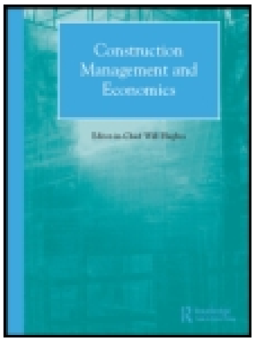

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Sustainable construction: principles and a framework for attainment

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The evolution of the concept of sustainable development is used as a basis for advancing understanding of sustainable construction. Principles of sustainable construction are developed and divided into four 'pillars' – social, economic, biophysical and technical – with a set of over-arching, process-oriented principles, to be used as a checklist in practice. A multi-stage framework is proposed which requires the application of Environmental Assessment and Environmental Management Systems for construction projects.

Keywords: Sustainable, development, environment, assessment, management

Introduction

Development efforts which seek to address social needs while taking care to minimize potential negative environmental impacts have been called sustainable development. Given the fact that the concept of sustainable development has been open to a wide range of interpretations, it would seem appropriate to summarize the evolution of the concept within the context of the environmental movement, and to propose a practical framework for the attainment of this concept in the construction industry. The purpose of this paper, then, is to: outline the evolution of the concept of sustainable development; advance understanding of the concept of sustainable construction; enunciate principles to be upheld in order to attain sustainable construction; and to propose a practical framework for the attainment of sustainable construction.

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Evolution of the concept of sustainable development within the environmental movement

The concept of sustainability was probably intuitively understood by early human civilizations such as the South African Bushmen. These hunter-gatherer people recognized the importance of utilizing the resources provided by nature on a sustainable basis and had practical experience of the fact that humans are dependent on the Earth's life support systems for survival (Van der Post and Taylor, 1984). The World Commission on Environment and Development (WCED) observed that, while modern cultures have only now begun to search for sustainable forms of development, traditional cultures have practised sustainable resource use for millennia (WCED, 1987).

Over the course of this century, the rapid advance of scientific and technological knowledge has provided humankind with the power to drastically alter planetary systems. This new-found power, together with increasing human numbers, has led to the excessive exploitation of renewable natural resources such as fish, wildlife and forests. There is growing scientific consensus that vast stocks of biological diversity are in danger of disappearing just as science is learning how to exploit this diversity through genetic engineering (WCED, 1987).

By the middle of this century, people were starting to question the capability of the earth to sustain the affluent lifestyle of the developed world. This questioning was based on the view that technology, far from providing answers to the issues facing society, was actually responsible for the escalation of environmental degradation. Writers such as Leopold (1949) and Carson (1962) called for people to embrace a lifestyle which showed more consideration for the environment and which sought to reduce the environmental impacts caused by material- and energy-intensive development. Such writers sowed the seeds of the environmental movement by advocating qualitative forms of development which gave precedence to spiritual and psychological needs over material wants, the so-called 'post-materialistic society' (Gardner, 1989).

In the developed world, public concern for the environment increased throughout the decade of the 1960s, and the first Earth Day was celebrated in April 1970 in Vermont, United States of America (Fuggle *et al.*, 1992). International concern was reflected in the United Nations Conference on the Human Environment which was held in Stockholm in 1972. The idea of ecodevelopment emerged from this conference as 'an approach to development aimed at harmonising social and economic objectives with ecologically sound management' (Gardner, 1989, citing Sachs, 1978). Ecodevelopment was the precursor of the concept of sustainable development.

In the same year as the Stockholm Conference, the Club of Rome published *The Limits to Growth*, a document which emphasized that concerns about pollution, environmental degradation and natural resource depletion were crucial to the long-term future of humanity (Meadows *et al.*, 1972). The limits-to-growth perspective challenged the pro-growth perspective of the previous decades, and, because this threatened important ideas and interests, reaction was intense. A synthesis of these conflicting perspectives eventually emerged in the perspective of sustainable development (Stockdale, 1989). This synthesis may be more usefully described as a continuum of perspectives in the middle ground between the extremes of the limits-to-growth perspective and the pro-growth perspective. Differing perspectives of sustainable development have been grasped by both environmentalists and the proponents of development to bolster their respective viewpoints. This clearly illustrates that the concept of sustainable development is value laden.

In the 1970s, the practice of nature conservation still largely embraced a preservationist philosophy, which held that nature could and should be conserved within the neatly demarcated boundaries of conservation areas. Development and conservation were seen as two ideals which were in direct conflict with one another. In 1980, the International Union for the Conservation of Nature and Natural Resources (IUCN) published the *World Conservation Strategy* (IUCN, 1980). The Strategy marked a significant shift in conservation, from focusing solely on the practice of fencing off nature reserves to viewing conservation and development as integrated concepts. The Strategy defined development as 'modification to the biosphere to satisfy human needs', and conservation as 'the management of human use of the biosphere to yield the greatest sustainable benefit to present and future generations' (IUCN, 1980).

On a practical level, the *World Conservation Society* translated a concern for the conservation of life support systems, ecological processes and genetic diversity into priorities for action. The priority requirements for the conservation of genetic diversity were founded on the notion of the *Genetic Management Iceberg* (IUCN, 1980), which has important implications for the concept of sustainable construction. The Strategy used the 'iceberg' to illustrate that efforts to conserve biodiversity in zoos, botanical gardens, seed and sperm banks, and even in National Parks and nature reserves, only reflect the tip of the 'iceberg', and that, if one wants to make a meaningful contribution to conserving genetic diversity and ecological processes, one should also focus efforts on the bulk of the 'iceberg', hidden from view, which represents areas outside of conservation management – the areas where most construction projects are implemented. In these areas, the Strategy urged that all development should aim to achieve 'sound planning, allocation and management of water and land uses' (IUCN, 1980). The message was that development and construction activities can make an important contribution to the conservation of biodiversity by applying environmental management in the execution of projects.

In 1987, the World Commission on Environment and Development (WCED) produced a publication entitled *Our Common Future* (WCED, 1987), which is referred to as the 'Brundtland Report'. The Commission stated that the essential needs of vast numbers of people were not being met, and warned that a world where poverty and inequity were endemic would be prone to ecological and other crises. The publication described the concept of sustainable development as meeting the basic needs of all people and extending to all the opportunity to satisfy their aspirations for a better life without compromising the ability of future generations to meet their own needs. In contrast to the limits-to-growth perspective, sustainable development placed more emphasis on the social and economic goals of society, particularly in the developing countries, but stressed that the attainment of these goals was interconnected with the achievement of environmental goals.

Although the concept of sustainable development was now firmly entrenched within the environmental movement, debate continued on appropriate definitions for, and uses of, the concept. One attempt to define the meaning of 'sustainability' was proposed by resource managers in the term 'sustainable utilization' of natural resources. However, in response to this notion, the question was raised as to how non-renewable resources, such as oil and minerals, could be exploited on a sustainable basis. The term 'sustainable utilization' was deemed, therefore, by some to be limited in applicability to renewable natural resources, for example, to water resources, plants and animals, and implied using them at rates within their capacity for renewal.

In the 1991 update to the World Conservation Strategy, entitled *Caring for the Earth* (IUCN, 1991), the World Conservation Union stated that the term 'sustainable development' had been criticized as ambiguous and open to a range of interpretations, many of which were contradictory. The authors suggested that this was because the term had been used interchangeably with 'sustainable growth'. They stated that sustainable growth is a contradiction in terms because nothing physical can grow indefinitely. *Caring for the Earth* defined 'sustainable development' as development which 'improves the quality of human life while living within the carrying capacity of supporting eco-systems'.

The operationalization of this concept remains contentious because of difficulties in determining the 'carrying capacity of supporting ecosystems' and difficulties in identifying the actions undermining ecosystems. Accusations between the nations of the North and the South over who is overextending the carrying capacity of local and global systems have become habitual, and formed the topic of heated debate at the 1992 United Nations Conference on Environment and Development in Rio de Janeiro.

A comprehensive and 'an almost practical step toward sustainability' was proposed by the economist Solow (1993). Solow argued that development will inevitably cause at least some drawdown of current stocks of non-renewable resources, and that sustainability should mean more than just the preservation of natural resources. To maintain the capacity to meet the needs of future generations, concern is required for society's total capital, taking into account the substitution possibilities between natural and other forms of capital. Solow proposed that fairness towards future generations requires that some of the proceeds from the exploitation and depletion of non-renewable resources should be invested in other assets, which could include social or human-made capital (e.g. education and factories), to maintain productive capacity to meet the needs of future generations (Solow, 1993).

The divergence of opinions relating to the term proves that 'sustainability' is so broad an idea that a single definition cannot adequately capture all the nuances of the concept. It is probably true that the dichotomy of the development/environment debate in the 1970s and the 1980s has been replaced by a sustainable development synthesis, in that there is general agreement that uncontrolled exploitation of natural resources is not beneficial to humankind in the long term.

Advancing understanding of 'sustainable construction'

Having discussed, albeit briefly, the evolution and uses of the term 'sustainable development', the purpose of this section of the paper is to discuss the concept of sustainability as it relates to the construction industry and to advance understanding of the term 'sustainable construction'. For the purposes of this paper, the construction industry is deemed to comprise the civil engineering and building construction industries.

The environmental impacts of the construction industry are extensive. The November 1994 issue of the journal *World Watch* noted that *Homo sapiens* has become a super species through the use of buildings, capable of adapting to life anywhere on the planet. This ability to shape one's surroundings has obvious financial and environmental costs. According to *World Watch*, one-tenth of the global economy is dedicated to constructing, operating and equipping homes and offices. This activity accounts for roughly 40% of the materials flow entering the world economy, with much of the rest destined for roads, bridges and vehicles to connect the buildings (Roodman and Lenssen, 1994).

The term 'sustainable construction' was originally proposed to describe the responsibility of the construction industry in attaining 'sustainability'. November 1994 saw the holding of the First International Conference on Sustainable Construction in Tampa, Florida, United States of America. A major objective of the conference was 'to assess progress in the new discipline that might be called "sustainable construction" or "green construction"' (Kibert, 1994a). The conference convener, Kibert (1994b), proposed that sustainable construction means 'creating a healthy built environment using resource-efficient, ecologically-based principles'.

It is inevitable that the term 'sustainable construction' will initiate a number of semantic problems. When one considers that the IUCN (1991) described a sustainable activity as one which can continue forever, it is clear that a construction project cannot fall within this category of sustainable activities. To compound the problem, the term 'sustainable construction' is generally used to describe a process which starts well before construction *per se* (in the planning and design stages) and continues after the construction team have left the site. Wyatt (1994) has deemed sustainable construction to include 'cradle to grave' appraisal, which includes managing the serviceability of a building during its lifetime and eventual deconstruction and recycling of resources to reduce the waste stream usually associated with demolition.

One response to the confusion inherent in the term 'sustainable construction' would be to revert to the use of the term 'sustainable development'. In applying this suggestion, one would seek to ensure, for example, that the construction of a building, house or road satisfies the principles of sustainable development. However, sustainable development is such a broad term that it may well be useful to distinguish between general and specific applications such as 'sustainable construction'.

Semantic considerations aside, the various definitions of sustainability hitherto proposed need to be examined in an attempt to find common ground between the ideals of 'sustainability' in general, and those of 'sustainable construction' in particular. Four attributes of sustainability – social, economic, biophysical and technical – have been singled out to advance understanding of the concept of sustainable construction. Because these attributes underpin and support the attainment of sustainability, they have been conceptualized in this paper as the four 'pillars' of sustainable construction. Thus, the formulation of solutions, to the range of issues inherent in these four attributes, might be viewed as the construction, 'stone' by 'stone', of the 'pillars' of sustainable construction.

The social 'pillar' of sustainable construction is based on the notion of equity or social justice. This notion, which formed a cornerstone of the Brundtland Report (WCED, 1987), requires what has been described as 'opportunity redistribution on a massive scale' (Gladwin *et al.*, 1995). This necessarily requires more than the IUCN's general call for improving the quality of human life (IUCN, 1991) – it calls specifically for addressing poverty and inequity. The issue of social justice has been given scant attention in most of the literature on sustainable construction, which seems to focus mainly on the biophysical environment and technical issues (see for example: Kibert, 1994c; Roodman and Lenssen, 1994, 1995; *Environmental Building News*, undated; Loftness *et al.*, 1994). According to Kirkby *et al.* (1995), social sustainability requires, *inter alia*, a return to the high ideals of Brundtland which they suggest were diluted at the Rio Conference when the 'north turned "green" and the south was turned away'. Although Brundtland called for reviving growth as a way to reduce poverty, Goodland (1995) has proposed that poverty reduction has to come from, *inter alia*, redistribution and sharing, with a focus on development (as realizing potentialities) rather than from Brundtland's emphasis on throughput growth. Goodland (1995) noted that 'our planet develops over time without growing', and suggests that our economy, as a subsystem of the earth, must eventually adapt to a similar pattern in seeking 'development' rather than 'growth' as an objective. The social justice perspective of sustainable construction is perhaps the most difficult component to address in individual projects. Although the achievement of global social sustainability is an awesome task, some practical and attainable suggestions for construction projects are presented in the following section of this paper, under the heading 'Social principles of sustainable construction'.

The concept of sustainability proposed by Solow (1993) is a key element in the economic 'pillar' of sustainable construction. While accepting that some depletion of non-renewable resources is inevitable when development is undertaken, Solow suggests that sustainability is concerned with the substitution of natural to human-made capital. As the construction industry is constantly involved in this substitution, it is feasible to describe the industry as involved in operations which are supportive of sustainable development, although there is much debate around the issue of the degree to which human-made capital can provide substitutes for natural capital (Goodland, 1995).

The biophysical 'pillar' of sustainable construction is founded on the second part of the definition of sustainability proposed by the IUCN (1991). The IUCN stated that sustainability requires the improvement of the quality of human life within the carrying capacity of supporting ecosystems. As construction is largely involved with improving the quality of human life, if construction could demonstrate a responsible approach towards operating within the carrying capacity of supporting ecosystems, the ideals of sustainability could feasibly be attained from a biophysical perspective.

Consideration of the technical 'pillar' of sustainable construction does not necessarily mean constructing buildings or structures that will last for a few thousand years, like some ancient Roman aqueducts or Greek temples. One can argue that such structures were economically inefficient in that resources used for their construction were tied up for generations after they ceased to be useful. In our rapidly changing age, some structures may only have a limited economic life, after which they become redundant (Wyatt, 1994, citing Switzer, 1967). The technical 'pillar' of sustainability has been used in this paper to group a number of concepts, including concepts that relate to the performance, quality and service life of a building or structure.

Having introduced the concept of sustainable construction and its relationship with sustainable development, the following section of the paper develops and discusses principles for the attainment of sustainable construction.

Principles of sustainable construction

This section of the paper outlines a number of principles whose application would make the construction industry more sustainable. The principles are divided into the four main 'pillars' of sustainability – social, economic, biophysical, and technical – with a set of over-arching, process-oriented principles. These process-oriented principles suggest approaches to be followed in deciding the emphasis to be given to each of the four 'pillars' of sustainability, and each associated principle, in a particular situation.

Before introducing the principles of sustainable construction, it is necessary to give an indication of how these might be used in practice. It should be noted that optimization of all the listed principles is not always possible, and that trade-offs and compromises may be necessary. Indeed, some of the principles cannot be considered immediate priorities, but this does not mean that they should be ignored. The choice of which principles to apply to a particular construction project, and the decision on the extent to which each chosen principle should be applied, reflect value judgements, i.e. whether to apply weak, strong, or very strong sustainability. It is best if these judgements are made by the interested and affected parties involved in a project. The emphasis, therefore, should be on implementing a process which seeks to achieve consensus among interested parties on which principles are more, and which are less, important.

Because the guidance offered on implementing the principles is limited to recommendations on matters of process, this paper may be criticized for not providing quantitative standards to determine whether an action meets the sustainability criterion for a certain principle, or not. Absolute standards are not provided for two reasons. The first reason is to avoid the proselytizing and prescriptive nature of much writing on sustainability. The second reason is the recognition that trade-offs are sometimes required between the different 'pillars' of sustainability. This recognition should not, however, hinder the search for creative solutions which satisfy as many of the seemingly conflicting principles as possible. The interested parties involved in a project should use the principles listed for each 'pillar' of sustainability as a checklist, and then themselves make the important decisions on which should not be applied, which should, and the extent of application.

The principles of sustainable construction are summarized in Figure 1 and discussed below. The question to be asked for each principle is: In what way can this principle be practically and most effectively applied in this situation?

Social principles of sustainable construction

This section outlines social principles of sustainability. Some of the principles listed below could be categorized as either 'social' or 'economic', or both: these principles have been allocated to the 'pillar' that reflects the most prominent attribute of the principle. The social 'pillar' of sustainable construction requires that practitioners seek to:

- Improve the quality of human life by ensuring secure and adequate consumption of basic needs, which are food, clothing, shelter, health, education, and beyond that by ensuring comfort, identity and choice (Yap, 1989). The first step towards achieving this goal is poverty alleviation.
- Make provision for social self determination and cultural diversity in development planning (Gardner, 1989), and ensure that the operation of development (after the construction process is complete) is compatible with local human institutions and technology (Yap, 1989).
- Protect and promote human health through a healthy and safe working environment. Plan and manage the construction process to reduce the risk of accidents, and carefully manage the use of substances which are hazardous to human health.
- Implement skills training and capacity enhancement of disadvantaged people to allow them to meaningfully participate in a project. Such training and participation should ensure that development of human resources is a lasting legacy of construction, in addition to the physical presence of facilities.
- Seek fair or equitable distribution of the social costs of construction and, where this is not achieved, determine fair compensation for people adversely affected by construction operations. This principle and the following two principles can be applied at local, regional, and international scale where, for example, large inequities exist between developed and less-developed countries in terms of access to resources.

PROCESS-ORIENTED PRINCIPLES OF SUSTAINABLE CONSTRUCTION

Over-arching principles indicating approaches to be followed in evaluating the applicability and importance of each 'pillar', and its associated principles, to a particular project.

- Undertake prior assessments of proposed activities
- Timeously involve people potentially affected by proposed activities in the decision-making process
- Promote interdisciplinary collaborations and multi-stakeholder partnerships
- Recognize the necessity of comparing alternative courses of action
- Utilize a life cycle framework
- Utilize a systems approach
- Exercise prudence
- Comply with relevant legislation and regulations
- Establish a voluntary commitment to continual improvement of performance
- Manage activities through the setting of targets, monitoring, evaluation, feedback and self-regulation of progress
- Identify synergies between the environment and development

PILLAR ONE: SOCIAL SUSTAINABILITY

- Improve the quality of human life, including poverty alleviation
- Make provision for social self determination and cultural diversity in development planning
- Protect and promote human health through a healthy and safe working environment
- Implement skills training and capacity enhancement of disadvantaged people
- Seek fair or equitable distribution of the social costs of construction
- Seek equitable distribution of the social benefits of construction
- Seek intergenerational equity

PILLAR TWO: ECONOMIC SUSTAINABILITY

- Ensure financial affordablity for intended beneficiaries
- Promote employment creation and, in some situations, labour intensive construction
- Use full-cost accounting and real-cost pricing to set prices and tariffs
- Enhance competitiveness in the market place by adopting policies and practices that advance sustainability
- Choose environmentally responsible suppliers and contractors
- Invest some of the proceeds from the use of non-renewable resources in social and human-made capital, to maintain the capacity to meet the needs of future generations

PILLAR THREE: BIOPHYSICAL SUSTAINABILITY

- Extract fossil fuels and minerals, and produce persistent substances foreign to nature, at rates which are not faster than their slow redeposit into the Earth's crust
- Reduce the use of the four generic resources used in construction, namely, energy, water, materials and land
- Maximize resource reuse, and/or recycling
- Use renewable resources in preference to non-renewable resources
- Minimize air, land and water pollution, at global and local levels
- Create a healthy, non-toxic environment
- Maintain and restore the Earth's vitality and ecological diversity
- Minimize damage to sensitive landscapes, including scenic, cultural, historical, and architectural

PILLAR FOUR: TECHNICAL SUSTAINABILITY

- Construct durable, reliable, and functional structures
- Pursue quality in creating the built environment
- Use serviceability to promote sustainable construction
- Humanize larger buildings
- Infill and revitalize existing urban infrastructure with a focus on rebuilding mixed-use pedestrian neighbourhoods

Figure 1 Principles of sustainable construction

- Seek equitable distribution of the social benefits of construction and, where this is not achieved in the intended use of a facility, seek to optimize benefits which arise during the construction process, such as employment opportunities.
- Seek intergenerational equity so that significant social, biophysical and financial costs of current construction are not passed on to future generations. This requires, *inter alia*, the avoidance of excessive resource consumption (from environmental sources) and not overtaxing the assimilative capacity of the environment to absorb wastes (the environmental 'sinks'). Injudicious use of these environmental 'goods and services' forecloses options for future generations. Sustainability requires a change in consumption patterns, and a concern for managing or constraining the flow of natural capital in the form of energy and materials (Goodland, 1995). This principle aptly demonstrates the linkages between social, economic and biophysical sustainability.

Economic principles of sustainable construction

This section lists principles of economic sustainability. The economic 'pillar' of sustainable construction requires that practitioners seek to:

- Ensure financial affordability for intended beneficiaries by reducing the overemphasis on technical sustainability. For example, appropriate sets of minimum housing and associated service standards need to be developed to promote the acquisition of affordable formal housing.
- Promote employment creation and, in some situation, labour intensive construction for disadvantaged communities as this should result in a significant portion of the financial contribution of a project remaining and circulating in local hands.
- Use full-cost accounting and real-cost pricing to set prices and tariffs, for goods and services, that fully reflect social and biophysical costs. This seeks to achieve more equitable development and more efficient use of resources. Liddle (1994) contends that, while legal control was the primary vehicle for managing the environment under the paradigm of environmentalism, the emphasis under the paradigm of sustainability is on economic approaches.
- Enhance competitiveness in the market place by adopting policies and practices that advance issues of sustainability.
- Choose environmentally responsible suppliers and contractors who can demonstrate environmental performance.
- Invest some of the proceeds from the use of non-renewable resources in social and human-made capital, to maintain the capacity to meet the needs of future generations.

Biophysical principles of sustainable construction

This section lists the principles that constitute the biophysical 'pillar' of sustainable construction. The term 'biophysical' is used to include the atmosphere, land, underground resources, the marine environment, flora, fauna and the built environment. The biophysical 'pillar' of sustainable construction requires that practitioners seek to:

- Extract fossil fuels and minerals, and produce persistent substances foreign to nature, at rates which are not faster than their slow redeposit into the Earth's crust (Robèrt, 1995). This principle contains two elements which are discussed together in the following text. Robèrt (1995) has proposed four system conditions which represent very strong sustainability. These were derived from a systems perspective of planet Earth in considering flows of matter and energy in terms of the laws of thermodynamics. Robèrt therefore considers that these conditions allow one to 'strive for an absolute as opposed to a relative frame of reference'. The first two of these system conditions require that substances from the Earth's crust (minerals and fossil fuels) and substances produced by society (persistent compounds foreign to nature) should not be produced at rates faster than their slow redeposit into the Earth's crust, i.e. such substances should not systematically increase in nature. Robèrt (1995) suggests that the implementation of these two conditions requires answers to the following question: 'In what ways can your organisation systematically decrease its economical dependence on these substances?' The third and fourth of Robèrt's conditions are to phase out diminishment of the productivity and biodiversity of nature and seek resource-savings methods to meet human needs, both of which are discussed in subsequent principles for biophysical sustainability.
- Reduce the use of the four generic resources used in construction, namely, energy, water, materials, and land, at each stage in the project life cycle (Kibert, 1994c). This principle addresses the underlying causes of much environmental degradation – overconsumption of resources (Kibert, 1994c).

  Optimization of this principle for energy requires reduction of both embodied and operating energy (Loftness *et al.*, 1994). Embodied energy of building materials and products is the total energy used in the processes of production, from extraction of raw materials to final delivery. Operating energy includes that used to cool/warm and light rooms and heat water.

The adoption of the conservation principle for water is of particular importance to South Africa, where it is a limiting resource for development. Examples include: roof-top rain-water harvesting for outdoor watering; water efficiency in buildings through the specification of conserving fixtures such as low-flow showerheads, tap aerators and water conserving toilets; and indigenous, drought resistant plants for landscaping. Such planting also optimizes for the principle on creating a healthy, non-toxic environment through reducing the need for potentially polluting pesticides, herbicides, and fertilizers.

- Maximize resource reuse, and/or recycling as this leads to a reduction in waste thereby prolonging the life of landfill facilities and reducing the need to select new landfill sites. It also reduces the need for raw materials thereby contributing to the attainment of the second principle of reducing resource consumption.

Examples of reuse include the renovation of existing buildings and refurbishment for a new purpose. This requires that buildings are designed and constructed with adaptability in mind (Roodman and Lenssen, 1994). Where demolition is absolutely necessary, this principle requires the implementation of salvage which necessitates the reinstitution of hand-wrecking and, importantly, planning for disassembly or deconstruction (Wyatt and Gilleard, 1994). The aim should be to reuse as much of the structure as possible on another project and to recycle what cannot be directly reused. Central to this is the need for planning for disassembly, entailing the requirement that fixing details allow for the non-destructive separation of different materials at the end of the life of a building (Wyatt and Gilleard, 1994).

Recycling is different from reuse in that existing items are not used intact but are reduced to raw materials and used in new products (Kibert, 1994c). On the construction site, recycling requires educating workers about recycling procedures and instituting on-site sorting of usable waste into bins clearly marked for different types of waste.

Extra attention should be given to the 3Rs (Reduce, Reuse, Recycle) when considering the use of non-renewable resources. While non-renewable resources cannot be used sustainably, their 'life' can be extended by reducing their use in product manufacture, reusing a product a number of times rather than discarding after using once, recycling of the resource at the end of the usable life of the product, and switching to renewable substitutes where possible (IUCN, 1991).

- Use renewable resources in preference to non-renewable resources. This principle can be applied to both building materials and energy. For energy, this indicates the use of passive thermal design, daylighting, solar heating of water, and the use of photovoltaics to generate energy. Passive thermal design, defined as '. . . building in harmony with the local climate, obtaining indoor thermal comfort with minimal recourse to artificial heating or cooling' (National Energy Council, undated), includes con-siderations of building orientation, the use of breezes for natural cooling, solar warming of buildings, and even the siting of buildings to benefit from existing and planned vegetation. For materials, using wood as an example, this implies the use of sustainably-managed forests and avoiding the use of so-called 'old growth' timber when other alternatives are available (*Environmental Building News*, 1994).
- Minimize air, land and water pollution. This principle can be applied to various environmental concerns, which may vary from global to local, at one or more stages in the life cycle of projects. As for global concerns, it can include the reduction or elimination of pollutants causing ozone depletion and global warming. At a local level, it requires the development of operational procedures for controlling various activities including emergencies, and the management of noise, odour, dust, vibration, chemical and particulate emissions, and solid and sanitary waste during construction operations.
- Create a healthy, non-toxic environment through the elimination or careful and managed use of hazardous and toxic products in the indoor and exterior built environment (Kibert, 1994c). This includes minimization of the use of solvent-based finishes, adhesives, carpeting, and particleboard which release formaldehyde and volatile organic compounds into the air (*Enviromental Building News*, undated). These chemicals can affect the health of workers and occupants and contribute to 'sick building syndrome' (Roodman and Lenssen, 1994). This principle can also be applied in day-to-day management of the use and disposal of hazardous wastes, such as metal polish, paint thinners, ammonia-based cleaners and chlorine bleach, which should not be discarded down the sink or drain. Outdoors this principle requires minimizing and managing the use of pesticides and other persistent toxic chemicals to prevent soil and water contamination.
- Maintain and restore the Earth's vitality and ecological diversity, through:
  i) conserving life support systems, which are the ecological processes which shape the climate,

cleanse air and water, regulate water flow, recycle essential nutrients, create and regenerate soil and enable ecosystems to renew themselves.

ii) conserving the biodiversity of plants, animals and other organisms, the range of genetic stock within each species, and the variety of ecosystems, with special attention to protecting rare and endangered species and ecosystems.

iii) minimizing damage to renewable resources such as soil, wild and domesticated organisms, forests, rangelands, cultivated land, and the marine and freshwater ecosystems that support fisheries (IUCN, 1991).

iv) restoring ecological processes that have been disrupted by past human activities. UNEP (1994) proposes that current activities should be judged in terms of whether they contribute towards improvements in indicators of environmental health, such as biodiversity, and not only on whether they have maintained the current, in many cases, inadequate situation.

The application of the first three of the above-mentioned components of this principle has hitherto formed the focus of most efforts to achieve sustainable construction in South Africa. This has been through the evaluation of alternative sites to avoid sensitive environments and the on-site protection of vegetation, topsoil and river water quality during construction. These efforts should be extended to consider the ecological impacts, often at remote locations, caused by extraction, processing and transport of materials to the construction site.

- Minimize damage to sensitive landscapes, including areas which are valuable from a scenic, cultural, historical, or architectural point of view, and minimize intrusion into wilderness areas.

Technical principles of sustainable construction

This section lists the principles that constitute the technical 'pillar' of sustainable construction. The term 'technical' has been chosen to describe those principles that relate to the performance and quality of a building or structure, but also includes a principle which requires humanizing larger buildings because, although this might be seen as a social concern, it requires the application of technology to achieve the desired outcome. This illustrates the somewhat artificial separation of principles into the four 'pillars', in that one principle could incorporate elements which relate to more than one 'pillar'. The technical 'pillar' of sustainable construction requires that practitioners seek to:

- Construct durable, reliable and functional structures. Considerations of technical sustainability start with the requirement that structures are able to withstand the destructive forces of nature. Beyond this, Keoleian and Menerey (1994) note that product life extension is at the top of a hierarchy of life cycle design strategies. A durable building that lasts, due to competent design, manufacturing and construction procedures (Halliday, 1994a), and one that reliably and continuously fulfils its intended purpose, usually saves energy (because manufacturing and construction are energy intensive) and also contributes less to solid waste problems. For consumer products, Keoleian and Menerey (1994) have proposed that durability should not be enhanced beyond the expected useful life of a product as this can be wasteful. The applicability of such limitations on the life of a building (although discussed in the principle on reuse and recycling) may be questionable, however, given the focus of the next principle on pursuing quality. Brand (1994) has suggested that the real test of a building is how it serves its users as they constantly adapt and alter it. He also states that the most significant failing of contemporary architecture is its focus on style at the expense of good function.
- Pursue quality in creating the built environment. This traditional criterion (taken from Kibert, 1994c) is important for sustainability because cherished spaces are cared for and maintained while dehumanizing structures are prone to vandalism. Loftness *et al.* (1994) suggest that the pursuit of sustainability requires a shift away from 'maximum quick-profit financing' and 'tight-fit designs' to buildings that 'are designed for life cycle value', and which embody 'generous design', 'modifiability through modularity' (see principle on reuse) and 'cherishable delight and craftsmanship' (Loftness *et al.*, 1994). The creation of buildings that imbue users with a sense of well-being does tend to ensure that such buildings are modified to meet changing needs without resorting to demolition. Such treasured buildings can have life spans measured in centuries rather than decades, and will be defended vigorously against demolition.
- Use serviceability to promote sustainable construction. According to Wyatt (1994), serviceability provides an approach to life assessment quality from the pre-briefing stage of a project to its final deconstruction. In essence, serviceability accepts and recognizes that each constituent part of any building and its systems possesses its own unique decay curve, and hence service life, that, in some cases, can be extended through replacement, renovation and other such measures. In this regard, there is a

need to understand serviceability loss, whether attributable to deterioration, failure or outright obsolescence.

Wyatt (1994), citing Masters (1984), has gone some way to developing the serviceability discipline. In time, an approach to designing for sustainability, using target and design service life profiling, within defined reliability parameters, will be possible. The concept of serviceability necessitates determining each building's unique quality decline tree and at what point to extract part of an element, building system or component from service to replace it. Consideration should also be given to an upgrading strategy to be effected in the future.

- Humanize larger buildings so that individual users can control indoor environmental conditions (which requires a move away from centralized, uniform control). Loftness *et al.* (1994) suggest that this challenge should be tackled through a combination of: the use of 'thin' buildings (which optimize inside-outside contact, i.e. contact with nature, by avoiding large central areas which do not have contact with the building perimeter); and the use of low-resource solutions of the past (windows that open) together with advanced 'distributed, user-controlled, environmental conditioning and networking systems' (Loftness *et al.*, 1994).
- Infill and revitalize existing urban infrastructure with a focus on rebuilding mixed-use pedestrian neighbourhoods which integrate housing, retail space, and work places (Loftness *et al.*, 1994; Calthorpe, 1996; and Downs, 1996). Halliday (1994a) has expressed this principle as a requirement to enhance living, working, and leisure environments. While infrastructure and buildings themselves obviously play an important role in considerations of sustainability, the interrelationships between buildings and the quality of the intervening spaces also deserve attention. Loftness *et al.* (1994) bemoan the over-emphasis on the development of single-use suburban development and rural office, school, and shopping 'parks'. Such low-density urban sprawl consumes valuable open space, in the form of both agricultural land and natural habitat, and produces excessive dependency on the private car for transportation. The environmental impacts inherent in increasing populations of cars and the increasing annual distance travelled by each vehicle are multifarious. According to Goodland *et al.* (1993), the impact of the worldwide annual production of 48 million cars 'vastly exceeds' the impact of the human population growth of 90 million. Impacts of car use include energy inefficiency, in terms of energy consumption per passenger per kilometre, air pollution and congestion. Various authors (e.g. Lofthouse *et al.*, 1994; Calthorpe, 1996; and Downs, 1996) have motivated the need for a new vision and a new development model. Calthorpe (1996) envisions 'new communities as more finely integrated, walkable neighbourhoods with a strong local identity and convivial public spaces'.

Process-oriented principles of sustainable construction

As previously mentioned, the principles outlined above are divided into four main 'pillars' of sustainability – social, economic, biophysical and technical. The principles outlined in this section of the paper may be conceptualized as a set of over-arching, process-oriented principles. These process-oriented principles suggest approaches to be followed in considering the applicability of, and importance allocated to, each of the four 'pillars' of sustainability, and to each of the principles embodied in these 'pillars'. The process-oriented principles require that sustainable construction is characterized by approaches that:

- Undertake prior assessments of proposed activities, to integrate information concerning social, economic, biophysical and technical factors in decision-making.
- Timeously involve people potentially affected by proposed activities and present equal access to such people in the decision-making process (World Commission on Environment and Development, 1987).
- Promote interdisciplinary collaborations and multi-stakeholder partnerships between government, industry, consultants, contractors, non-government organizations and the general public (Gardner, 1989), in a process that is participatory, interactive and consensual. This principle also suggests the need for international cooperation to accelerate the attainment of sustainability.
- Recognize the complexity and multiplicity of objectives inherent in the concept of sustainability, and the necessity of comparing alternative courses of action, in terms of the extent to which each alternative satisfies a range of objectives and stakeholders (Pètry, 1990), at each stage in the project life cycle.
- Utilize a life cycle framework, which recognizes the need to consider all of the principles of sustainable construction at each and every stage in planning, assessment, design, construction, operation and decommissioning of projects.
- Utilize a systems approach, which recognizes the interconnections between economics and the environment.
- Exercise prudence or caution in the face of uncertainty, unpredictability and risk (Goodland, 1995).

- Comply with relevant legislation and regulations. This is a minimum requirement, and compliance could extend to professional and industry codes of practice; agreements with public authorities; and non-regulatory guidelines (ISO, 1995).
- Establish a voluntary commitment to continual improvement of performance, in striving to attain sustainable construction, which goes beyond compliance with legal requirements. The rate and extent of such improvement would be decided for each project and would be influenced by economic and other circumstances (ISO, 1995).
- Manage activities through the setting of targets, monitoring, evaluation, feedback and self-regulation of progress (Gardner, 1989), in a process that is iterative and adaptive in nature. This process can be applied both within a specific contract and in ensuring that knowledge from one contract is integrated into future contracts, essentially what Boye-Moller and Larsen (1994) call a 'continuous learning process'.
- Identify synergies between the environment and development rather than trade-offs (Liddle, 1994). An example of this is the concept of 'eco-efficiency' (Gladwin *et al.*, 1995), in which reducing the use of resources and pollution prevention at source rather than clean-up can lead to increased economic efficiency. Liddle (1994) contends that the search for synergies is what distinguishes the paradigm of sustainability from that of environmentalism which is locked into the view that development and environmental quality are inherently contradictory outcomes, i.e. more of one must necessarily mean less of the other.

While the lists of principles for sustainable construction outlined in this paper are not exhaustive, they do indicate the wide range of principles that should be considered in determining a more sustainable course of action for individual construction projects.

A framework for the attainment of sustainable construction

Where previous sections of this paper have developed the concept and principles of sustainable construction (the 'what'), this section presents a framework for the attainment of sustainable construction (the 'how to'). The process-oriented principles listed in the previous section can be satisfied in the implementation of a proposed multi-stage framework (Hill *et al.*, 1994) which requires:

- application of Environmental Assessment (EA) during the planning and design stages of projects, provided that the traditional EA is expanded to include assessment of all four 'pillars' of sustainable construction and is undertaken in accordance with the process-oriented principles of sustainable construction, and,
- implementation of Environmental Management Systems (EMS), as described in the specification prepared by the International Organization for Standardization (ISO, 1995), within construction organizations, and for each project, during construction, operation and, where appropriate, even decommissioning.

The framework and its components are summarized in Figure 2 and discussed below.

In this paper, a broad meaning is given to the term 'environment', to include the physical, biological, social, and economic circumstances that affect the existence and development of an individual or group (Department of Environment Affairs, 1992). Given this definition, an 'Environmental Assessment' could include assessment of all four 'pillars' of sustainable construction, although a Sustainability Assessment might be a more appropriate term. However, for ease of recognition this paper will continue to use the existing term of EA.

The remainder of this section of the paper outlines the role of both EA and EMS in achieving sustainable construction, with emphasis (and more detail) on the role of EMS during construction. This emphasis has been chosen because the role and objectives of EA are well documented (e.g. Brown and Hill, 1995) whereas the use of EMS in the construction industry has not been adequately discussed in the literature.

Environmental assessment in the planning and design stages

In the planning and design stages of projects, sustainable construction can be achieved by applying the principles, procedures and methods of Environmental Assessment (or Environmental Impact Assessment). The South African procedure for environmental assessment and management has been called Integrated Environmental Management (IEM). The IEM procedure was 'designed to ensure that the environmental consequences of development proposals are understood and adequately considered in the planning process. . . . The purpose of IEM is to resolve or mitigate any negative impacts and to enhance the positive aspects of development proposals' (Department of Environment Affairs, 1992).

The IEM procedure makes provision for an Environmental Assessment to: identify potential impacts, resulting from actions at each stage of the project life cycle; formulate and evaluate alternatives,

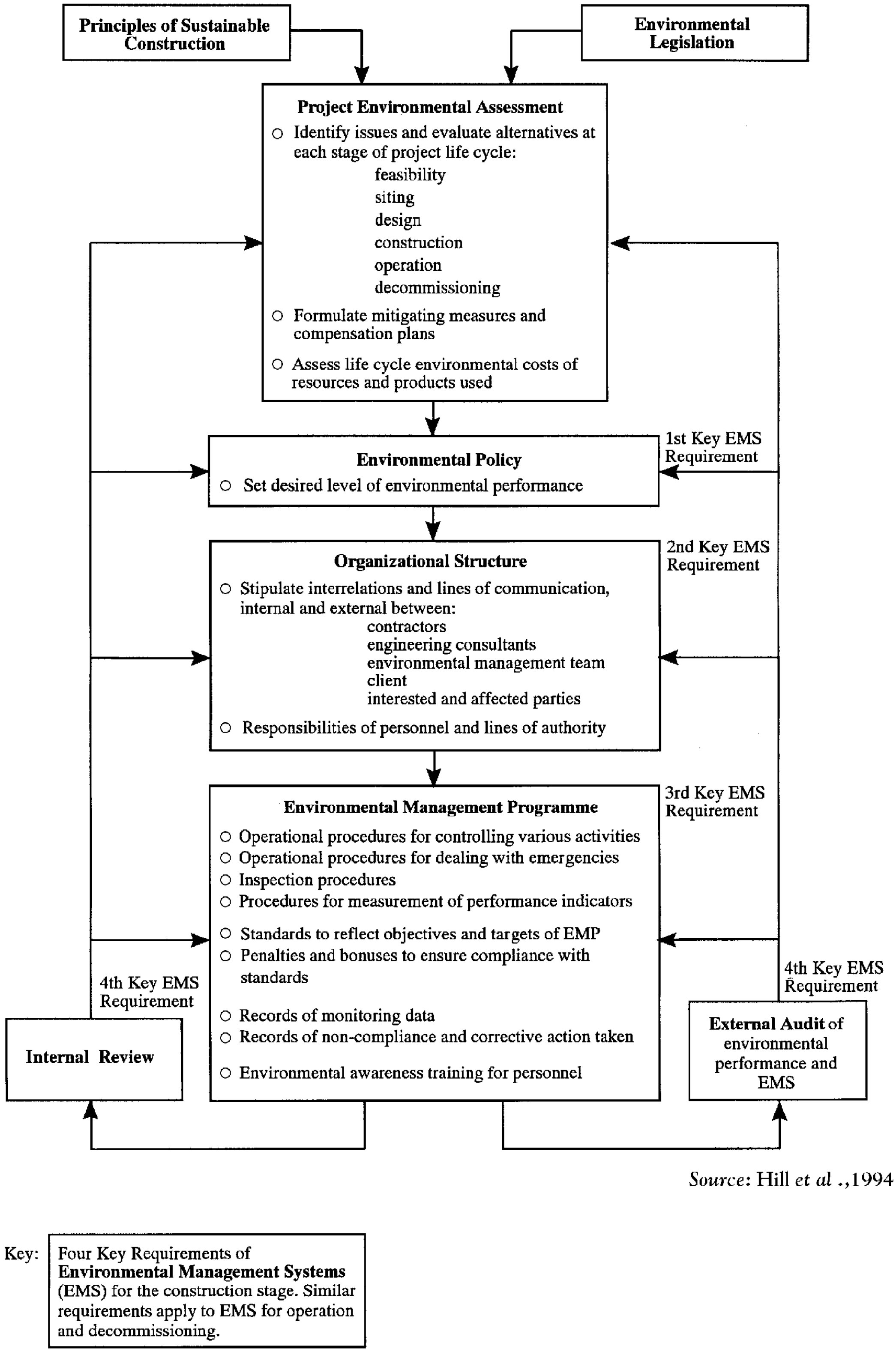

Figure 2 A framework for sustainable construction

in order to identify the preferred option at each stage (Brown and Hill, 1995); and, formulate mitigating measures to reduce impacts and develop compensation plans and monitoring programmes for residual impacts which cannot be mitigated to insignificance (see 'Project Environmental Assessment' in Figure 2).

A comprehensive traditional EA would evaluate alternatives for the sourcing of certain materials, such as the siting of quarries for stone aggregate, but would be unlikely to consider the life cycle environmental costs of most materials and products used in the construction process. The traditional EA should be expanded to consider life cycle assessment of alternative materials and products which could be used in the construction process. In addition, the EA should ensure that efficiency is a key criterion in the use of water, energy and land. The results of such a life cycle assessment should influence the purchasing specifications for materials and products to be used. These examples illustrate how application of the principles of sustainable construction would expand the practice of EA towards the goal of attaining sustainability.

The approach and methods of EA should also be applied, not only when evaluating siting, design, and material and product alternatives, but also during the stage when the planning and formulation of construction activities is undertaken. For instance, the choice of site for a concrete batching plant should be subject to the same rigour in assessing alternative sitings as is the case for the structure to be constructed.

After the EAs at each stage of planning and design are complete, the IEM procedure stresses the importance of formulating environmental management plans and the drawing up of an environmental contract to ensure implementation of the management plan, during project construction, operation and, where appropriate, even decommissioning. The IEM procedure provides few details as to how this should be done, and this is where specifications for Environmental Management Systems are more helpful.

Environmental management systems in sustainable construction

In discussing the use of Environmental Management Systems (EMS) as part of a framework for the attainment of sustainable construction, this paper draws on the *Code of Practice for Environmental Management Systems* published by the South African Bureau of Standards (SABS, 1993). In the preface to this Code of Practice, the SABS acknowledges the valuable assistance derived from the *Specification for Environmental Management Systems*, published by the British Standards Institution (BSI, 1992). These national specifications are to be superseded by the new international specification for EMS which has recently been developed by the International Organization for Standardization (ISO, 1995). The international specification has structured its model for EMS under five headings which represent consecutive stages in the planning, implementation and review of an EMS. The key requirements of an EMS for construction projects used in this paper are all contained in the ISO specification.

In South Africa, most formal EMS instituted to date have been implemented by large industrial or business organizations. The environmental management that has been implemented in a few major South African construction projects did not, in most cases, initially use an EMS specification for guidance. Such specifications nevertheless provide comprehensive checklists that should improve the practice of environmental management of construction. The implementation of EMS is essentially a voluntary and proactive approach which should afford construction companies a far better chance of addressing the issues of sustainable construction and testing solutions before legislative involvement by government.

Implementation of Environmental Management Systems (EMS) as part of a framework for attaining sustainable construction starts with the adoption of an EMS within a construction organization. This organization-wide EMS would make provision for the application of project specific EMS for each new construction activity. After construction, when a facility is handed over to the client, a new organization usually takes over management of the facility and yet another EMS could be developed to deal with the operation of the facility. A final EMS could be developed, where appropriate, for facility decommissioning. The use of EMS for the operation and decommissioning of facilities constitutes an essential part of the framework, given the definition of sustainable construction to include facility maintenance and deconstruction. However, because the application of EMS to the operation of existing facilities forms the focus of most of the literature on the subject of EMS, the use of EMS in operation and decommissioning is not addressed further in this paper, and the chosen focus is on the environmental management of the construction process.

In this paper, the components of an EMS are grouped under four key requirements for the sake of improving clarity (see Figure 2). In order to ensure implementation of environmental management during a construction project, these components should be documented as requirements in the contract specifications and bills of quantities. The purpose of this section of the paper is to outline these key requirements of Environmental Management Systems.

The first key requirement in developing an EMS is to determine an environmental policy to judge all the activities which are to be managed. Such a policy would set the desired level of environmental performance (see 'Environmental Policy' in Figure 2). Construction organizations could adopt a general environmental policy which could inform policies for specific projects. For instance, Shimizu Corporation, a Japanese construction company, adopted a Global Environmental Charter in 1991 (Miyatake, 1994). This Charter commits the company to six key policies which include 'evaluating environmental impact at each stage of construction', and 'harmonisation with the community'. At the level of individual construction projects, environmental polity would emanate from: company policy, if available; relevant legal requirements, and the EA for the project, which would identify those principles of sustainable construction deemed relevant to the project through consultation with interested parties at an early stage in the EA.

The second key requirement is to provide an organizational structure and to determine the responsibilities, authority, lines of communication and the resources needed to implement the EMS (see 'Organizational Structure' in Figure 2). At company level, this could necessitate, *inter alia*, a number of committees, each constituted to address a particular environmental issue. For example, in 1994, the Global Environment Committee of Shimizu Corporation had a subcommittee which had been tasked with reducing the usage of tropical wood composite boards for concrete formwork. Another committee was tasked with research and development of waste disposal technology (Miyatake, 1994). At the level of a particular construction project, a range of different organizations interact in the undertaking, and an EMS would need to define the required interactions between the various contractors, consultants and clients involved in the project. Similarly, lines of communication should link the organizations involved, and should also provide a connection with a range of interested and affected parties external to the construction process. With the exception of the management representative charged with implementing an EMS and those carrying out specialized environmental management functions, many of the personnel within the implementing organizations would need exposure to environmental awareness training.

The third key requirement is to develop an environmental management programme (EMP) that stipulates environmental objectives and targets to be met and work instructions and controls to be applied in order to achieve compliance with the environmental policy (see 'Environmental Management Programme' in Figure 2). For example, the Shimizu Corporation has set targets for three different types of construction waste. The reduction target for mixed wastes is 70% of the 1990 volume in the year 2000, and other targets are provided for concrete debris and construction sludge (Miyatake, 1994). At project level, the EMP would contain operational procedures for controlling various activities, which would include: work instructions for defining the manner of conducting an activity; inspection procedures to ensure that mitigating measures are applied; procedures for dealing with accidents and emergencies; and, procedures for the measurement of performance indicators, for example, accidental and controlled release indicators, and site impact indicators. Documentation plays an important role in the implementation of an EMP: in addition to an environmental management manual describing procedures, records should be kept of the monitoring data collected to test the effectiveness of mitigation measures and impact controls. Data collected to monitor performance indicators would be compared with standards chosen to reflect the objectives and targets of the EMP. These standards should be quantified as far as possible to facilitate verification of objectives. In construction, where the primary goals of the contractor and the environmental management team may be different, the EMP may need to rely on penalties and bonuses to ensure compliance with standards. Records should also contain details of incidents of non-compliance with stipulated policy and standards, and should describe corrective action taken. Records should also be kept of environmental training activities.

The fourth key requirement is to undertake periodic audits of the environmental performance of the construction team and the effectiveness of the Environmental Management System. An audit report provides an essential information feedback loop to management who can take corrective action to address the identified weaknesses of the EMS. For some years there has been debate as to whether environmental auditing should be a voluntary internal management tool or a compulsory external reporting mechanism (Soutter and Möhr, 1993). Auditing of an EMS for a construction project could be done internally by the environmental managers or externally by a consultant. Typically, an external audit would be preferred for a large construction project of extended duration with potential to cause significant environmental impacts. Ongoing internal review of the environmental performance of the construction team and the functioning of the EMS would complement the periodic audits (see 'Internal Review' and 'External Audit' in Figure 2). The results of company-wide and project specific environmental audits could be incorporated in the annual company report, which could eventually evolve into what UNEP (1994) has called annual 'sustainable development reporting'.

Complementary measures for the attainment of sustainable construction

In order for this framework to be successfully implemented, the professionals involved will need continuing education so that they can master the evolving concept, principles and applications of sustainable construction. Many of these professionals will also need to enhance their capacity to work in inter-disciplinary teams. Much information on the application of sustainable construction can be gleaned from sources such as the UK Building Services Research and Information Associations' *Environmental Code of Practice for Buildings and their Services* (Halliday, 1994b), and the American Institute of Architect's (1992) *Environmental Resource Guide*. In addition, the requirements of environmental labelling systems and voluntary rating systems for buildings can be applied in the design and construction of facilities (Roodman and Lenssen, 1995), and, in so doing, should improve the professionals' understanding of the issues involved. Roodman and Lenssen (1995) also note that 'sustainable building' design contests have been valuable in educating both professionals and the public about the issues of sustainable construction because of the high profile attached to such competitions. Another educational opportunity, which is only starting to receive appropriate recognition, is the educational role of Environmental Assessment (Brown and Hill, 1995). In assessing the sustainability of projects, the EA process fulfils a critical role in the education of developers, planners, architects, engineers, decision-makers and the public.

A further *caveat* to the successful implementation of the proposed framework relates to the financial and fiscal measures which are needed to sustain its technical implementation. Roodman and Lenssen (1995) report many examples of financial institutions giving preferential lending rates for the construction of sustainable buildings, and water and electricity supply utilities offering fee rebates on payment for services used in water and energy efficient buildings. As for fiscal policies, governments could tax pollution and the use of raw materials in production, and use part of the revenue to support research and development of sustainable technologies (Roodman and Lenssen, 1995). Such measures would complement the implementation of the framework in the quest for the attainment of sustainable construction.

Conclusions and recommendations

Consensus has not been reached on definitions for the terms 'sustainability' and 'sustainable development'. It is probably true, however, that the dichotomy of the development/environment debate in the 1970s and the 1980s has been replaced by a sustainable development synthesis, although this synthesis may be better described as a continuum of perspectives representing differing degrees of sustainability.

The term 'sustainable construction' is generally used to describe a process which starts well before construction *per se* (in the planning and design stages) and continues after the construction team have left the site. Sustainable construction includes managing the serviceability of a building during its lifetime and eventual deconstruction and recycling of resources to reduce the waste stream usually associated with demolition.

The principles of sustainable construction outlined in the paper are divided into four 'pillars' of sustainability – social, economic, biophysical and technical – with a set of over-arching, process-oriented principles. It is recommended that the interested and affected parties involved in a particular construction project use the list of principles for each 'pillar' as a checklist, and then seek consensus and compromises in reaching decisions on: the emphasis to be given to each of the four 'pillars' of sustainability; which principles to apply; and the extent to which each chosen principle should be applied. These decisions reflect value judgements which are best made by the interested and affected parties in the context of the project under consideration. It is suggested that these decisions are most likely to satisfy the different sustainability objectives of a range of interested parties, if the decisions are the outcome of a process which is managed in accordance with the process-oriented principles of sustainable construction.

A multi-stage framework for sustainable construction is proposed which requires application of Environmental Assessment (EA) during the planning and design stages of projects, and implementation of Environ-mental Management Systems (EMS) within construction organizations, and for each project, during construction, operation and, where appropriate, even decommissioning. In order to ensure implementation of environmental management during the construction stage of a project, it is recommended that these components are documented as requirements in the contract specifications and bills of quantities.

The application of the principles listed in this paper and the implementation of the framework, together with the complementary implementation of continuing education for construction professionals, should facilitate the attainment of sustainable construction.

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