RESOURCE CONSCIOUS BUILDING DESIGN METHODS

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Summary

Resource-efficiency is one of the primary requirements for sustainability in general and for the built environment in particular. Buildings consume on the order of 40% of all extracted materials in industrial countries and between 30 and 40% of primary energy for their operation. For example, on the order of 3.5 billion metric tones (BMT) enter the built environment annually in the U.S. In comparison, just 135 million metric tones (MMT) result from demolition operations, meaning that materials are accumulating in buildings and infrastructure at a very rapid rate. It has been estimated that, in the U.S., 90% of the materials ever extracted reside in today's built environment. At some point in time the inflow and outflow of materials will reach a steady state and the tremendous mass of materials will either be largely a resource or an immense waste stream. Water is probably the limiting resource for development and hence for construction and learning

how to use it efficiently through the use of rainwater harvesting and water recycling systems will be a key element of sustainable building. Appropriate landscaping is also important because maintaining it can consume about 50% of residential water use. Landscaping itself is emerging as a key ingredient for resource-efficiency because trees and other plants can shade buildings, uptake stormwater, and even process the waste of the inhabitants. Land is also an important resource, both for buildings and preserving biological capacity and biodiversity. Recycling used urban land, for example brownfields, must be an aspect of sustainability for the built environment. Resource-efficient design should have its roots in ecology and use the lessons learned from the relatively new discipline of industrial ecology for its basis. For resource-efficient behavior to take hold, however, the intervention of government in the form of policy instruments will be necessary. The signals sent to the marketplace and the best way forward for society both need to be provided by a well-informed, and in this era, courageous group of policymakers who can help shift the playing field to the benefit of the population as a whole. In this article, the subject of resource-conscious design is discussed for the entire life-cycle of the built environment to include materials extraction; product manufacture; building design and construction; and eventual disposal.

1. Introduction

The rapidly growing worldwide sustainable construction movement is affecting the design and construction of buildings in many countries worldwide. Sustainable construction is simply the design and operation of a healthy built environment using ecologically based principles. It is alternatively referred to as green building, ecological design, and ecologically sustainable design. These alternative references to sustainable construction all differ slightly in their meaning. The inclusion of ‘ecological’ or ‘ecologically’ in the title is generally an indication that the proponents are attempting to use ecology as the basis for their decision making, as both model and metaphor to guide built environment design. Sustainable construction has two key components: environmental protection and resource-efficiency. Contemporary sustainable construction considers five categories of resources: land, materials, landscape (biota), energy, and water. These are the ‘stuff’ of the built environment and the essential components that are used to create and operate the built environment. Using these resources ‘efficiently’ means that the need to extract the materials resources from the biosphere is minimized, that energy as much as possible is derived from renewable sources, and that land is used to preserve biodiversity, biological function, and natural system services. Resource-efficient design is the process by which planners, architects, engineers, and other actors describe the location and content (design) of buildings to use resources efficiently.

Sustainable construction is defined as “...the creation and operation of a healthy built environment based on resource-efficiency and ecological principles”. In fact resource-efficiency and ecological principles are in fact coupled and must be considered together. Sustainable construction is in effect the efforts by which construction industry support sustainable development. Clearly, and as is explicitly spelled out in its definition, sustainable construction is of primary importance for achieving sustainability in this industrial sector. In most industrial countries, buildings consume on the order of 40% of the nation’s primary energy for their operation. In the U.S. buildings consume 30% of primary energy supplies because transportation takes a larger portion of energy than in other nations. With respect to materials, the built environment absorbs about 40% of all extracted materials in industrial countries and probably higher percentages in developing countries. It has been estimated that the built environment contains as much as 90% of all materials ever extracted in the U.S. The built environment can be a major source of resources for future generations or a major disposal headache. In addition to materials and energy, the built environment is a major consumer of land resources and its creation generally results in the destruction of significant biological resources. Consequently buildings have profound impacts on efforts to use resources more wisely.

2. Resource-Efficiency and Sustainable Construction

The first description of sustainable construction emerged from the activities of CIB Task Group 8 (Building Assessment) and Task Group 16 (Sustainable Construction), both organized in 1993. These Task Groups created international forums to enable collaboration among construction researchers and professionals to sort out the issues and priorities of an emerging class of high performance buildings that were beginning to emerge in the late 1980’s and 1990’s. The American Institute of Architects (AIA) established its Committee on the Environment (COTE) in 1989. In the U.K., the Building Research Establishment (BRE) developed the first truly successful building assessment system in 1992. Known as BREEAM (Building Research Establishment Environmental Assessment Method), this system initially focused on new and existing office buildings and represented the first attempt to differentiate the performance of green buildings from their conventional counterparts. 1993 also marked the organization of the U.S. Green Building Council (USGBC) with the first conference on green buildings in the U.S. being organized in March 1994. Additionally the USGBC initiated the process of developing a building assessment method for the U.S. Known as LEED (Leadership in Energy and Environmental Design), the final operational version was made available for use in early 2000 and has since been adopted by wide variety of public and private organizations for guiding the design of their facilities. Task Group 8 held the Buildings and Environment Conference in May 1994 in the U.K. and Task Group 16 organized the First International Conference on Sustainable Construction in Florida in November 1994. These initial meetings were followed by numerous conferences on a wide variety of green building issues. Task Group 8 became Working Commission 100 (Building Assessment) and has since held Green Building Challenge conferences in Vancouver (1998), Maastricht (2000), and will hold one in Oslo (2002).

2.1 Resource-Efficiency as a Key Concept of Sustainable Construction

The efficient and effective use of resources is an essential element of sustainability for the built environment. Buildings are storehouses of materials and have embedded in them a potential for consuming energy, water, and materials over their unusually long lifetimes. When considering building products and systems, the entire life cycle of the materials utilized in the building, from extraction to disposal, needs to be considered. Buildings differ from other human artifacts because they incorporate a significant number of high mass, low performance materials, the latter in the sense that comparatively massive materials are used to accomplish the intended function. For example, the built environment makes extensive use of fill dirt, aggregates, cement, concrete blocks, clay block, bricks and other similar low technology materials. The recycling potential for these types of materials is relatively low compared to metals and plastics. Consequently resource-efficiency, in the sense of being able to close materials loops, is difficult to achieve due to the use of significant quantities of these high mass, cheap, and difficult to reuse or recycle materials.

Figure 1. illustrates how resource efficiency is a key issue for sustainability in the built environment and how resources can be evaluated using the seven principles shown on the 'Principles' axis. The fundamental idea is to insure the resources of construction are used in a sustainable manner throughout the life-cycle of the constructed artifact, from planning through ultimate disposal in a sustainable manner. The physical resources needed to create constructed artifacts are: land, energy, water, materials, and landscaping or biota. Over the life-cycle of a building, significant resources will be consumed as it is used, operated and maintained. For instance, in a typical building, the operational energy will amount to 5 to 10 times the embodied energy of the building's components. Virtually all the water consumed by a building will be by its occupants or by its landscaping over its lifetime. Landscaping is a greatly overlooked resource of the built environment and can have both positive and negative impacts. At one extreme the misuse of landscaping can result in significant water consumption and energy use for maintenance as well as biological consequences depending on the species selected for incorporation with the building. At the other extreme, landscaping can be integrated in with the building to provide a wide range of services that would otherwise have to be provided by human-fabricated systems. Among these services are passive heating and cooling, waste assimilation and processing, food production, and stormwater handling.

For the purposes of sustainability the end-stage of a constructed artifact is referred to as 'deconstruction.' Deconstruction is the disassembly of the building to promote the reuse and recycling of its material content, that is, to enhance the 'recycling potential' of its constituent materials.

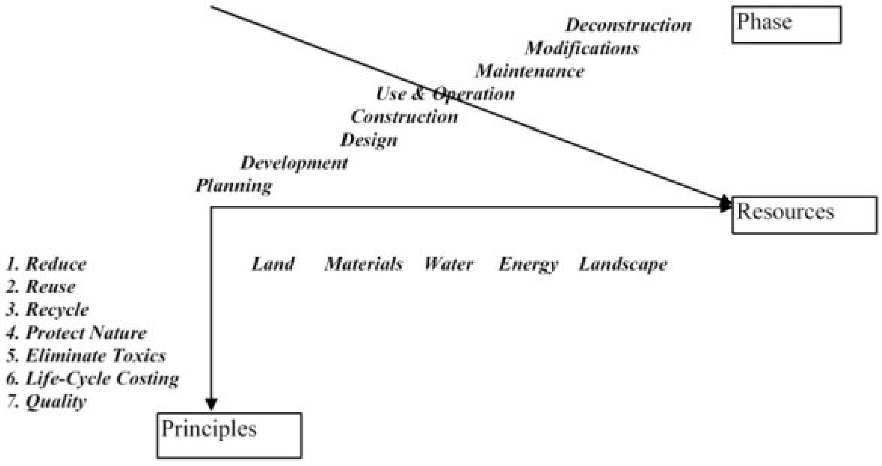

Figure 1. Framework for Sustainable Construction. Resource efficiency is a key and it is the application of the basic principles during all phases of the life-cycle of the built environment that provides the potential for sustainability.

The issue of resource conscious design is central to sustainable construction and the question to be resolved when designing under this paradigm is how to minimize virgin resource consumption and the resulting impact on ecological systems. The following is a brief summary of how resources can be considered for efficiency in building.

Materials: With respect to materials selection, closing loops and eliminating emissions (including solid waste) are the key concepts. The types of materials that account for the bulk of construction do not lend themselves to true recycling but to downcycling, that is lower value reuse. Aggregates, concrete, fill dirt, block, brick, mortar, tiles, terrazzo, and similar low technology materials are fortunately largely inert. More effort needs to be made to keep these low-end materials in productive use. Other than these high mass materials, most other building components are manufactured in factories and it is the design of these products plus their manufacture that must be examined for their resource impacts. For "closed loop" behavior, products should be able to be easily disassembled and the constituent materials capable and worthy of recycling. Because recycling is not thermodynamically 100% efficient, the recycled materials must be inherently safe for biological systems because dissipation into the biosphere of the residue is inevitable.

Land: Conversion of natural and agricultural land or 'greenfields' to built environment should be minimized and land must be 'recycled' in the sense that disturbed land such as former industrial zones (brownfields) and used or blighted urban areas (greyfields) need to be restored to productive use. Land use is also connected to patterns of development that either create efficient urban forms at one extreme or urban sprawl at the other. Urban sprawl leads to overdependence on the automobile for transportation and significant fossil fuel consumption and emissions. Land also provides environmental amenity, biodiversity, and food. Over production of the built environment, coupled with inefficient layout of the built environment in the form of planning leads to excessive consumption of this very finite, important resource.

Energy: Energy in most cases remains the paramount issue for building design and has three general approaches that can be integrated: (1) Envelope resistance to conductive, convective, and radiative heat transfer; (2) Employment of renewable energy resources; and (3) Passive Design. Passive design is perhaps the most critical of all aspects of resource conscious design because it uses building geometry, orientation, and massing to obtain conditioning from natural effects such as solar insolation, thermal chimney effects, prevailing winds, local topography, microclimate and landscaping.

Water: In many areas of the world, the availability of potable water is the limiting factor for both development and construction. Only a small portion of the earth's hydrological cycle is comprised of a potable component and protection of existing ground and surface water supplies is becoming increasingly critical. Once contaminated, it is extremely difficult if not impossible to reverse the damage. Emphasis must be placed on low flow fixtures, water recycling, rainwater harvesting, and low water use landscaping.

Landscape: Landscaping can play an important role in resource conscious design because it can supplant conventional manufactured systems and complex technologies in controlling external building loads, processing waste, absorbing stormwater, providing food, and of course, providing environmental amenity.

2.2 Resource-Efficiency Economics

One of the key challenges of sustainable construction is demonstrating the economic advantage of choosing resource-efficient strategies over conventional approaches. It is clear that high performance buildings that are well-designed in an eco-efficiency sense will most often have lower total lifetime costs than the typical alternatives. Although the initial cost will sometimes be higher, the operational costs are usually significantly lower. Additionally creating a healthy built environment, a key concept of sustainable building, provides significant additional benefits such as increased productivity and lower absenteeism. A typical U.S. office building will lease for $220/m^2 annually but the cost of the employees is on the order of $1,500/m^2. Consequently a readily achievable increase in productivity of 10% would produce a payback of about $150/m^2, a cost benefit approaching the entire lease cost of the office space. To-date this type of benefit has not been included in the economic analysis of high performance green buildings because the results have not been scientifically verified and also because the impact is so enormous. In general, for the economic advantages of green buildings to be fully evident, the employment of Life Cycle Costing (LCC) is essential. LCC readily demonstrates that the total cost of a building, its construction and operational costs, are lower for high performance buildings. Generally energy consumption is the driving force in LCC because it is most readily affected by building design, is readily quantifiable, and there are extensive simulation programs to help optimize energy measures versus costs. Broadened LCC’s that include water consumption, maintenance, and other operational costs should be used whenever adequate data exists.

3. Ecology as the Basis for Resource Efficient Design

To-date the green building concept has been slightly hampered by the lack of a philosophical and technical foundation that would give it a unifying theme and direction. In effect the definition of sustainable construction mentions what should most clearly provide this direction, that is, ecological principles. Unfortunately, it is the rare building professional, even one dedicated to green building, that has developed more than a very cursory knowledge of the science of ecology. In this section some of the basic ecological concepts that should be understood for resource efficient design are covered.

3.1 Ecological Concepts

Ecology is a science which involves the study of systems, specifically the study of the interactions of organisms, populations, and biological species (including humans) with their living and nonliving environment. The green building movement espouses that the built environment should be created using ‘ecological’ principles, yet their is little evidence that there is any real understanding of ecology or ecological principles on the part of the various actors in the building process. The reasons for this disconnect are fairly obvious. Foremost among these reasons is that the actors are generally designers, builders, managers, and investors with no environmental or ecological education or training. Consequently, although their intuition is that ecological literacy is an important aspect of creating a high performance built environment, adhering to ecological precepts is strictly by a ‘seat of the pants’ approach. A deeper understanding of ecology and ecological concepts is essential for a truly effective green building movement. Without it, these efforts are not much more than mere decor or window dressing.

Some have suggested that human industrial systems can and must use both the metaphor and actual behavior of ecological systems as guidance for their design. Current industrial systems are the equivalent of ecosystem r-strategists [pioneer species] that rapidly colonize areas laid bare by fire or other natural catastrophes. Their strategy of maximum mobility and reproduction invests all their energy in seeds and rapid growth and minimizes investments in structure. r-strategists are mobile, surviving by being the first at the scene of a disturbance and securing resources before they are eroded away. However when the resource base has been expended, their populations will diminish to very low levels. They are not competitive in the long run and only excel at outcompeting each other in a loose ‘scramble competition,’ eventually losing out to better strategies. In natural succession, K-strategist species supplant r-strategist species because they spend less energy on generating seeds and more on systems such as roots that will enable their survival during periods of lower available resources. K-strategists live in synergy with surrounding species and are far more complex than the other the r-strategists. K-strategists, unlike r-strategists, are not mobile but survive longer at higher density by developing highly efficient resource and energy feedback loops. K-strategists invest more in structure than mobility and this is the template around which their complex interrelationships efficiently conserve the flow of energy and resources.

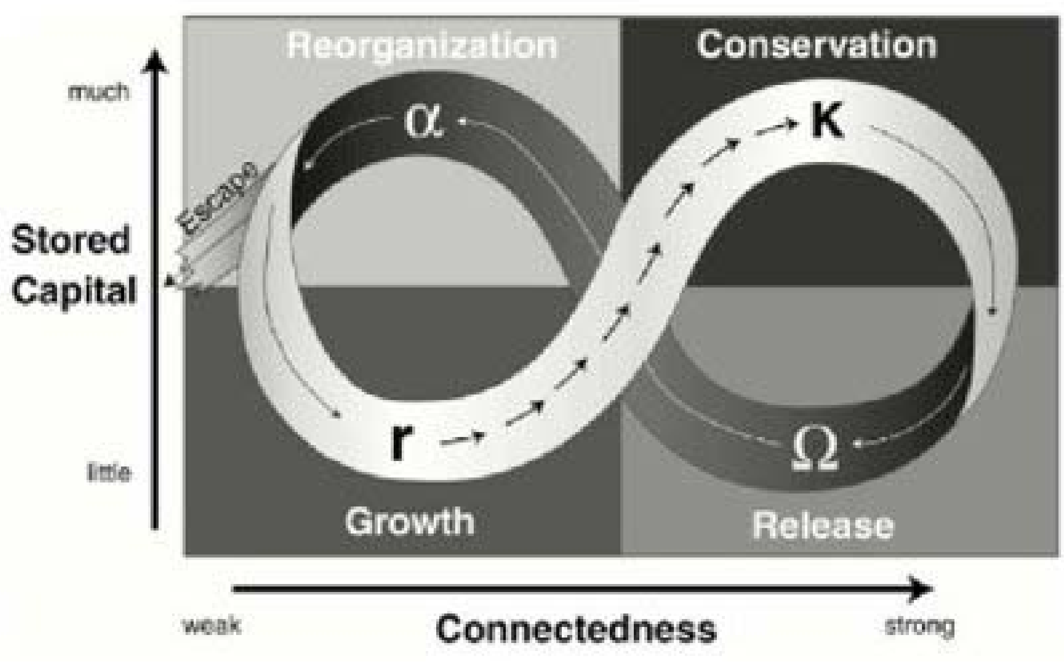

Figure 2 Ecological systems from the point of view of ‘adaptive management.’ Ecosystems have cyclic behavior starting with a growth, r-strategy in which energy is directed toward growth and reproduction, eventually shifting to a synergistic K-strategy in which species occupy specialized niches. Ecosystems are eventually upset and crash

(e.g. through disease or fire), moving rapidly through Ω- and α-stages back to a point where it can cycle back into its original system or exit into a totally new system (the ? in the diagram above). A forest can cycle through multiple iterations as a pine forest but exit into a state as a cypress swamp. Source: Peterson (2002)

In a similar manner it could be said that industrial systems behave in a similar fashion. r-strategist industries employ the typical industrial processes of today, linear systems with little or no recovery of materials from the waste stream. Closed-loop K-strategist industrial ecosystems with full materials recovery do not exist at present, partially due to a lack of technology and partially due to poor product design. It is only very recently that industrial products such as automobiles are being ‘designed for the environment,’ that is designed for reusing or recycling components and with full consideration of how to reduce the impacts on ecological systems. Today’s r-strategist industrial system is simply a primitive stage in a process of never ending evolution of human designed systems that evolve in a manner similar to nature. The question for humankind emerging from this observation of nature is how to move as rapidly as possible from our r-strategy global economy to an advanced, closed materials cycle K-strategy.

The primary lesson construction industry can learn from nature is to cycle its materials in a closed-loop manner, the goal being a ‘zero waste’ system. This could be achieved by designing all components from recyclable materials and for quick disassembly. For example, when its useful life has ended, an air handler in a large commercial building would be returned to its producer who would then be able to quickly separate all steel, copper, and aluminum components for recycling, compost the organic insulation, and throw away essentially nothing. Building structural elements would be designed to be unpinned or unscrewed rather than demolished in place. Integrated with a similarly functioning industrial system, builders and manufacturers of building materials and products would exchange resources with automobile industry, computer chip manufacturers, and consumer products on an as-needed basis. Today’s building curtain wall system may be comprised largely of yesterday’s washing machine, Ford transmission, and other artifacts, all designed as part of a larger human ecosystem.

The outcomes of applying these natural system analogues to construction would be a built environment [1] that is readily deconstructable at the end of its useful life; [2] consists of components that are decoupled from the building for easy replacement; [3] is comprised of products that are themselves designed for recycling; [4] whose bulk structural materials are recyclable; [5] whose metabolism would be very slow due to its durability and adaptability; and [6] that promotes health for its human occupants.

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