Sustainable Building Materials: A Primer

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This document provides an introductory overview of the concept of sustainability as it applies to building materials. Given increased interest in sustainability as it applies to the built environment, many designers and decision makers are accepting the challenge of making their built facilities more sustainable. What does sustainability mean for built facilities? How can it be used as a selection criterion for specifying more sustainable facility systems and materials? This primer provides an answer to these questions from a standpoint addressed to the manufacturers of building materials and components, who provide the products from which designers and decision makers must choose.

What is Sustainability?

The concept of sustainability is gaining increased global, national, and local interest with respect to how it can be applied as a strategic planning tool to increase the viability, profitability, longevity, and ultimate success of human actions on a variety of scales. In parallel to increasing attention to the concept in the academic community, sustainability is being embraced as a decision criterion by public and private sector decision makers in fields ranging from the U.S. military to individual communities to large corporations.

Sustainability has been defined in the context of sustainable development as “meeting the needs and aspirations of the present without compromising the ability of future generations to meet their own needs and aspirations” (WCED 1987). This definition highlights the most important thrust of any sustainability initiative: to seek the continued perpetuation of the human species by ensuring that human activities do not compromise the critical life support systems of the Earth upon which we all depend.

Inherent in the concept of sustainability is the assumption that human development will not decline or cease but rather continue to progress, albeit at a pace which can be sustained by the ultimately finite resources of the earth. Thus, sustainability is a system state marked by stability, where changes remain constrained so as to maintain the stability of the system into the foreseeable future. Three primary objectives emerge in seeking to achieve sustainability for the human species:

- Minimizing consumption of matter and energy, and

- Avoiding negative impacts on environmental life support systems, while
- Satisfying human needs and aspirations.

Sustainability offers a new approach to problem solving which takes into consideration the finite resources of Earth within the context of the foreseeable future, while maintaining the importance of meeting human needs and aspirations both now and in future generations. Sustainable problem solving requires increasing the scope of considerations, both in temporal and spatial scales, to incorporate the impacts of potential actions outside traditional problem boundaries into the decision making process. In the present global decision making environment, where ecological considerations are playing an ever-increasing role in the form of regulatory mandates, litigation avoidance, and competitive business practices, sustainability is being embraced as a framework for decision making which incorporates resource, ecological, sociopolitical, and economic factors into the decision process.

Figure 1 shows a model of the traditional “linear throughput” paradigm governing the interactions between human technological systems and the ecological systems which comprise their context. Resources to supply, create, and perpetuate technological systems (i.e., matter and energy) are harvested by humans from natural resource bases such as forests, fossil fuel reserves, oceans, and solar input. These resources serve as inputs to human technological systems, in which they are processed and used, usually once, in a process of throughput consumption. Entropy is generated by consumption. The residual outputs of the process are “thrown away” to environmental sinks, including air, water, and land, where they either are incorporated as inputs to ecological systems or accumulated without assimilation.

The center ring representing throughput consumption is the primary driver of the process from a human technology perspective. The five interlocking circles inside the consumption ring represent the life cycle phases of the built environment, which drives the linear throughput process as a technological system.

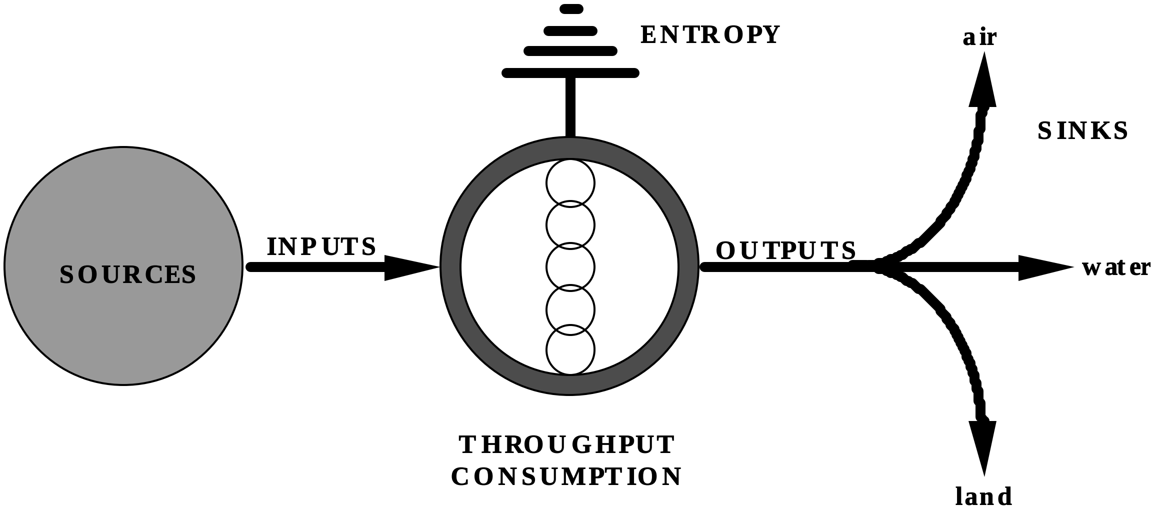

Figure 1: Linear Throughput Model of Human Technological Systems
(Adapted from Lyle 1994)

An alternative to the Linear Throughput paradigm is the Regenerative model of human technological systems (Figure 2). In this model, the consumption ring remains the central driver of the process, but resources (i.e., matter and energy) are recirculated within the consumption process (i.e., reused) rather than being used only one time and thrown “away” to environmental sinks. A larger emphasis is put on solar input as the regenerator of sources for human technological systems, since solar energy is the ultimate enabling factor for sustainability of the Earth system.

The primary difference between the regenerative and linear throughput paradigms can be found with respect to outputs from the consumption ring. Whereas outputs are dumped into natural ecosystems without regard for assimilation capacities in the linear throughput model, human-made systems for assimilation, filtration, storage, and recirculation provide a supplement to these capacities of natural ecosystems in the regenerative model. Constraints on consumption are encouraged by an increased awareness of the assimilative capacities of the technology-supplemented ecosystems, and source regeneration capacity is increased by a better integration of outputs from technological systems with natural ecosystems that regenerate the resource base.

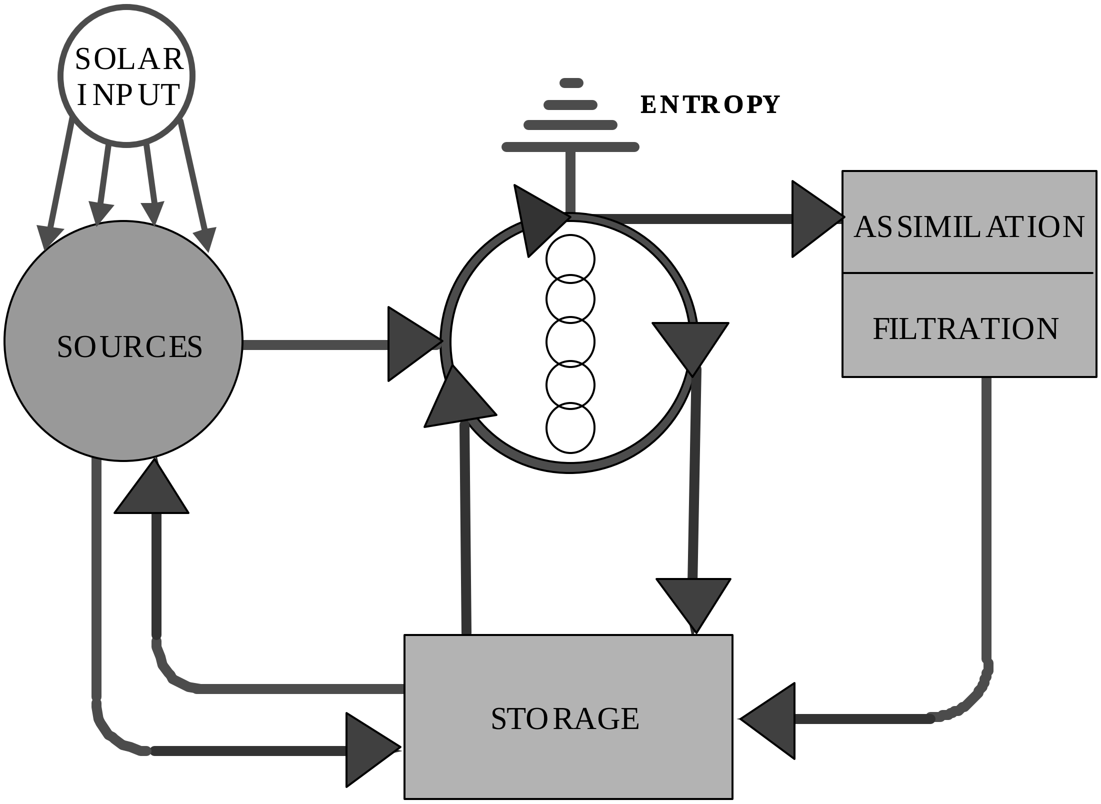

Figure 2: Regenerative Model of Human Technological Systems
(Adapted from Lyle 1994)

Regenerative systems are based on self-renewing processes whose end products are also their raw materials, modeled after the natural ecosystems upon which humanity depends. Lyle defines sustainable systems as "systems that do not deplete their resources or damage their environment, but employ technology to integrate natural and man-made processes" (Lyle 1994, overleaf).

In the linear system (Figure 1), raw inputs are taken from natural sources such as farms, mines, and forests and are transformed into products and services used by humanity. In this transformation or throughput process, large amounts of the raw resources are lost to a gain in entropy. After human consumption has extracted the last bit of utility from the products or services of the linear model, the resultant waste products flow back to the natural environment, which acts as a "sink" for this waste material.

By contrast, the regenerative or sustainable system replaces traditional throughput flows with cyclical flows at sources, consumption centers, and sinks (Figure2). In Lyle's words, "A regenerative system provides for continuous replacement, through its own functional processes, of the energy and materials used in its operation. Energy is replaced primarily by incoming solar radiation, while materials are replaced by recycling and reuse" (ibid., p. 10).

Regenerative or sustainable systems exhibit the following characteristics (ibid.):

- operational integration with natural processes, and by extension with social processes;
- minimum use of fossil fuels and manmade chemicals except for backup applications;
- minimum use of nonrenewable resources except where future reuse or recycling is possible and likely;
- use of renewable resources within their capacities for renewal;
- composition and volume of wastes within the capacity of the environment to reassimilate them without damage.

Given these objectives of sustainable systems, we can begin to see how building materials play an important role in the sustainability of the built environment. The next section describes the roles of building materials in the built environment, and describes opportunities to increase its sustainability.

What does Sustainability Mean for Building Materials?

The built environment impacts the sustainability of our world and the human species in many ways over its life cycle. One source has shown that buildings are responsible for over ten percent of the world's freshwater withdrawals, twenty-five percent of its wood harvest, and forty percent of its material and energy flows (Roodman & Lenssen 1996). Figure 3 shows some of the environmental impacts of built facilities over their life cycle, with links to external systems indicated by arrows. The following sections describe the impacts of buildings on human sustainability over the phases of a typical building's life cycle.

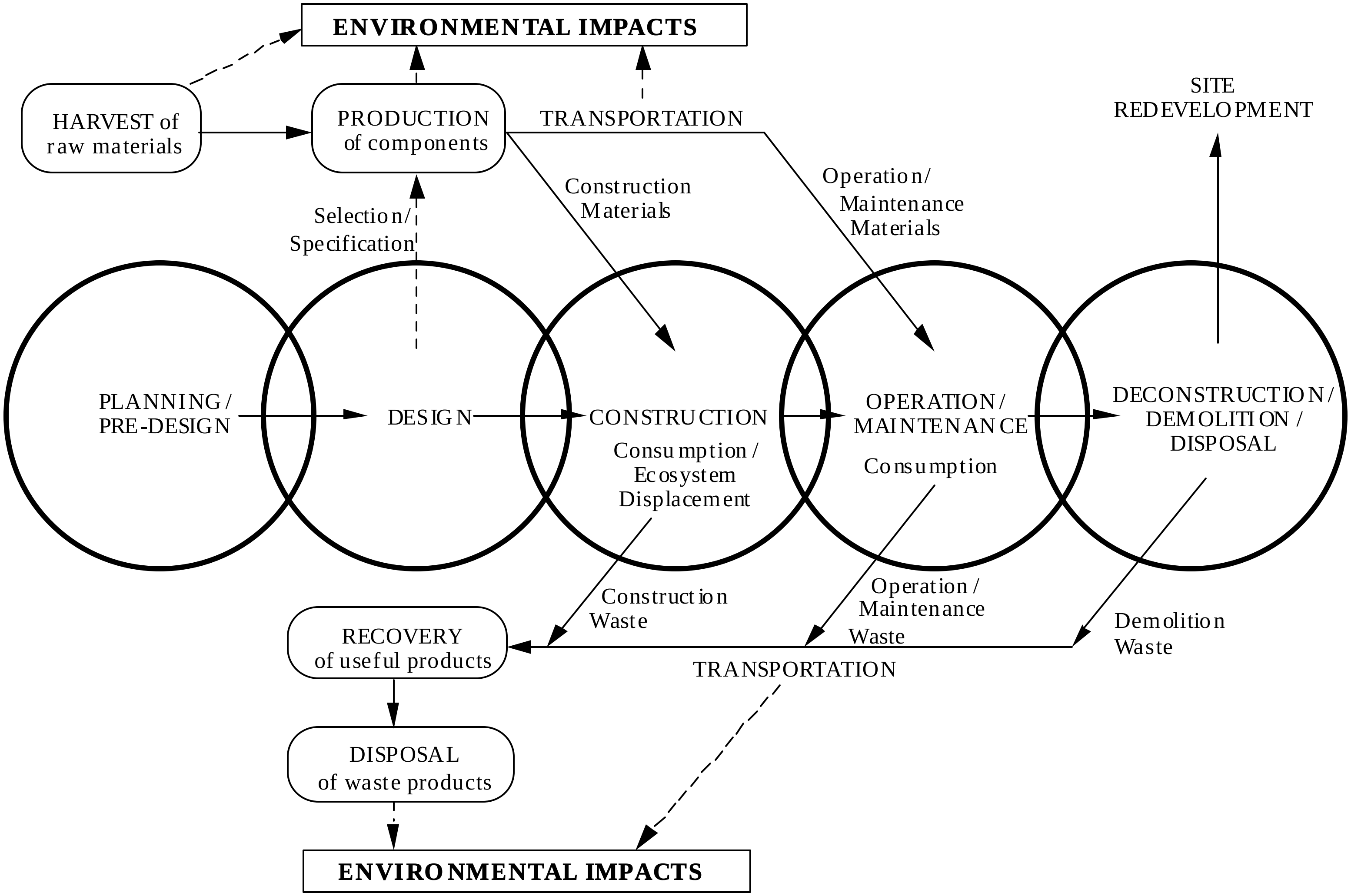
ENVIRONMENTAL IMPACTS
HARVEST of raw materials
PRODUCTION of components
TRANSPORTATION
SITE REDEVELOPMENT
Construction Materials
Operation/ Maintenance Materials
Selection/ Specification
PLANNING / PRE-DESIGN
DESIGN
CONSTRUCTION
Consumption / Ecosystem Displacement
OPERATION / MAINTENANCE
Consumption
DECONSTRUCTION / DEMOLITION / DISPOSAL
Construction Waste
Operation / Maintenance Waste
Demolition Waste
RECOVERY of useful products
TRANSPORTATION
DISPOSAL of waste products
ENVIRONMENTAL IMPACTS

Figure 3: The Built Environment as a Technological System (Pearce 1999, adapted from Yeang 1995, Roberts 1995)

System Flows During Planning/Pre-Design

Since during Planning and Pre-Design the built environment system is merely a conceptual idea rather than an existing system, there exist few connections during this phase to other technological or ecological systems. With the participation of planners, developers, zoning agencies, and regulatory agencies, informational links are established with the technological systems containing these entities. However, no matter or energy flows are directly associated with the built environment system, and minimal flows of matter and energy may be ascribed indirectly to the system due to overhead requirements for the flow of information to and from the external stakeholders involved.

The potential for influencing the rest of the life cycle of the facility system during Planning and Pre-Design is quite large (Figure 4), and decreases during subsequent phases of the life cycle. During Planning and Pre-Design, the facility system is a concept and may not even yet exist on paper, so changes can be made easily and at low cost during this phase. Thus, careful attention should be paid to all decisions made during Planning and Pre-Design to ensure that the functional and performance specifications developed in this phase reflect the true intent of the internal stakeholders.

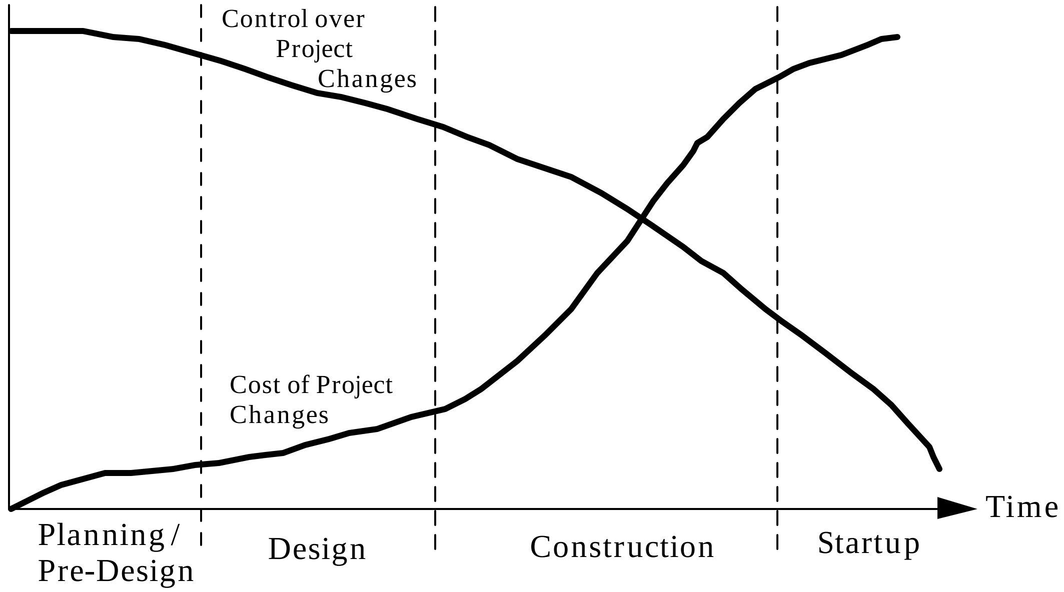

Figure 4: Cost and Control vs. Time for a Construction Project
(adapted from Raubacher 1992)

System Flows During Design

As during the Planning/Pre-Design phase, the flows of matter and energy attributable to the built environment system remain small; resource flows due to the system are primarily from overhead incurred by external stakeholders due to the flow of information necessary to create a design from the Program of Requirements for the facility system. Links to technological systems for this phase include the systems represented by the various members of the design team, along with site and contextual ecosystems which are surveyed to develop the design.

The primary difference between Planning/Pre-Design and Design in terms of links to external technological and ecological systems is the making of decisions pertaining to the selection and specification of materials and methods for construction of the facility. These decisions also have longer-term impacts over the post-startup life cycle of the facility, since they constrain options for maintenance, operation, deconstruction, demolition, and disposal. For example, a decision made during design to utilize fluorescent light fixtures in the facility means that replacement bulbs and ballasts of a specific type will have to be used during maintenance, specific quantities of foot-candles will be generated during operation, and special provisions will have to be made during disposal for the hazardous materials contained in some types of fluorescent ballast units.

Selection and specification of materials and methods during design has impacts as well on external technological and ecological systems. Specification of particular materials creates a market demand for those materials during construction, stimulating the harvesting of raw materials to be manufactured into the specified components, which in turn must be transported to the site and assembled into the facility system. Each of these operations has impacts on the technological systems which generate them, as well as impacts on natural ecosystems and the net resource base on Earth. Thus, decisions made during the Design phase have significant impacts on the technological and ecological systems to which the facility is linked, and these impacts should be carefully considered in decision making during design.

System Flows During Construction

A significant inflow of matter and energy to the built environment system is observable during the Construction phase of the life cycle. During this phase, building materials, equipment, and personnel come together on site to create the raw infrastructure of the facility according to the plans and specifications developed during design. A set of external stakeholders is assembled to comprise a construction team, consisting of contractors, consultants, and subcontractors. Each of these stakeholders brings its own links to technological systems, based on its knowledge, resource, and expertise bases. Physical links to contextual infrastructure systems are also established during this phase, including utility hookups, connections to water, waste water, and stormwater drainage systems, and services afforded by the community context such as roads or transit systems.

On site, existing ecosystems are directly displaced by the footprint of the facility as it is being constructed, and surrounding ecosystems are disturbed by the presence and activities of construction. The act of construction results in the consumption of large quantities of energy and materials over a relatively short period of time, and can generate significant quantities of waste which must be recovered or disposed. The waste and residuals from the construction process must either be assimilated by human or natural ecosystems, or be "stored" in landfills for future use. This downstream link to technological and ecological systems is a significant but often overlooked feature of the construction process. The transportation required to move materials and equipment to and from the site also consumes energy and results in environmental impacts due to emissions and other conflicts with natural ecosystems.

After the facility has been constructed, the relationships between entities on the construction team are often dissolved when the facility system is turned over to the owner for occupancy. This transition marks the point in time when the facility system becomes operational, and begins to fulfill the purposes for which it was created. New links are established which serve these purposes, and the facility moves into the next phase of its life cycle: Operation and Maintenance.

System Flows During Operation/Maintenance

The largest flows of matter and energy through a built environment system typically occur during the Operation and Maintenance phase of the life cycle (St. John 1994). During this phase, the facility system functions according to the purpose for which it was designed and constructed. Significant stakeholders during this phase are the building occupants and operators, including users, tenants, clients, facilities managers, maintenance staff, and other operational staff. Not only does the building system consume energy for heating, cooling, lighting, and other purposes, but also it consumes matter for both operation of the physical structure and for the processes undertaken by users such as manufacturing, residential applications (e.g., cooking, dining, and bathing), or retailing. While the matter and energy consumed by user processes is not usually directly attributable to the facility itself, it often affects the operational requirements of the facility and is typically a part of traditional life cycle analysis for a facility (Graedel & Allenby 1995).

Matter and energy are imported into the facility system from complementary technological and ecological systems, and waste matter and energy are exported back into the system context, where they are either assimilated, reused, or stored by downstream technological or ecological systems. Information and value are also typically part of the flows into and out of the built environment system during Operation and Maintenance, and are dependent on the nature of the facility system and the processes it hosts. Built environment systems in their Operation and Maintenance phases are typified by consumption; this is the phase where the facility is "used up", and is analogous to the consumption phases of other types of consumable goods.

During this phase, the facility has its most significant chain of secondary and indirect stakeholders, including the dependents of the users who rely on the facility for their livelihood. The nature of the flows and links to other technological and ecological systems is greatly dependent upon the nature of the facility and the processes which it hosts; further examination of these context-dependent variables is necessary to capture the essence of the impacts the facility has on its context.

At the point in time when the facility system ceases to be useful for its intended purpose, the decision makers responsible for the system may elect to rehabilitate or reconstruct the facility, at which point the links and flows described in the previous sections are sequentially reestablished. Alternatively, the decision makers may elect to end the life cycle of the facility through deconstruction, demolition, or disposal. At this point, the normal Operation and Maintenance cycle of the facility comes to a close, the occupants of the facility system move out, and the system moves to the final phase of its life cycle.

System Flows During Deconstruction/Demolition/ Disposal

In most cases, Deconstruction/Demolition/Disposal is the life cycle phase where the most significant flows of matter and energy leave the system and enter corresponding downstream technological and ecological systems as a waste stream from the built environment system. A typical path for this waste stream after on-site salvage has retrieved the most useful products for reuse is via transportation to an off-site location, where reusable or recyclable materials are recovered by waste disposal and/or recycling companies, and the remaining products are sent to a man-made technological storage system: the local landfill.

Various techniques exist for disposing of a built facility at the end of its useful service life, ranging from careful deconstruction in which nearly all of the materials are salvaged or recovered (NCSU 1996), to the archetypical demolition via wrecking ball, where the building is simply knocked down, the components loaded into trucks, and the entire facility rendered into landfillable waste. Depending on the nature of the facility and the care with which it is disassembled, large amounts of materials can be recovered for reuse or recycling into other products or facilities.

As with Operation and Maintenance, many context-dependent variables influence the links which can be utilized to other technological and ecological systems during this phase, and facility systems must be considered individually to evaluate the nature of these links. Ideally, the site of a deconstructed facility would be returned to its original state to facilitate redevelopment; however, this is seldom the case. In most cases, the level of entropy of the site has been significantly increased as a result of human intervention, and future uses of the site are subsequently constrained.

After the facility system has been deconstructed and its components either removed from site and passed on to other systems or assimilated by ecosystems on site, the facility life cycle has reached its close. The links associated with the built environment system are closed, and only potential future users remain as stakeholders in the system. Within this life cycle of built facilities, materials manufacturers have the potential play a variety of roles in improving sustainability. The next section explores the roles of materials manufacturers in creating a sustainable built environment, and presents objectives for creating sustainable building materials based on the guiding principles of sustainability presented in the first part of this Appendix.

The Role of Materials Manufacturers in Creating a Sustainable Built Environment

While much debate exists over the economic, ethical, and policy implications of sustainable development (Rees 1988), there is general agreement that one of the most important issues for sustainable development is careful stewardship of natural resources, both renewable and nonrenewable (e.g., Gardner 1989; Pearce 1988; Lozar 1993). The Canadian National Task Force on Environment and Economy has expressed an interpretation of sustainable development which is almost entirely resource-based, writing that "sustainable development is...development that ensures that the utilization of resources and the environment today does not damage prospects for their use by future generations" (1987). Since the initial source for all physical resources is the natural environment, protection of environmental quality is also a critical factor of sustainability. Construction materials manufacturers, as the controlling stakeholder in resource consumption for built facilities, have a critical role to play in influencing the sustainability of our built environment.

Construction Materials Technology

Construction materials technology has changed rapidly in recent years, with significant changes including increased reuse and recycling of construction and demolition waste materials like timber, steel and concrete (e.g., Brown & Bassett 1988), improvements to traditional products such as fiber-reinforced concrete and plastic-reinforced wood (e.g., Plevris & Triantafillou 1992), and development of completely new technology such as geotextiles (Richardson 1988). While use of innovative materials is growing, many designers and contractors are reluctant to try materials which are not yet "tried and true," particularly in civil engineering projects where public funding is involved and where failure could mean the loss of many human lives. Building codes and other regulatory restrictions impose further limitations on the use of recycled or innovative materials, often taking years to catch up to changes in materials technology. Finally, the sheer number of potential materials available to designers and contractors makes optimization of material choices a nearly impossible task.

Environmental Impacts of Building Materials

Quite a few attempts have been made to describe materials in terms of their impacts on the environment. For example, one reference guide on engineering materials developed at the Center for Resourceful Building Technology presents a listing of sources for materials which contain recycled materials or are low in embodied energy (Loken et al. 1994). However, there are often significant environmental tradeoffs to be considered in trying to choose the "optimal" material for a given application. For example, the benefits of recycling materials, such as conserving landfill space and reducing demands on virgin resources, are sometimes overshadowed by increased energy expenditures required for collection and reprocessing (Scarlett 1991; Scott 1992).

Often, environmentally benign materials are technologically unavailable at the time of materials selection (Bjerklie 1993). Even when ecologically sound alternatives to traditional building materials can be found, their use often presents conflicts with other parameters for materials selection, especially economic considerations. Typically the initial cost of using recycled materials is higher than for virgin materials. And sometimes otherwise sound alternative materials present the same bad features as the traditional materials they replace. As one architect pointed out, "recycled carpet made from old plastic soda bottles still gives off the same toxic gasses that regular nylon carpet does" (Paul Bierman-Lytle, quoted in Bjerklie 1993).

A variety of materials selection technologies have been developed specifically to assist designers with environmental issues. Design tools range from indexed sourcebooks such as the *Guide to Resource-Efficient Building Materials*, which lists "green" materials and their properties, to computer-based information systems such as the Forest Resource Information System, which offers a computerized database on the characteristics and potential uses of thousands of virtually unknown tropical species of wood. However, these systems usually provide only facts related to each material's characteristics, and rely on human judgment to compare alternatives in the context of the intended use.

Considerations for the Sustainability of Building Materials

Considerations for materials manufacturers seeking sustainability for the built environment range from ensuring that the raw materials for their products come from sustainable sources, to specifying sustainable construction methods for installing the materials and sustainable maintenance practices to ensure that the materials function properly to meet the needs for which they were designed. Increasingly, materials manufacturers may also be called upon to play a role in recovering and recycling their products at the end of their useful life cycle. New regulations in the European Economic Community, for example, require manufacturers to take back their products and packaging, relieving society in general of the responsibility for dealing with product waste (Hawken 1994).

Materials manufacturers interested in sustainability should be concerned about the sources of their manufacturing stock, the impacts of their manufacturing and distribution processes, the installation and maintenance of their products, and the eventual take-back or disposal of the products at the end of their life cycle. Beyond these issues, an essential component of sustainability for materials manufacturers is to provide information to designers and users of the materials about the sustainability of their processes and products. Table 1 shows the range of information necessary to evaluate and compare the sustainability of building materials.

Table 1: Sample Information Requirements for Sustainable Building Materials

Environmental Performance	Technological Performance	Resource Use Performance	Socio-Economic Performance
Impacts on Air Quality	Durability	Energy	Occupant Health/

			Indoor Env’l Quality
• Carbon Dioxide	Service Life	• Embodied	• VOC Outgassing
• Hydrocarbons	Maintainability	• Operational	• Toxicity
Impacts on Water Quality	Serviceability	• Efficiency	• Susceptibility to biocontamination
Impacts on Soil Quality	Code Compliance	• Distributional	Appropriateness for:
Ozone Depletion Potential	R-value	Degree of Processing	• Scale
Site Disturbance	Strength	Source Reduction	• Climate
Assimilability	Constructability	Materials	• Culture
Scarceness		• Renewable	• Site
Impacts during Harvest		• Recycled/ Recyclability	Economics:
Processing Impacts		• Reused/ Reusability	• Contribution to Economic Dev’t.
		• Renewability	• Cost
		• Local/Transport Distance	• Labor Skill Requirements
		• Packaging Requirements	• Labor Amount Requirements

Objectives for Creating Sustainable Building Materials

Based on the sustainability considerations presented in the previous section, several objectives emerge to guide materials manufacturers in making their products and processes more sustainable. In order to increase the sustainability of the built environment, materials manufacturers should strive to create materials that:

- have the lowest possible life cycle consumption of matter and energy
- have minimal net negative impacts to the natural environment
- maintain some reasonable level of human satisfaction in their technological and socio-economic performance.

In addition to these basic sustainability objectives, materials manufacturers should also strive to influence other built environment stakeholders to ensure sustainability, by:

- providing sustainability-related information about their products to designers and specifiers
- developing installation specifications to ensure the first three objectives are met during facility construction
- developing maintenance/operation specifications to ensure the first three objectives are met during facility use
- developing removal/disposal specifications to ensure that the first three objectives are met at the end of the facility life cycle

Materials manufacturers interested in sustainability can work toward "closing the loop" in their manufacturing, distribution, and product cycles by:

- developing take-back policies for used materials at the end of their life cycle
- using reused, recycled, or sustainable and renewable source materials whenever possible
- using sustainable or renewable sources of energy
- minimizing the use of packaging, or using reusable packaging

These sets of objectives embody one common theme of sustainability: expanding the scope of considerations to include the entire life cycle of a material, in the context of its use. Figure 5 provides a graphical representation of how "thinking outside the box" is necessary to increase built environment sustainability.

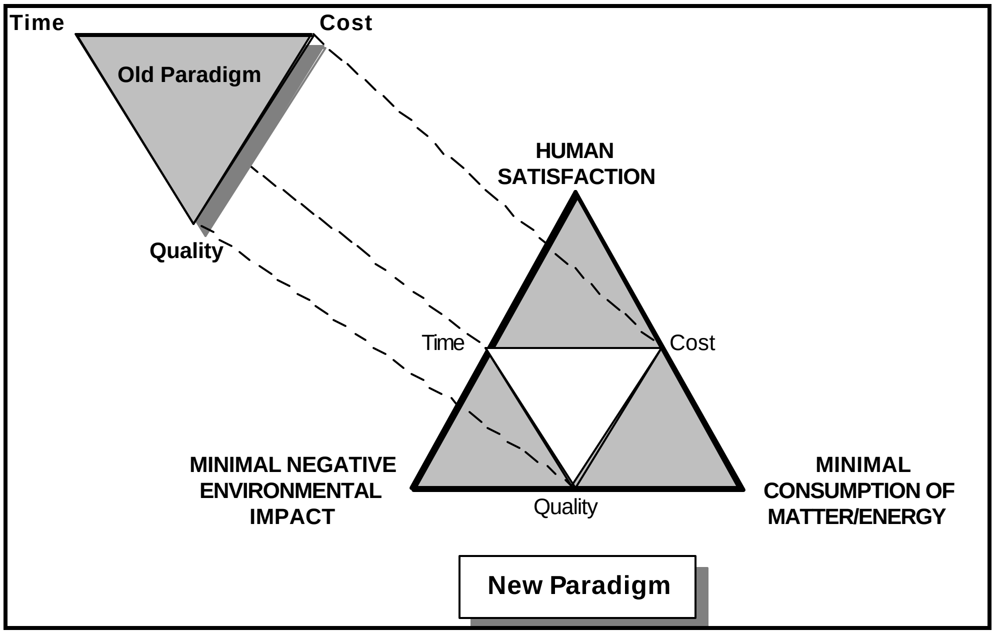
Time
Cost
Old Paradigm
Quality
HUMAN SATISFACTION
Time
Cost
MINIMAL NEGATIVE ENVIRONMENTAL IMPACT
Quality
MINIMAL CONSUMPTION OF MATTER/ENERGY
New Paradigm

Figure 5: Thinking Outside the Box for Built Environment Sustainability (Pearce 1999)

Benefits and Impacts of Sustainability for Materials Manufacturers

One exciting feature of sustainable development is the potential for economic benefits to those who implement it. While sustainability is sometimes used to refer to the behavior of closed systems which have zero growth (Brown et al. 1987), most sources agree that in order to realistically implement policies of sustainability, economic growth is essential, particularly in developing countries (e.g., Rees 1988). Especially in attempting to motivate corporate change in a highly competitive, profit-based industries like construction, every new idea must show promise of economic benefit to find acceptance. Even small increases in costs can pose considerable risk, sometimes resulting the loss of market-share to a competitor or even bankruptcy. Thus, any attempt to motivate consideration of environmental or long-term resource conservation issues must be accompanied by assurances that change toward sustainability does not necessarily mean economic disadvantage. The concept of sustainable performance, as developed by Kinlaw (1992), addresses the competitive reality of corporate environments by showing that incorporating sustainability into company strategies can lead to many economic advantages, including waste reduction, increased market share of eco-conscious consumers, and reduction of environmental liability.

Increasing Profitability

Many opportunities exist to save money and increase profitability by adopting sustainability as a guiding principle over the life cycle of built facilities. By focusing on reducing the consumption of matter and energy in their manufacturing processes and facility operation, manufacturers of building products can increase their profits by:

- Reducing waste, thus minimizing subsequent disposal costs
- Minimizing input requirements for raw materials and energy to create the product
- Minimizing matter and energy requirements to create, operate, and maintain manufacturing facilities.

54% of U.S. energy consumption is directly or indirectly related to buildings and their construction (Loken et al. 1994). This single indicator reflects the significance of both buildings and the materials that comprise them in consuming the limited quantities of matter and energy available on Planet Earth. By optimizing manufacturing processes and paying careful attention to opportunities for resource conservation, materials manufacturers can not only reduce their overall impacts on global sustainability, but also realize increased profits by virtue of the competitive edge provided by increased resource efficiency.

Another way to increase profits via sustainability is to take advantage of the increased employee productivity resulting from better working conditions, increased human health, and worker satisfaction. The following quotes illustrate the potential savings from giving attention to indoor environmental conditions in built facilities:

- "...the indoor ecosystem...is the place where the average urban dweller spends nearly 90% of an average day. The World Health Organization estimates that 30% of all new and remodeled buildings suffer from poor indoor environments caused by noxious emissions, off-gassing, and pathogens spawned from inadequate moisture protection and ventilation, resulting in $60 billion annually in lost white-collar productivity from Sick Building Syndrome (SBS) in the U.S. alone" (Kibert et al. 1994).

- "Several recent studies have shown that making a building environmentally responsive can increase worker productivity by 6% to 15% or more. Since a typical commercial employer spends about 70 times as much money on salaries as on energy, any increase in productivity can dramatically shorten a green building's payback period...[*saving energy costs] is absolutely swamped by the benefits of keeping workers--employed at an average annual cost of at least $130 per square foot--happy and productive.*" (Barnett & Browning 1995, p. 9, emphasis original).

- "One study cited a 25% reduction in sick days due to improved lighting systems" (Allen 1982, in Browning & Romm 1995).

This evidence illustrates the opportunities to save money by paying attention to the most significant cost of any business enterprise: personnel. By implementing sustainability in their own facilities, materials manufacturers can directly realize savings in terms of personnel costs. And by making materials with which others can create sustainable buildings, manufacturers can mobilize evidence such as the previously listed quotes to help sell their materials to profit-conscious owners, designers, constructors, and users.

Capturing the Green Market

In terms of the market for construction materials, adopting sustainability has the potential to help materials manufacturers appeal to the growing sector of environmentally conscious designers, constructors, and owners. A growing number of resource guides focusing on green or sustainable building materials is available to help designers specify products for their buildings that have low environmental impacts, are non-toxic, or conserve resources. Table 2 shows a sample of some of these commonly available resource guides in which sustainable building products are listed. While the requirements for being listed vary from guide to guide, in some cases the criteria are as simple as documenting that the material has recycled content, is non-toxic, or is made from 100% natural materials.

Another way to publicize the "green-ness" or sustainability of a building product is through ecolabels or certification labels, such as Scientific Certification Service's *Green Seal* Program (SCS 1998). By providing sustainability information for their products in the form of labels or certifications, materials manufacturers can emphasize the actions they are taking to improve their sustainability and thus attract the attention of the green market.

In attempting to capture the green market, a company should strive to establish credibility by incorporating an environmental ethic before communicating the message to its market (O'Brien & Palermini 1993). Credibility is essential to overcome the skepticism and uncertainty currently pervading the green market due to the "rash of confusing and unsupported messages" purveyed in the marketing of early products for the green market (ibid., p. 49). Manufacturers must be sure to "practice what they preach," by not only creating green building products but also paying attention to the whole business enterprise, including using recycled papers and non-toxic inks for marketing materials, practicing sustainable building operation and maintenance in their facilities, and adopting an environmentally sustainable policy as part of the mission statement (ibid.).

Table 2: Commonly Available National Sustainable Building Material Guides

RESOURCE GUIDE	REFERENCE	CRITERIA
Sustainable Design Guide	St. John (1994)	Environmentally responsible manufacturing process; Benign substitute for a known “bad actor”; “More than token” recycled content
The Natural House Catalog	Pearson (1996)	100% natural materials Non-toxic alternative to traditional materials
Consumer Guide to Home Energy Savings	Wilson & Morrill (1996)	Energy efficient alternative to traditional product; Contributes to thermal efficiency
Guide to Resource Efficient Building Elements	Loken et al. (1994)	Resource-efficiency Recycled content
The Green Pages	Bennett (1990)	Non-toxic 100% natural materials
Sustaining the Earth	Dadd-Redalia (1994)	Renewable or natural; Organic; Reused/Reusable; Recycled/Recyclable; Sustainably harvested; Energy- or Resource-efficient; Nontoxic; Ozone-friendly; Biodegradable; Socially Responsible
The Official Recycled Products Guide	American Recycling Market (1997)	Recycled content
The Harris Directory	Harris (1993).	Recycled content
The REDI (Resources for Environmental Design Index) Guide	Iris Communications (1994)	Recycled content Resource efficiency Sustainably managed wood sources
Environmental by Design	Leclair & Rosseau (1994)	Interior products, including thermal insulation

Reducing Liability

Reducing potential liability is a third benefit of sustainability. By virtue of its goal of reducing negative impacts to the environment and natural ecosystems, sustainability provides a framework for proactive and anticipatory environmental compliance. In contrast with competitors who likely view environmental compliance as a problem to be solved, sustainable materials manufacturers can consider environmental responsibility an opportunity to increase product sustainability and capitalize on the marketing edge it provides. By incorporating sustainability into the manufacturing process, materials manufacturers can not only reduce the probability of failure to comply with environmental regulations, but also can actively anticipate future regulations and be well-positioned to take them in stride. Materials manufacturers can also use their proactive environmental practices as a marketing tool (O’Brien & Palermini 1993).

Liability can also be reduced by focusing on the third objective of sustainability: achieving human satisfaction. By attending to the needs and aspirations of company personnel, sustainable manufacturers can reduce not only the incidence of sick days and accidents, but also prevent liability that might result from environmental exposure to toxins or unhealthy indoor environments in the manufacturing facility. Increasing the sustainability of the product may also result in increased customer satisfaction, fewer product returns or replacements, and lower liability as the product is installed, used, maintained, and eventually disposed.

Gaining a Competitive Edge

All of the potential impacts and benefits described here can help a sustainable manufacturer of building products gain a competitive edge over the competition (O'Brien & Palermini 1993). Given all the benefits of adopting sustainability as a guiding principle, the future will likely bring widespread incorporation of the concept into business practice at all levels. By proactively becoming a sustainable manufacturer of sustainable building products, companies can stay at the leading edge, and help to ensure that future generations can meet their needs even as the present generation meets its own needs.

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