Sustainability and the Indigenous Materials Heuristic

by Annie R. Pearce, Ph.D. Candidate
School of Civil and Environmental Engineering
Georgia Institute of Technology, Atlanta, GA, USA

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1.0 Introduction

Many approaches to achieving sustainability in the built environment have been proposed in the practicing literature (c.f., Loken et al. 1994, St. John 1994, Ander 1994), primarily in the form of general heuristics such as "use passive solar techniques whenever possible to reduce building energy costs" or "minimize waste in creating materials and during construction". One of the most common sustainable architecture heuristics, "use indigenous or locally-produced materials whenever possible," (hereafter denoted as the indigenous materials heuristic) is the subject of this discussion.

1.1 Definition of Key Terms

Indigenous materials are generally considered to be materials which are produced in the same bioregion or regional ecosystem where they will be used (Loken et al. 1994), although some practitioners consider materials to be indigenous only if they are available on the same site where they will be used. Indigenous materials are also subject to the widespread but generally erroneous belief that a material is indigenous only if it is "primitive" and as such requires little or no processing between harvest and use. For the purposes of this paper, however, the definition of indigenous materials will include all materials which remain in their bioregion of origin, from harvesting, through processing, and on to incorporation into a built facility or artifact.

Harvesting of materials in this paper is taken to mean the collection of raw materials from the natural environment, as a source of input for some process which yields building materials as output. Processing refers to the transformations which are made to the raw input material to convert it into the output building material. Transportation requirements may occur at various points in the harvesting and processing of materials, and may necessitate the use of modes and related infrastructure such as trucks and highways or access roads, trains and railroads, or overland conveyors (Tavares 1984).

Embodied Energy?

Ecosystems are collections of biological entities which depend on each other for their continued existence, and which interact symbiotically to recycle matter and energy, with output from one class of entity serving as input for another class, in a nearly closed cycle. A bioregion is considered to be a geographical area containing groups of ecosystems which are related to each other and which may or may not be dependent on exchanges of matter and energy for coexistence. A single contiguous wetland is an example of a semi-aquatic ecosystem, whereas a series of wetlands, marshes, rivers, and other related ecosystems such as the Chesapeake Bay is an example of a bioregion.

Entropy is a thermodynamic term which refers to the degree of chaos or disorganization inherent in matter. Matter such as a solid has a higher degree of order and thus a lower entropy than does a gas, which has a much less rigid organization. Exergy, on the other hand, is a measure of the utility of the energy contained within matter. A material which has been repeatedly recycled loses exergy with each recycle, since the level of potential energy within that matter has been lowered as a side effect of the processing. Materials which are high in exergy and low in entropy have the most anthropocentric utility and are thus more sustainable than materials which are high in entropy or low in exergy.

1.2 Objectives of the Paper

The purported rationale behind using indigenous materials varies from source to source; however, the most common reason cited is minimization of the transportation portion of energy embodied in the material (c.f., Loken et al. 1994, Bell et al. 1992). Other reasons given are the idea that using materials generated within a bioregion to meet the needs of that bioregion increases its robustness and stability (e.g., Perry 1994a, Bennett et al. 1994), and that using indigenous materials for architecture is somehow "better," more satisfying, or more architecturally appropriate than using non-indigenous materials (e.g., Day 1990, Perry 1994b).

The objective of this paper is to examine the assumptions which underlie the indigenous materials heuristic, and to qualify the heuristic by defining the boundaries of the situational region where it can be effectively applied. In the following sections, a definition of sustainability is developed, first from a thermodynamic systems perspective, then progressing to an anthropocentric view, and finally being adapted to the specific problem of material selection. Then, the scope of the indigenous materials heuristic is explored in terms of the four categories of sustainability impacts: technology, ecology, economics, and ethics. A set of relationships is hypothesized to govern the range of applicability of the indigenous materials heuristic, and a collection of policy objectives and options is proposed to extend that range of applicability toward the goal of increased sustainability. Conclusions are presented, and directions for continued research are discussed.

2.0 Sustainability: Development of a Goal-Based Definition

Sustainability at its most general has been defined as a system state marked by stability, where changes to the system remain constrained so as to maintain the stability of the system into the foreseeable future (Pearce 1994). Critical to this definition of sustainability is the notion of a bounded system, where the sustainability of the system within its boundaries is largely dependent on the delineation of those boundaries due to the requirement that consumption of resources within the bounded system be sustained by input from some energy source outside the system.

The sustainability of a bounded system is dependent on its respect for thermodynamic constraints with regard to changes in the states of matter and energy. More than this, however, converting a system from an unsustainable to a sustainable state must be undertaken with reference to the rational self interest of the actors which act to change the state of the system to sustainability. Finally, the context of the specific problem within the bounded system is important for the framing of the operational objectives of a goal-based definition of sustainability. In the following sections, one possible a goal-based definition of sustainability as it relates to construction materials selection is developed.

2.1 Thermodynamic Foundations

In order for any system to be perfectly sustainable, there must be no net loss of the sum total of matter and energy circulating within the system. This state exists for the system of the whole universe according to the first law of thermodynamics: matter can be neither created nor destroyed. Such a state is also possible for the nearly closed system of the Earth – energy lost as thermal radiation from the Earth can be offset by solar radiation absorbed from the sun.

In addition to conservation of matter and energy, the state of entropy within the system must be stable in order for the system to survive into perpetuity (Georgescu-Roegen 1971). In all systems, however, entropy increases with every expenditure of energy, and can only be offset in one system by a greater sacrifice of entropy in some other system; therefore, the total net entropy of the universe is continually increasing toward a state of total inevitable disorder (Rifkin 1980). Fortunately for us, the amount of energy received by Earth from the sun currently exceeds the amount of energy lost as thermal radiation (the difference is commonly called the solar energy budget), and can be used to offset increases in entropy resulting from transformations of matter and energy within the Earth system. Thus sustainability is theoretically possible for the system defined as Earth, even though for the entire universe entropy is continually increasing and sustainability is impossible (ibid.).

Perfect sustainability for the Earth system is theoretically possible as long as we live within the solar energy budget and as long as the sun continues to shine, of course. To remain within this budget (described quantitatively by Vitousek et al. 1986), several global objectives of sustainability can be identified:

1) Minimize negative impacts on natural ecosystems (since they are the mechanism for capturing solar energy in the form of photosynthesis)
2) Minimize the gain in entropy of matter as a result of consumption-related processes.

These two objectives have been formulated into a variety of directives by various authors to address issues such as the consumption of renewable and nonrenewable resources, maintenance of biodiversity, and minimization of unassimilable wastes (c.f., Ruckelshaus 1989, Rees 1990, Solow 1991, Daly 1994).

2.2 The Human Component

No definition of sustainability is complete without considering the rational self-interest of the actors who seek to change their context to achieve it. Accordingly, anthropocentric slants on the thermodynamic requirements for sustainability are inherent in most, if not all, definitions of sustainability in the literature (see Pearce 1988 for a blatant example). The various operational objectives found in the literature can be summarized in three general directives: maintain standards of living at least as good as the ones which currently exist, leave the Earth in at least as good a condition as we found it, and bring everyone else up to at least a "decent" standard of living.

The first of these directives, maintain standards of living at least as good as the ones which currently exist, is borne of practical considerations. By definition, no rationally self-interested person will voluntarily sacrifice his or her own standard of living without some compensating benefit of equal or greater utility (Simon 1983). Moreover, reliance on such constructs as conscience or guilt to motivate human behavior to become more sustainable is unwise, since such motives tend to be generally unreliable and often self-extinguishing (Hardin 1968). Therefore, in order to foster acceptance of any proposal for sustainability, assurances must be included that those who undertake to change their lifestyles to achieve sustainability will not suffer as a result of their commitment.

The second directive, leave the Earth in at least as good a condition as we found it, is aimed at achieving intergenerational equity. By leaving the Earth as good as or better than it was when we arrived, we ensure that future generations will not only have the same set of resources with which to work that we have, but also the accumulated body of knowledge that we have developed as a result of our life experiences. However, the phrase "at least as good" has been interpreted in various ways in the sustainability literature, ranging from leaving the nonrenewable resource base completely unchanged from its present state (e.g., Daly 1994) to using nonrenewable resources as necessary provided that we create adequate substitutes (e.g., Solow 1991, Mikesell 1992). Adopting the more conservative view of Daly, our ultimate goal should be to strive to leave our resource base as unchanged as possible while working toward achieving the first and third directives.

The third directive, bring everyone else up to at least a "decent" standard of living, is concerned with the issue of intragenerational equity. Achieving intragenerational equity is important not only because of ethical considerations for the welfare of people in developing nations, but also because we cannot hope to develop common goals and a coordinated course of action for achieving sustainability when people are concerned for their very survival and lacking in basic human rights (e.g., Jacob 1994). Common goals and coordinated action are required to achieve sustainability because no action within the Earth system is entirely without ramifications for other entities and processes in the system. Due to the contextual nature of sustainability, actions which seem rational and sustainable to one party acting in isolation may actively conflict with the rational actions of other parties in the interconnected "real world". Thus, global objectives and cooperative actions are needed to reach a state of sustainability, and achieving some degree of intragenerational equity is essential to elicit that cooperation (Ruckelshaus 1989, etc.).

2.3 Sustainable Material Selection

The general goals of sustainable material selection follow from the thermodynamic and anthropocentric objectives of sustainability:

1) Minimize the consumption of matter and energy, while
2) Maintaining some reasonable degree of human satisfaction and
3) Causing minimal negative environmental impacts.

The first goal, minimization of matter and energy consumption, is based on minimization of entropy gain as well as intergenerational equity objectives. Consumption processes inherently involve increasing the entropy of materials and energy, rendering them of lower exergy and thus of lower utility for future use (Robert 1994, Rees 1990). By subjecting materials and energy to consumption processes and thus lowering their exergy and increasing their entropy, we generally decrease their potential utility to future generations. Therefore, consuming as little matter and energy as possible, or "doing more with less," is a fundamental objective of sustainability and of sustainable material selection (ibid.).

Doing more with less relates as well to the second goal of sustainable material selection: maximizing human satisfaction. While it is true that one cannot simultaneously optimize more than one variable at a time (e.g., Daly 1994), some sort of tradeoff must ultimately be made between human satisfaction and resource consumption in order to achieve sustainability. For the same reasons which justify maintaining current standards of living in achieving sustainability, including human satisfaction as an objective is important: people will not accept the measures necessary to change the world unless they are satisfied as a result of those changes. Thus, maintaining human satisfaction and satisfying human preferences is a sustainability objective along with minimizing resource consumption. Economics also ties into the human satisfaction component of sustainability – within the current paradigm of economics-driven society, no human satisfaction is likely to occur without ensuring that economic interests are protected.

Finally, causing minimal negative environmental impacts (as well as maximizing positive impacts) is an important objective of sustainable material selection, since the environment consists of ecosystems whose ongoing health is essential for human survival on Earth (e.g., Goodland 1994, etc.). For reasons of biodiversity, continued biomass generation and photosynthesis, and potential for future human needs for ecological resources, sustainability of the human race requires that ecosystems be protected and preserved in a respectable state of health.

Thus, a measure of sustainability for material selection includes consideration of the level of resource consumption, the degree to which human satisfaction is achieved, and the net level of negative environmental impacts. In the following sections, these measures will be used to evaluate the principle of sustainable design which advocates the use of indigenous materials, and to define a range or scope of applicability for the heuristic.

3.0 Range of Applicability of the Indigenous Materials Heuristic

The thesis of this paper is that the indigenous materials heuristic does not yield the most sustainable material choice under certain conditions. The definition of sustainability developed above, along with the three objectives of sustainable material selection, will be used in this section of the paper to outline a range of applicability within which the indigenous materials heuristic may be used effectively for material selection.

3.1 Relationships to Sustainability Conditions

Three factors from the objectives of sustainable material selection are **hypothesized** to vary according to the degree of non-indigenous material use: quantity of resources used for "overhead," net negative environmental impact, and degree of human satisfaction. Note that non-indigenous material use, rather than indigenous material use, is used in the figures so that increasing along the horizontal axis corresponds to obtaining materials farther and farther away from the site where they will be used. In addition, it is assumed that the scope of material harvest increases with degree of non-indigenous resource use. For example, the lowest value on the indigenous material use scale might correspond to an individual landowner harvesting stones on his property to build a small stone wall, whereas the higher values might represent a commercial timber company harvesting an entire forest. Finally, note that all figures are not to scale. These hypotheses are currently being tested using simulation models as a part of the author's ongoing research.

3.1.1 Embodied Energy vs. Non-Indigenous Resource Use

In Figure 1, a hypothetical relationship between the quantity of material and energy resources used for "overhead" vs. the degree of non-indigenous resource use is shown. In this comparison, embodied energy or overhead resources typically include materials and energy used for harvesting, transportation and processing of the material, including the share of the materials and energy used for the infrastructure facilities themselves, proportional to the harvested material's "share" of those facilities.

In region A of the curve, harvesting is assumed to be occurring in an area where no harvesting infrastructure currently exists. In this instance, the curve increases steeply as the most indigenous materials are sought, since the new infrastructure required to harvest the material in the most indigenous case is likely to also have to be the farthest distance from existing infrastructure. The shape of this curve will vary significantly with the scope of the harvest effort. For example, a stonemason harvesting enough rocks in a field for a small stone wall can probably get by with a pickup truck, a pry bar, and no road. However, if the mason wants to harvest enough for a whole structure in a reasonable amount of time, a larger truck may be required. Consequently, a road may have to be cleared to accommodate the larger vehicle and the area of harvest may have to increase, requiring more effort both to collect the stones and to get the truck to where the stones are.

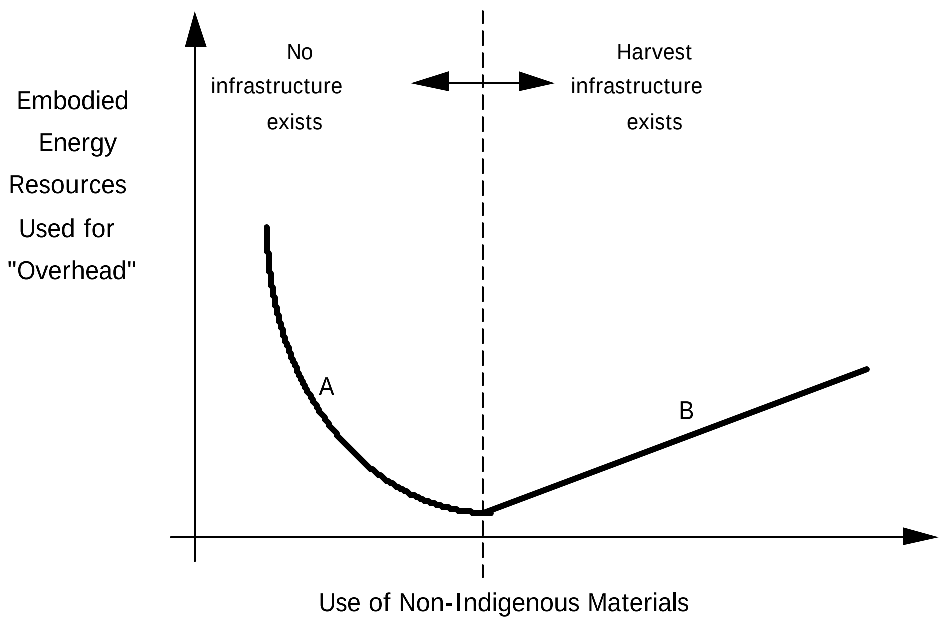

Figure 1: Quantity of Resources Used for Overhead vs. Use of Non-Indigenous Materials

Region A of the curve is also dependent on the degree of processing required by the materials between harvesting and use. However, practitioners often limit their definition of indigenous materials to include only those materials which require very little processing, with what processing is required to be done by hand, and with only hand tools as infrastructure. This bias of practitioners to consider only relatively “primitive” materials to be indigenous is not reflected in the shape of the curve in region A of Figure 1. The steepness of the curve has been hypothesized to reflect the possibility for indigenous materials to receive large amounts of processing on site, to rival the technological attributes of their non-indigenous counterparts and to overcome one of the biggest barrier to indigenous resource utilization: the primitive nature of the resources on site.

In region B of the curve, harvesting, transportation and processing infrastructure are assumed to already exist – a reasonable assumption in many developed countries. In this case, the linear slope of the curve reflects the increase in transportation costs and energy consumption proportional to increased transport distance. In the hypothetical curve, no differentiation is made between probable modes of transport with respect to distance and the relative efficiency of those modes in terms of resource consumption. In the simulation testing of these hypothetical curves, this differentiation will be included in the model, based on efficiencies and mode selection versus distance likelihoods found in the literature.

Finally, no adjustments were made to the hypothetical curve to reflect the embodied energy effects of economy of scale. This adjustment was not made since it was unclear how scale of effort would impact generation of waste – a significant source of resource consumption in harvest and processing. However, the existence of infrastructure in region B of the curve likely means that additional economies will occur in terms of energy consumption, since a reasonably well-optimized process is assumed to be already established and no learning or further adjustment will probably be necessary.

3.1.2 Net Negative Environmental Impacts vs. Non-Indigenous Resource Use

In Figure 2, a hypothetical relationship between net negative environmental impacts and degree of non-indigenous resource use is shown. In this hypothetical relationship, net negative environmental impacts are assumed to stem from human intervention in natural ecosystems during the harvest of raw natural resources from those ecosystems. While the possibility of positive impacts on ecosystems due to human intervention exists, the likelihood of such positive impacts occurring during harvest of natural resources is assumed to be negligibly small. Negative impacts are assumed to be proportional to the scope of the harvesting effort, which is presumed to increase directly with degree of non-indigenous material use.

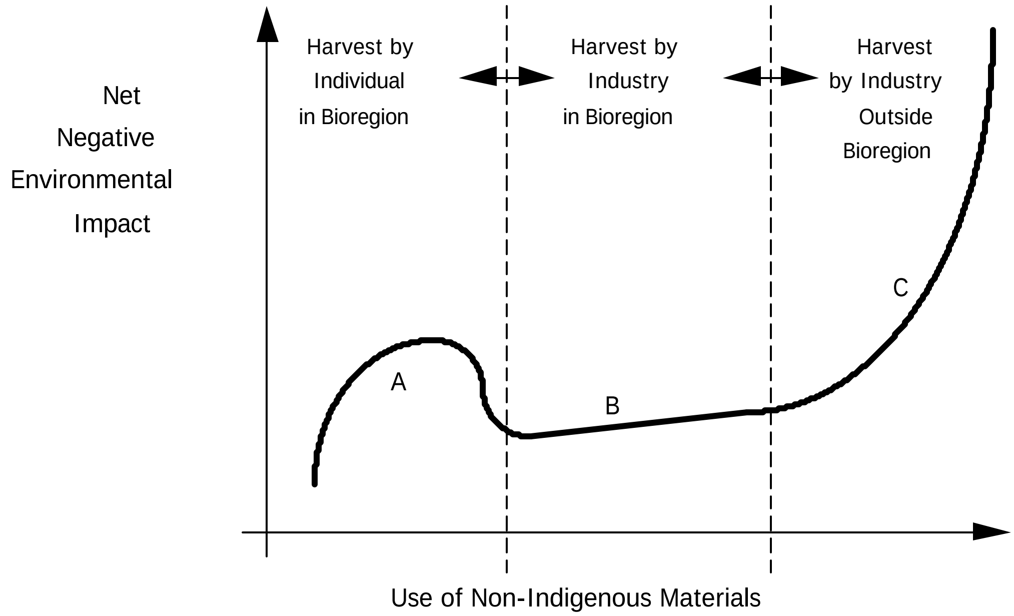

Figure 2: Net Negative Environmental Impact vs. Use of Non-Indigenous Materials

In region A of the curve, the small peak which occurs as use of non-indigenous materials increases is hypothesized to occur as the scope of harvest for the individual landowner/harvester increases. The peak reflects the probable learning curve which will occur with the harvester as the scope of the harvest progresses past the point where simple or familiar infrastructural tools will suffice to undertake the scale of operation desired. For example, as the stonemason realizes a need for more stones than can be harvested with a pry bar and pickup, he or she may decide to rent or purchase a heftier implement like a hydraulic excavator to facilitate harvesting larger quantities of stone. In the process of learning to operate the excavator and developing a procedure for using it to harvest stone, the mason may initially wreak a lot of environmental havoc due to being a novice, but will eventually improve the efficiency of the process, and hopefully reduce the resulting negative environmental impacts to a more reasonable level.

In region B of the curve, harvesting is done within the same bioregion as eventual use, but is of a large enough scope that it is undertaken by some commercial or industrial entity, not by an individual. In such cases, a certain amount of transportation is required, since the site where the material will be used is likely to be some distance from the site of the harvest or processing site;

however, the material remains within the same bioregion throughout its life cycle. The increasing slope of the hypothetical curve in this region reflects those indirect transportation impacts, as well as the assumption that the scope of the harvest and the resulting negative impacts will increase as the harvest approaches the threshold of expanding beyond the bioregion and becoming non-indigenous.

In region C of the curve, harvesting of the material occurs outside the bioregion, and is assumed to be of an industrial scale. As the scale of the harvest increases, the resulting negative environmental impacts increase nonlinearly, since impacts no longer affect just portions of ecosystems but rather entire ecosystems or bioregions, reducing the assimilative and recovery capabilities of the affected ecosystems.

Two other significant impacts on the mean values of the curves in each of the three regions relate to the psychological investment of the harvester in localized resources. First, for harvesting done within the same bioregion as eventual use, there is an inherent motivation to minimize negative environmental impacts, given some awareness of how those impacts will influence the future health of the bioregion, upon which the harvester is dependent. This motivation does not necessarily exist for harvesting done outside the bioregion of use. Dissociation between the effects of harvest and market demands for the products of the harvest makes including feedback about negative environmental impacts in material selection decisions extremely difficult. By limiting selection to indigenous materials, this feedback has a much better chance of being received and considered in the selection process.

Second, the nature of the party undertaking the harvest effort affects the nature of external environmental standards which may be imposed on harvesting efforts. While many policy efforts have been devised to regulate environmental impacts of projects undertaken by industry, relatively fewer such tools exist to impose environmental standards on the individual landowner/harvester. Those regulations which do include individual harvesters within their scope of jurisdiction rely largely on an awareness of the activities of those harvesters which may not always be easy to acquire. Keeping track of industrial-sized efforts undertaken by corporations is much easier than trying to monitor the activities of individuals and impose some consistent standard for environmental impact mitigation on each of them. Thus, the status quo of environmental regulation favors imposing standards on large-scale efforts, and letting impacts from small-scale efforts slip through the cracks.

3.1.3 Human Satisfaction vs. Non-Indigenous Materials Use

In Figure 3, a hypothetical relationship between the degree of human satisfaction as it may depend on degree of non-indigenous materials use is presented. In this admittedly highly speculative relationship, the human satisfaction scale is intended to reflect human preference for the resulting artifacts which are constructed using materials of various degrees of indigenousness. In the lower end of region A of the curve, materials are assumed to be harvested at or near the eventual site where they will be used, by the person who intends to use the materials in construction. The reason for the higher degree of satisfaction in this region is hypothesized to reflect the personal satisfaction which likely results from harvesting one's own materials and incorporating them into an artifact or facility in which one has a vested interest. The curve is assumed to decrease as the scope of effort increases, due to the decreased probability of personal vesting of interest due to involving others in the project or using more sophisticated tools to harvest, process and incorporate the materials into the built facility. This hypothetical relationship is based on what the author calls the "I built it with my own two hands" phenomenon, where psychological investment in a project is related to the amount of personal and independent effort one puts into the project.

A parallel explanation for the higher values of human satisfaction in region A is the architectural idea that a certain symbiotic effect occurs when indigenous materials are used for built facilities. This effect is presumably due to the fact that the materials are naturally suited to the unique characteristics of the site and region where the facility is located, and result in a more "appropriate" artifact than one constructed from imported materials, with little or no regard for the natural and unique characteristics of the site (e.g., Day 1990, etc.).

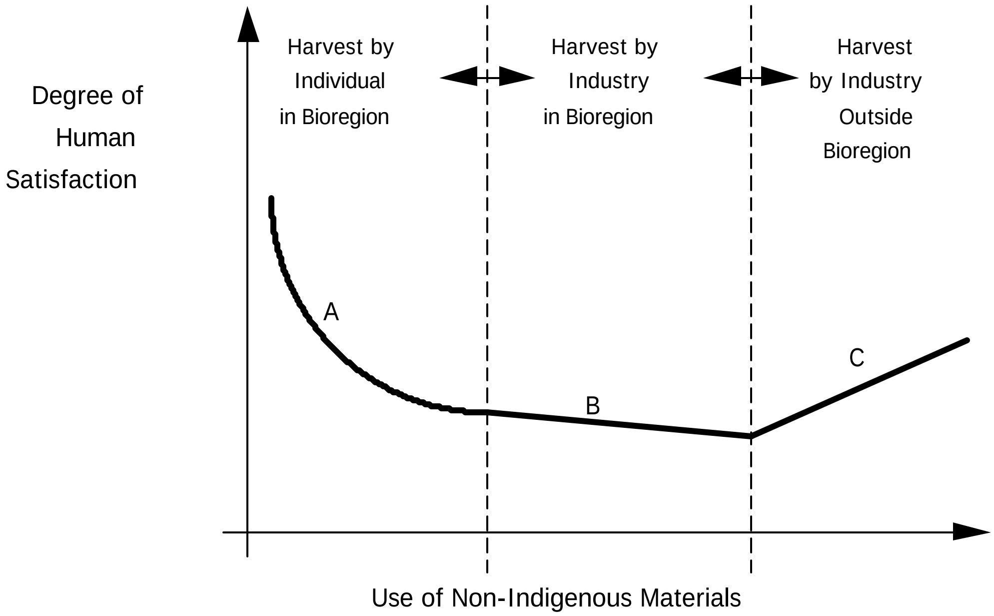

Figure 3: Degree of Human Satisfaction vs. Use of Non-Indigenous Materials

In region B, human satisfaction is hypothesized to decline with increased distance within the bioregion between harvest and use sites. This decline is based on the hypothesis that vested interest in the source of the material will decrease with increased distance from the harvest site. Conversely, in region C, human satisfaction is expected to increase with distance of the origin site of the material from the bioregion. The rationale for this hypothesis is a largely undocumented relationship linking human preference with exotic items. The author has been unable to find any studies to date which substantiate these hypothetical relationships between satisfaction and use of indigenous materials, indicating an opportunity for empirical research in this area.

3.2 Implications of the Indigenous Materials Heuristic

Attempting to utilize indigenous materials as a rule of thumb for achieving sustainable architecture and construction has many implications. As shown in the previous section, the relationships between sustainability goals and indigenous material use are not at all straightforward. While combining the variables into a single model is beyond the scope of the present paper, it should be clear from Figures 1, 2 and 3 that a composite model of sustainability vs. indigenous material use would be far more complex than the simple linear or binary relationship implied by the indigenous materials heuristic.

Even without mathematically investigating the nature of the combination, however, some useful insights can be gained from reflecting upon the relationships presented in the previous section. In the following subsections, an attempt is made to outline some of the issues which are inherent in the complex relationship between sustainability and indigenous material use, in terms of the four dimensions of sustainability proposed by Carpenter: technology, ecology, economics and ethics (1994).

3.2.1 Technology

Technology consists of all the tools, techniques and knowledge accumulated by humankind in the course of its existence to date. In the realm of construction materials, technology provides one distinction between indigenous and non-indigenous materials, at least in the eyes of some practitioners. From this perspective, indigenous materials are defined as those materials which can be extracted on site and used with a minimum of technological intervention in the construction process. In not so many words, indigenous materials are "low-tech," and include such substances as adobe, straw bales, and rammed earth (e.g., Dry 1986, Moquin 1994).

This state of low technology is not necessarily bad in terms of sustainability. In fact, the fewer technological processes to which a raw material is subjected, the higher its overall exergy remains, and the lower its entropy level stays. In terms of the second objective of thermodynamic sustainability described above, low-tech materials are more sustainable than high-tech materials in one sense, because they have lower entropy and higher exergy.

In another sense, however, low-tech materials do not meet all of the contextual requirements of sustainability in today's anthropocentric context. In some cases, particularly where human priorities have developed unsustainably as a result of cheap energy (Van der Ryn and Calthorpe 1986), high-tech materials are required to minimize the consumption of resources under conditions which would ordinarily be unsustainable. For example, from an energy standpoint, putting large windows in a house situated in a cold climate is unwise and potentially unsustainable, given that ordinary windows allow large heat losses and there exist finite constraints on energy resources for heating. Yet humans are dissatisfied without windows in their houses, no matter in what climate they live. As a result, humans have undertaken to improve window technology to improve its energy efficiency, with dramatically successful results.

The window example shows how in cases where human preferences override pure sustainability constraints, technology serves the useful function of providing fixes to resolve such conflicts. Technological fixes are not without their price, however. As previously noted, as materials are processed and transformed, their entropy increases and their exergy decreases. Thus, technology serves as an essential, but limited, mediator of tradeoffs when conflicts exist between sustainability objectives.

3.2.2 Ecology

Ecology is the dimension of sustainability which is concerned with the natural environment, the context in which all human activity ultimately exists. All resources available to humans originate in the natural environment, and the Earth's ecological systems serve as both the source of energy to affect material transformations as well as the receptacle or sink to absorb the direct and indirect effects of those transformations.

As shown in region B of Figure 1, indigenous materials in general use fewer energy and material resources for transportation and processing "overhead" than their non-indigenous counterparts, especially when the infrastructure for harvesting, processing and transporting those materials is already in place. The potential for environmental degradation is highly dependent on the scale of material harvest and use as well as the context in which the harvest occurs. For example, in a relatively sparsely populated region, harvesting some of a particular material may be well within the carrying capacity of that material within its ecosystem, and thus the harvest may be sustainable. However, increasing the scope of the harvest may push the ecosystem beyond its carrying capacity by creating a level of environmental degradation which is unassimilable, rendering the harvest unsustainable. Moreover, increasing the human population or activity in the area may mean that a far smaller harvest is possible without crossing the line into unsustainability, due to the additional stresses placed on the ecosystem by the larger population and the competing demands of those others for the same resources.

Other ecosystem impacts may result from selecting indigenous as opposed to non-indigenous materials. An important effect on ecosystems which results from indigenous resource use is the psychological and physical self-interest people have in the health of the ecosystems by which they are directly affected. According to this theory, people will likely be more concerned about the natural environment directly around them than about ecosystems farther away. If resources come from the same ecosystem in which people themselves are located, the people may structure their use of the resources so as to minimize environmental degradation of that ecosystem. On the other hand, if resources originate in a remote ecosystem, less opportunity exists for feedback about the effects of resource harvest on the remote environment, and people are less likely to care about any negative effects because those effects are unlikely to impact them directly.

3.2.3 Economics

Although not shown directly in any of the preceding figures, economics is an integral factor in the selection and specification of construction materials. For example, the cost of materials is directly related to the amount of energy used in their harvest and production. While at first glance the use of indigenous materials seems to have immediate economic appeal, in fact the economics are quite complex. In many cases, indigenous materials are nearly free, at least in terms of their direct cost to the landowner. When they can be harvested and processed by hand or with tools that the landowner already owns, indigenous materials require no direct outlay of money to procure, only lots of back-breaking labor. Yet if harvesting the materials requires creating access infrastructure or obtaining special tools, the small scale of harvest may make such investment foolhardy. Sheer economy of scale often makes materials harvested commercially cost less than indigenous materials, at least in appearance (because often social and environmental costs are subsidized). And if the landowner is not inclined to expend his or her own labor to harvest the materials, hiring labor to harvest the material may make indigenous materials even less economically attractive.

One reason that manufactured materials may often appear to be less expensive than local materials is the fact that their prices do not reflect the true social or environmental costs of harvesting and producing the material (Ruckelshaus 1989). Particularly where transportation costs are involved, the fact that most transportation infrastructure is heavily subsidized by federal tax dollars disguises the true magnitude of production costs and spreads those costs over the entire population. A similar problem exists when materials are harvested from publicly owned lands at less than market price - the true economic cost of those raw materials is shifted onto future generations who will not have access to them. (e.g., Kothari 19??).

The life cycle energy efficiency of indigenous materials is an additional economic consideration. Operational costs of a facility are strongly influenced by the amount of energy needed to heat, cool, and provide light and other services for the facility. For certain applications, the life cycle energy efficiency of available indigenous materials is far overshadowed by that of more technologically advanced, industrially processed materials (Dry 1986). Windows are an excellent example of such an application. If a homeowner desires to put windows in his or her house, very few indigenous materials will suffice in any but tropical climates. And in the temperate and cold climates where much of the population is located, nothing but engineered and manufactured windows will work with any degree of energy efficiency at all. Thus, any cost savings that might be realized initially by using low-tech materials will quickly be overcome with higher operating costs.

3.2.4 Ethics

From an ethical standpoint, indigenous materials act as a socioeconomic equalizer. When materials are available locally and can be harvested at little or no cost by the people who need them, these indigenous materials may solve the problem of intragenerational inequity by providing the means for otherwise underprivileged people to construct housing and other facilities for themselves without other technological or economic intervention. For example, Dennis Weaver's Earthship house in Colorado is constructed out of rammed earth contained by scrap tires. The tires for the Earthship were obtained for free from facilities who were unable to find any other suitable disposal method, and the soil was obtained on site from the excavation of the foundation of the house (Weaver 1990).

Aside from considerable low-tech labor investment (lots of hours with a sledgehammer and wheelbarrow), the construction costs of Weaver's house structure were almost zero. Although the Earthship used a roofing system which required the use of timbers, current research in dome structures and other innovative roofing systems might make an Earthship-like structure possible using materials taken only from on-site and from waste streams. The low cost of materials for such a structure would seem to make it feasible for meeting housing needs all over the world, since soil is generally available everywhere and a large reserve of scrap tires exists in industrialized countries. Since lack of suitable housing is one of the most pressing problems in developing countries, using soil for building structures is a potential way to use indigenous materials to address the issue of intragenerational inequity (Dry 1986). And using indigenous materials empowers individuals by reducing their reliance on externally manufactured products for which they have to pay directly.

In addition, harvesting of materials on a localized scale encourages responsible use of resources more so than does harvesting on a commercial scale by faceless corporate entities. Harvesting done on a large scale by industrial organizations can often be controlled by entities within the organization who have no direct contact with harvesting efforts, and who may not ever even see the operations they control. Such remote control of harvesting lengthens the feedback loop which enables awareness of negative impacts, and allows greater opportunity for errors in the feedback cycle. Moreover, decision making and strategizing can occur on a strictly economic and legalistic basis, without any consideration for impacts of the decision which do not appear on the balance sheet or which go unreported by links in the feedback loop. Harvesting of indigenous materials by individuals puts people directly into contact with the effects of the harvest on the land, forcing awareness of those effects to the forefront of the individual's consideration. Accompanied by a land ethic such as proposed by Leopold (19xx), individualized or localized harvest of materials should promote greater conservation of the source land, and fewer negative environmental impacts.

On the other hand, trying to specify what materials people should use for building their facilities has some negative ethical implications. Some might argue that if policy mechanisms are used to ensure that market prices of materials reflect the total social and environmental costs of those materials, then the market itself will ensure the optimal harvest and use of materials (Pearce 1988). Some externally imposed standards will be essential to ensure that the harvest of indigenous materials does not create excessive environmental degradation. Such degradation, while most likely not intentional, will undoubtedly result as the individual harvester tries to learn the best way to harvest materials, or out of sheer ignorance of potential negative effects which are not immediately apparent.

3.3 The Sustainability of Indigenous Materials

As may be apparent after reading the previous discussion, no clear answer currently exists to the question of whether the use of indigenous materials is more sustainable than current patterns of material use. The importance of context is paramount in deciding the answer to this question, particularly in terms of the existence of infrastructure for harvest or transportation. What can be clearly stated, however, is that it is more sustainable to use materials which:

1) have the lowest possible life cycle consumption of matter and energy
2) have minimal net negative impacts to the natural environment
3) maintain some reasonable level of human satisfaction.

In general, using indigenous materials reduces the quantity of resources expended on transportation costs. By reducing the scope of harvesting and processing and transferring responsibility from the corporation to the individual, the use of indigenous materials may reduce the net level of negative environmental impact, and may increase the net level of human satisfaction by empowering people to provide building materials for themselves. As such, the use of indigenous materials may be more sustainable than using other commercially produced materials. However, in some cases commercially produced materials may prove to be more energy efficient over the whole product life cycle in the intended context of use, may require less investment in new harvesting infrastructure, or may simply be much more highly preferred by humans. In these cases, the commercial materials may be more sustainable than their indigenous counterparts under the definition in section 2.0.

3.4 Policy Options to Extend the Scope of the Indigenous Materials Heuristic

The complexity of issues surrounding indigenous material use as discussed in the previous sections suggests many opportunities for policy improvements. While the most sustainable policy action might be to directly command large commercial industries to reduce the scale of their harvest of materials and limit the scope of their operations to remain within individual bioregions, such a command and control strategy would no doubt cause a huge outcry from both the affected corporations themselves as well as consumers who developed needs and preferences for exotic goods freely distributed in a global market. Instead, less controlling strategies are necessary to help change consumer demands to favor more sustainable material choices (Rees 1990). Mobilizing consumer choice to influence sustainable material selection will naturally shape the market to favor those enterprises who use sustainable indigenous materials (Ruckelshaus 1989).

In particular, four policy strategies need to be implemented to realize the potential benefits for sustainability inherent in the use of indigenous materials. The following sections will discuss how the scope of indigenous materials use can be sustainably increased by promoting awareness of how human behavior impacts the natural environment and the sustainability of the human race, by changing market prices to reflect the true social and environmental costs of production, by requiring individual harvests of indigenous materials to meet minimum sustainability standards, and by changing building codes to permit more widespread use of indigenous materials.

3.4.1 Increasing Awareness of Links Between Behavior and Sustainability

Promoting an awareness of the connections between human behavior and the effects that behavior has on the natural environment is an essential desideratum of a sustainability policy. One of the most pervasive contributors to unsustainable behavior is the dissociation of the actor or perpetrator from the *effects* of his or her behavior. Accordingly, the goal of the first policy strategy is to develop mechanisms to reduce the opportunity for such dissociation and to increase awareness of all of the potential impacts of human actions, both immediate as well as long-term. The rationale for this strategy is that given the opportunity to choose the most sustainable course of action and a clear understanding of the utility of that course of action, humans will act in their own best interest and choose the sustainable course of action. Of course, before such clarity of understanding can be developed in the general populace, operational definitions and metrics of sustainability will have to be adopted, and a clear idea of the individual ramifications of unsustainable actions will have to be conveyed.

To make the public aware of unsustainable behavior, Hardin's idea of "mutual coercion mutually agreed upon" (1968) will be necessary. Fines and other economic disincentives will go a long way toward increasing awareness of unsustainable actions, and will make continued unsustainable behavior increasingly expensive. The most difficult part of this policy initiative will be to come to some mutually agreed upon definition of what is unsustainable behavior, although some standards such as Sweden's Natural Step program (Robert et al. 1994) are currently being developed which will provide an excellent move in the right direction.

A general strategy of education within existing school systems about the principles of sustainability and sustainable living would also be helpful in increasing awareness of the links between behavior and resulting effects or impacts on the natural and human environments. Techniques such as case-based education with examples of real cases which have had strong positive or negative impacts would serve to provide a basis for understanding the cause and effect relationships between human actions and intended and unintended environmental outcomes.

3.4.2 Changing Market Prices to More Accurately Reflect Total Costs

If we are to continue in our current market-based economic paradigm, market prices and evaluation metrics must be changed to reflect the total social and environmental costs of natural resource harvest and use. Currently, government subsidies serve to dramatically distort market prices by spreading costs for such services as transportation infrastructure and pollution regulation and cleanup over the entire base of taxpayers in the United States. Instead, these costs should be tied to the products for which they are expended, using mechanisms such as carbon taxes or user fees (Hawken 1994, Ruckelshaus 1989). In this fashion, consumers could make accurate product selections based on the true costs to society of those choices. Products such as indigenous materials which might be truly more sustainable would thus stand out in the market due to their lower environmental and social costs, and activities which conserved the base of natural resources would be reflected more favorably by economic indicators (Henderson 1994, Semple 1991, Faeth 1993).

3.4.3 Meeting Minimum Sustainability Standards for Individual Harvests

One of the most significant questions surrounding the sustainability of the indigenous materials hypothesis is the potentially greater net negative environmental impact resulting from dispersion of harvesting efforts, each of which may occur with lower efficiency and more environmental damage than would result from a unified, commercial harvesting effort. While these negative impacts may be counterbalanced by the potential for increased care with which individuals care for ecosystems of which they are a part, reliance on the ethics, awareness, and stewardship abilities of individuals to maintain the integrity of a commons such as an ecosystem is not necessarily a wise strategy (Hardin 1968).

Uniform policy initiatives are needed to impose and maintain minimum standards on individual indigenous material harvesting efforts. Although private landowners are currently regulated under a patchwork of regulations such as the Endangered Species Act and the Clean Water Act which affect the harvest of indigenous materials, most regulatory efforts are focused on commercial and industrial activities, while the actions of private landowners go largely unnoticed. Beginning with mechanisms for monitoring and tracking individual harvests, the proposed sustainability standards must ensure that individuals do not intentionally or unintentionally compromise the health of ecosystems by harvesting beyond the sustainable yield of the environment. In addition, programs of education for those who harvest sustainable materials would help to improve the learning curve for using new technologies as well as to ensure that harvesters are aware of the most current and least damaging techniques and tools for harvesting.

3.4.4 Changing Building Codes to Allow Indigenous Material Use

Finally, a need exists for reforming building codes and the processes used to change them, to allow for greater flexibility in adoption of innovative technologies and materials which may be more sustainable. Many types of indigenous materials fall into this category of materials which are ignored or prohibited by existing codes. The sheer amount of time required for change, along with institutional inertia, strongly inhibits changes in building codes and accepted standards (e.g., National Audubon Society 1991, Moquin 1994). The lack of uniformity in building codes from one location to another makes each instance of innovation a new battle; even though new technologies may have been tested and proven successful in other parts of the country, nothing says that the local building inspector will approve the technology in his or her jurisdiction (Weaver 1990).

Policy reform is needed to address building code development and enforcement processes. While the uniqueness of codes and enforcement from area to area has the potential to allow the needs of each jurisdiction to be specifically addressed, greater uniformity of codes would permit proven technologies in one region to be acceptable in other regions without encountering unnecessary resistance from the code enforcers who may resist innovation because it is unfamiliar. In addition, demonstration facilities in various areas and educational programs would also help to convince building code officials of the acceptability of innovative or nontraditional materials and technologies (Moquin 1994).

4.0 Discussion

In this paper, the range of applicability of the indigenous materials heuristic has been explored. Beginning with a goal-based definition of sustainability that incorporated minimizing entropy gain and limiting environmental degradation while maintaining human satisfaction, a set of operational objectives for selecting sustainable materials was developed. A set of hypothetical relationships between the use of indigenous materials and embodied energy, negative environmental impact, and human satisfaction were presented and substantiated, and representative issues related to use of indigenous materials with respect to technology, ecology, economics and ethics were discussed. Several policy objectives to increase the scope of applicability of the indigenous materials heuristic were proposed.

The hypothetical relationships presented in this paper are suspected to be heavily dependent on population density and subsequent proximity of material harvest sites to transportation and other infrastructure. If global human population does not stabilize but continues to increase, the distribution of population across the globe will approach a state of uniform density, and the effects in the curves in Section 3.1 which are attributed to distance of harvest sites from transportation infrastructure will likely disappear. However, this point may well be moot if population exceeds a certain threshold, since high enough densities of human population over large enough areas are certain to overwhelm the natural ecosystems which ultimately support human existence (e.g., Rees 1990). The exact nature of the relationship between the sustainability of indigenous resource use and increasing human population is unknown; however, we may be certain that continued population growth will limit the options available to us as we attempt to move toward sustainability in the future (Goodland 1994).

4.1 Directions for Continued Research

The research described in this paper is part of an ongoing effort to develop a methodology for selecting sustainable construction materials. Although the relationships presented here are still hypothetical, simulation testing is currently underway to refine the nature of those relationships, and additional empirical testing of the hypotheses is planned for the future.

In particular, research efforts will be directed toward isolating the relationship between scope of harvest and feasibility of indigenous resource use. This relationship is expected to be strongly dependent on whether indigenous resource use is limited to harvesting on site or within the same bioregion as eventual use. An examination of the human preference hypothesis, while expected to be heavily dependent on cultural context, will also be undertaken to determine the essence of the relationship between satisfaction and use of indigenous vs. exotic materials. Finally, determination of the nature of any symbiotic effects of indigenous architecture on human welfare is another direction for future research in this area.

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