at the Georgia Institute of Technology. Achieving true sustainability will require a paradigm shift that brings together sustainable technologies for built facilities as total systems.

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THE NEW PARADIGM: CYCLIC SUSTAINABLE DEVELOPMENT

Sustainable development offers a new way of thinking which reconciles the ubiquitous human drive to improve our 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. 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).

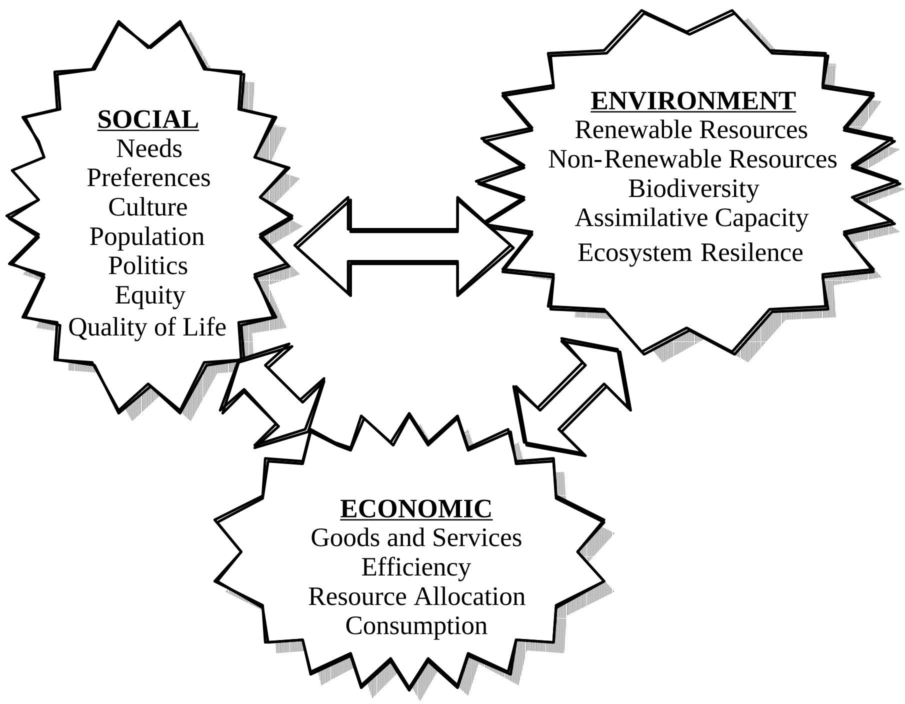

Figure 1: The Context of Sustainability. This figure is one representation of the issues which comprise sustainability. Sustainability is at the nexus of sociocultural, environmental, and economic factors. Although useful, this representation is deceptively uncomplicated in its portrayal of the relationships between sustainability issues, because in fact the relationships between these issues are quite complex.

Sustainability is a relationship, or balancing act, between many factors (social, environmental and economic realities and constraints) which are constantly changing (see Figure 1). As one expert has defined it "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" (Weston 1995). Because sustainability is a dynamic concept rather than a static state, it requires decision makers to be flexible and willing to modify their approaches according to changes in the environment, human needs and desires, or technological advances. This means that actions that contribute to sustainability 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 opened up by new knowledge and technological changes and the values, aspirations and institutions that channel human behaviour. Thus, visions of a sustainable world must naturally change in response to shifts in any part of this dynamic relationship (Pirages 1994, p. 200).

The next three sections discuss the social, environmental and economic issues which are essential to sustainability. These concerns will be applied to the construction and building industry in the latter part of the paper.

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, to have the best life possible. There are many sociocultural issues which influence sustainability. The most prominent issue is inter-generational equity, in which we must insure that we leave our progeny with the tools and resources they need to survive and enjoy life. As an African proverb says, "We do not own the earth, we are just taking care of our grandchildren's inheritance." In so doing, we should not forsake the quality of life that people today are experiencing. Instead, we must strive to raise the standard of living of those people who *today* lack the most basic requirements such as clean water and adequate food. Other issues in this realm 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 discussed below.

Environmental Sustainability

Environmental concerns are also very important for sustainability. The natural environment is the physical context within which we live. Sustainability 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, such as 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 which are essential to its health. For example, we might appear to provide enough timber for future generations, but if it is all contained in managed monoculture forests (which fail to duplicate the complexities of ecosystems), our efforts may not be adequate (Norton 1992). Protecting ecosystem health may involve the protection of an endangered species, the preservation of a wetland, or protection of biodiversity in general.

Economic Sustainability

Economics, as it pertains to sustainability, does not simply refer to Gross National Product, exchange rates, inflation, profit, etc. Economics is important to sustainability because of its broader meaning as a social science 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 term to long term impacts. Once this is done sustainable development will be revealed to be a more economically beneficial option than current development patterns.

ROLE OF TECHNOLOGY

Technology plays a very 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 use of technology that we have seen drastic improvements in the quality of life of 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 paper 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, p. 5). Thus, technologies include not only the physical tools we use to interact with our environment, but also symbols, processes, and other non-tangible effectors such as language and economic transactions which serve as interfaces between humans and enable actions to occur toward the solution of problems.

Sustainable Technology Characteristics

A sustainable technology is one that promotes a societal move toward sustainability, a technology 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, enhancing cost effectiveness, improving process efficiency, and creating processes, products or services that are environmentally beneficial or benign, while benefiting humans (National Science and Technology Council 1994, p. 4). 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
- Satisfying human needs and aspirations with sensitivity to cultural context
- Minimal 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 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 worked out. This is does not mean that human preferences should be ignored; fulfillment of our desires means the difference between surviving and 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 be protected and preserved in a reasonable state of health through maintaining biodiversity, adequate habitat, and ecosystem resilience.

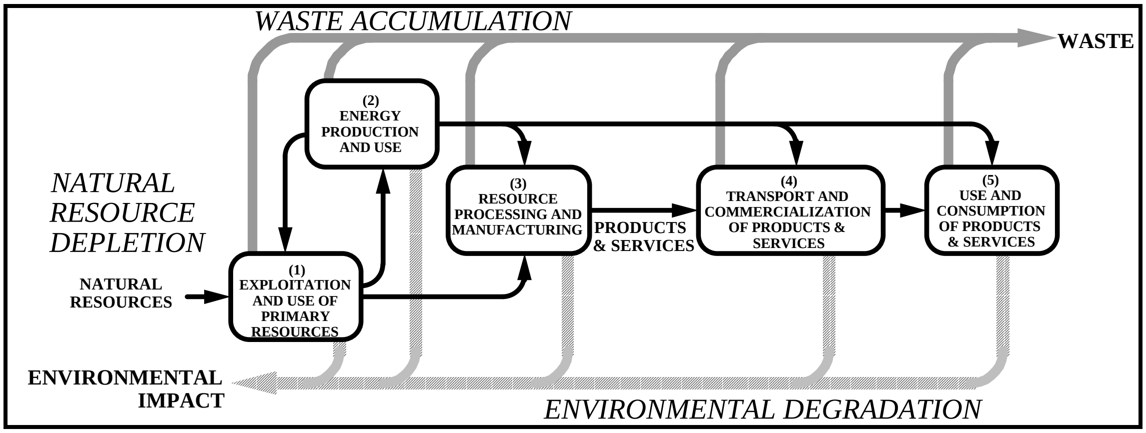

Figure 2: Unsustainable Linear Development
(adapted from Roberts 1994)

THE CURRENT PARADIGM: UNSUSTAINABLE LINEAR SYSTEM

In order to understand the changes that need to be made to develop sustainable technologies it is useful to look at the paradigm which is currently being employed. Despite a wide range of positions and opinions on the subject of sustainability, there is general agreement that the current paradigm of linear development, which disregards constraints to material or energy consumption, is unsustainable. In Figure 2, a model of the unsustainable linear development approach is shown which has prevailed over the last few centuries. In this model, several systems are linked in a linear process that begins with both renewable and non-renewable natural resources such as air, water, soil, mineral or biological resources. In this model, *exploitation and use of primary natural resources* occurs to provide inputs for industrial processes (Subsystem 1). The outputs of this system become the principal inputs for two other systems: the *production and use of energy* (Subsystem 2), whose output is a critical input to all the systems in the linear process; and *resource processing and manufacturing* (Subsystem 3), whose output is a set of industry-specific products or services that are *transported and commercialized* within Subsystem 4.

The linear process ends with the *use and consumption* (Subsystem 5) of the products or services generated by the industrial system across all segments of society. This process has two additional outputs from each of its systems, which are at the core of many problems facing the world today: increasing amounts of hazardous and non-hazardous waste, and increasing levels of environmental impact.

The process is linear because 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 linear process is fueled by continuous increases in the demand for, 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 unrelenting growth has created three serious problems: natural resource depletion, accumulation of waste, and environmental degradation. It is these challenges which must be addressed in achieving sustainability.

A FRAMEWORK FOR A SUSTAINABLE INDUSTRY

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 linear process described above in Figure 2, and offers a mechanism to gradually overcome the problems of unsustainability.

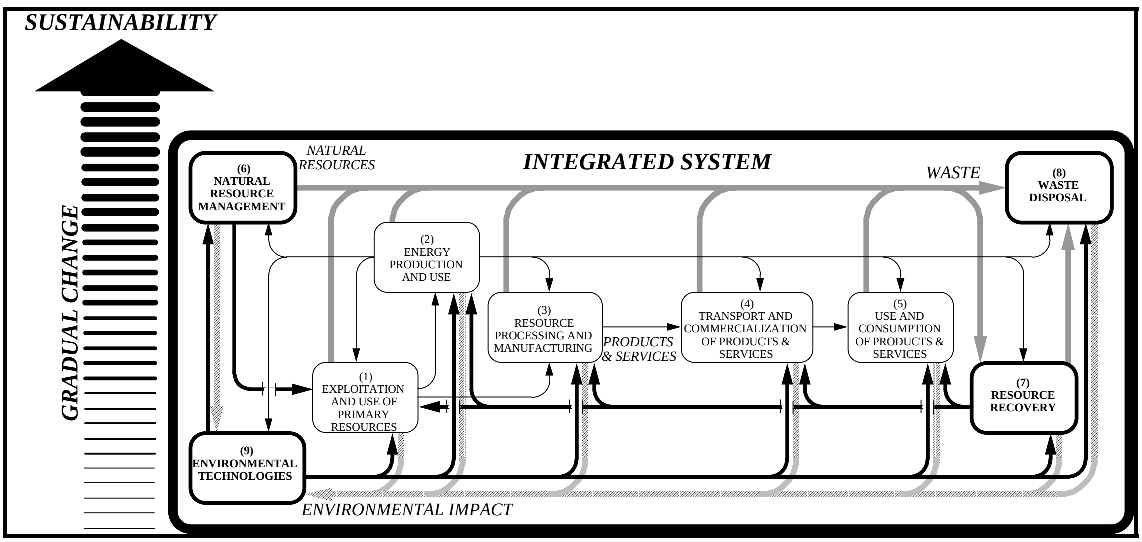

Figure 3: Cyclic Sustainable Development Process
(adapted from Roberts 1994)

The framework for a sustainable system presented in Figure 3 highlights one way of looking at this new approach. Developed from original ideas by D. V. Roberts, current President of the World Engineering Partnership for Sustainable Development (WEPSD), this framework is the basis of several initiatives of the Center for Sustainable Technology (CST) at the Georgia Institute of Technology in the areas of engineering education and construction engineering research. This system shows how to implement two of the three criteria for sustainable technology: frugal in use of nonrenewable energy and natural resources; and 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 remains important.

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

- *Natural resource management (Subsystem 6)* 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 non-renewable natural resources to prevent their total depletion.

- *Resource recovery (Subsystem 7)* 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 linear framework. They also would contribute to reducing the amount of waste that requires disposal.

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

- *Environmental technologies (Subsystem 9)* 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, which mimics natural systems. In this system the generation of waste is avoided; instead, all by-products 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.

SUSTAINABILITY AND THE BUILDING CONSTRUCTION INDUSTRY

While traditional design and construction focuses on cost, performance and quality objectives, sustainable design and construction adds to these criteria minimization of resource depletion and environmental degradation, and creating a healthy built environment (Kibert 1994). Figure 4 illustrates the primary paradigm shift to sustainability within the building design and construction industry. This model of the new sustainability paradigm shows issues which 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 which occurs naturally within the biosphere. In addition to the nonliving components which make up the built environment, sustainable designers and constructors must also consider the living components of the built environment (flora, fauna, and people) which 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 also the costs of the changes are lower, since the facility exists only "on paper" as opposed to being a physical artifact which 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 cost, resource, 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.

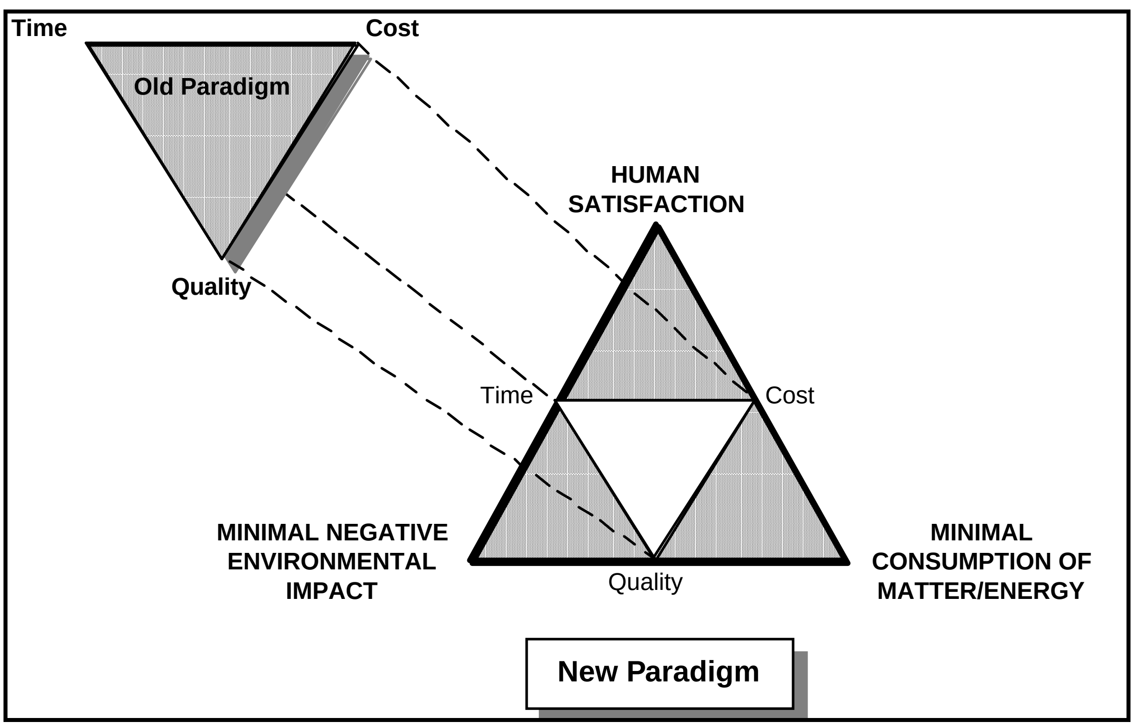

Figure 4: Paradigm Shift from Traditional to Sustainable Design and Construction

People who make project decisions with sustainability as an objective will need to evaluate the long-term as well as short-term impacts of those decisions 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-friendlier construction process, which will help future and current generations to achieve a better quality of life (Kinlaw 1992, Liddle 1994).

STRATEGIES, TECHNOLOGIES, AND OPPORTUNITIES FOR IMPLEMENTING SUSTAINABLE DESIGN AND CONSTRUCTION

In the creation of built facilities, there are many opportunities to improve how design and construction are currently done 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 above (social, environmental, and economics). These objectives are:

- Minimizing consumption of matter and energy over the whole life cycle of consumption, while
- Satisfying human needs and aspirations with sensitivity to cultural context, and
- 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.

Minimizing Consumption

Consumption of natural resources is at the heart of sustainability. With its large scale use of material and energy and 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 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 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 which 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 biggest impediments to this strategy are artifacts which are designed for obsolescence, with short life cycles, or where economic constraints have forced subquality 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 which do not rely on traditional types or amounts of materials and energy to meet human needs. Photovoltaic 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. Using waste masonry and concrete from demolished structures as aggregate in new concrete is one example of taking artificially-generated waste which would otherwise have been disposed in the natural environment, and using it as input back into the building process.

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. While 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 insidious problem of waste tire disposal, builders have developed a low-cost system which 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. While 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.

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, non-toxicity, shelter, aesthetics, and other functional requirements. Other human needs which 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 which 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 which assist in cost-benefit analysis, financial forecasting, and long term predictions. In addition, revised economic valuation schemes which 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 which 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 "establish[ing] 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 which must be met by the facility, designers and constructors must also strive to include factors which create a healthy environment both inside and outside the facility. Non-toxic materials are an essential component of a healthy built environment, as well as design features which convey aesthetic or spiritual values conducive to the tasks and activities which 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 (see Figure 3). Non-toxic 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, where people are taught techniques for constructing their own homes, invite a respect for the final outcome which might not exist for manufactured or contractor-built houses. This respect and understanding can only lead to more sustainable design and construction.

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 which built facilities have on the earth's ecological systems and resources:

- Spatial displacement of natural ecosystems, and modification of surrounding ecosystems as a result
- Impacts resulting by human use of the built environment, and the tendency for that use to spur further human development of the surrounding ecosystems
- Depletion of matter and energy resources from natural ecosystems during the construction and use of the facility
- 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 which can be taken to improve the sustainability of built facilities by avoiding negative environmental impacts over their life cycle.

Recovering Waste: Reduce, Reuse, Recycle. Various approaches exist to help recover waste from building construction and operation processes. Pollution prevention, for example, is a strategy which advocates anticipating and eliminating pollution before it is produced, and has been used very 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 complimentary processes. Construction and demolition (C&D) waste recycling is also becoming increasingly popular, as disposal options become more expensive. Promising applications include recycling C&D waste into new composite materials for construction, such as the concrete aggregate mentioned earlier.

Reusing Existing Development. Another way of minimizing impacts on the natural environment is by making better use of sites and facilities which have already been used. Rehabilitation of existing structures for similar or adaptive uses, as well as using retrofitted existing sites rather than greenfield sites for new development, are examples of strategies which 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 greenfield 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 encouraging further development.

Integrating the Built Environment into Ecological Systems. Sustainability must occur within the context of natural ecological systems, since it is these systems which 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. Greywater systems are an example of a technology which has been successfully used to facilitate the processing and absorption of human waste water back into the natural environment. Rather than collecting the wastewater and using artificial chemical treatment processes to eliminate contaminants, greywater systems take advantage of the naturally purifying processes of ecosystems in their operation. As an added bonus, the greywater 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.

CONCLUSIONS

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 of this paper is that the area of sustainable technologies is one of increasing interest which has many levels and complex dimensions. In this paper 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 different components of a sustainable system. We have stressed the importance of adopting a new paradigm which 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 which includes full consideration and knowledge of the many trade-offs and impacts associated with each alternative available to be chosen. Sustainability is a desirable state towards which to strive, but the journey is not easy.

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