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SYSTEMATIC EVALUATION AND ASSESSMENT OF BUILDING ENVIRONMENTAL PERFORMANCE (SEABEP)

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ABSTRACT

Escalating global environmental deterioration is due in significant part to buildings’ share of total environmental burdens - ranging from 15 to 45% of the eight major environmental stressor categories. Therefore, improved building environmental performance could substantially reduce harmful anthropogenic environmental impacts. Previous efforts to address buildings’ environmental impacts often lack a science-based approach and claims of “sustainability” or “green design” are often unsupported. Building design professionals set *de facto* environmental priorities by addressing a sub-set of environmental issues without articulating environmental goals and priorities. Optimizing total building environmental performance requires weighting environmental concerns to inform decisions. An approach to “systematic evaluation and assessment of building environmental performance” (SEABEP) is proposed. SEABEP includes characterizing the magnitude of buildings’ contribution to environmental problems, weighting the most important environmental problems, and establishing sustainability criteria. SEABEP can be used alone or with existing methods to improve building environmental performance.

INTRODUCTION

Many building design professionals are now involved in “green” building design or “sustainable design” in response to expressed interest or requirements from their clients, regulations, or their own intention to reduce human impacts on the environment - local and global. This appears to be occurring more frequently in Europe and North America. . The trend toward environmental protection is gaining public support and momentum [1]. Social and political forces will bring additional pressure for more environmentally-sound technological decisions and regulations that protect the environment In the future, economic criteria and regulatory mandates are likely to motivate more and more designers’ clients, building owners, and other public and private organizations to create “environmentally-responsible” buildings. As this occurs with increasing frequency, designing buildings with low environmental impacts will offer new opportunities for developers, product manufacturers, and others in the building industry. It is becoming clear that many environmentally preferable solutions, (e.g., using recycled steel and aluminum in building products) are also economically preferable.

To date, efforts to implement so-called “green” design practices have consisted largely of adoption or eclectic adaptation of various technologies and solutions to perceived environmental problems [2]. Some examples are listed in Table 1.

Energy conservation features: insulation, efficient lights and mechanical equipment
Solar energy utilization: passive space heating, cooling; water heating; photovoltaic electricity
Water conservation features: low consumption fixtures, gray water use
Incorporation of recycled materials, or materials with large fraction recycled content
Low emitting material selection and ventilation for improved indoor air quality
Reduced building construction waste and re-sourcing waste products
Less environmentally-destructive site development: run-off control, small footprint, preservation of water courses, natural vegetation and habitats
On-site wastewater treatment
Reduced or zero use of ozone-depleting compounds in refrigeration and fire suppression systems
Life cycle assessment (LCA) ("cradle-to-grave") of materials or building systems
Formal (regulatory) environmental impact assessment of the total building project
Recycling provisions (in building design) for occupants

Table 1. Common "Green Building" Features

In any design, trade-offs are made among alternative solutions aimed to optimize building performance for various objectives. Environmental objectives are diverse, complex, inter-connected, and, not infrequently, conflicting. Local, regional, and global objectives often conflict. Reducing impacts on one problem (e.g., air pollution) may increase impacts on another (e.g., solid waste generation). Typically, each building design-for-environment feature addresses one problem and initially appears environmentally beneficial. Life cycle assessment inventory analysis of the pre-use phase of a product may be used for decisions. The analysis is performed semi-quantitatively while use-phase environmental impacts are assessed qualitatively with the frequent exceptions related to energy, water, and waste. No comparison of the relative importance of energy consumption versus other environmental impacts such as water consumption, soil erosion, habitat destruction, or wastewater production is performed. There is no basis for weighting the various impacts.

To optimize performance of a building material, product, or system, it is necessary to weight environmental impacts, normalize sources of similar impacts, and calculate the total environmental performance in order to select the most preferable alternative. Also, sustainability criteria must be established to determine the performance of alternatives. There are no *a priori* environmentally benign products [3]. A more comprehensive evaluation is required to assess confidently the environmental performance of a particular design. Implementation of some or all the features listed in Table 1, although often labeled "green" design or "green building," are also promoted as "sustainable design" or sustainable building without evidence to support these claims.

Discussions, advice, directions, and even rating systems for environmental performance of building features abound. Scoring is implicitly or explicitly based on implied environmental goals. No method assesses trade-offs among various environmental objectives. These approaches, most notably BREEAM [4], BSRIA [5], and BEPAC [6], offer guidance to those lacking any other basis for choosing less environmentally harmful building technologies. But they lack an adequate basis to determine whether a particular design element is "sustainable" or environmentally benign from a comprehensive perspective.

Until recently no comprehensive effort has established a systematic approach for evaluating total building environmental performance. Two notable exceptions are "Building for Environmental and Economic Sustainability" (BEES) (being developed in the USA by NIST and EPA) [7], and EcoQuantum (being developed in the Netherlands by W+E

Consultants and the University of Amsterdam) [8]. Both are comprehensive in their scope, but neither addresses the problem of prioritizing environmental problems.

METHODOLOGY: TOWARDS A SUSTAINABLE BUILDING PRACTICE

Buildings are very large contributors to environmental deterioration. Buildings contribute from 15% to 45% of the total environmental burden for each of the eight major LCA inventory categories [9]. Determining buildings' contributions allows prioritizing generic environmental protection goals (discussed later in this paper). Table 2 shows an estimate of these contributions based on data from the United States. The portion of buildings' environmental impacts is generally consistent throughout the world [10].

RESOURCE USE	*% OF TOTAL*	*POLLUTION EMISSION*	*% OF TOTAL*
Raw materials	30	Atmospheric emissions	40
Energy use	42	Water effluents	20
Water use	25	Solid waste	25
Land (in SMSAs)	12	Other releases	13

Table 2. Environmental Burdens Of Buildings, U.S. Data [9]

Systematic Evaluation and Assessment of Building Environmental Performance

To address the shortcomings discussed above, we have developed SEABEP (shown in the diagram in Figure 1) SEABEP is based on building ecology, defined as the study of the dynamic inter-relationships of buildings to their occupants and the larger environment [11]. SEABEP addresses the need for comprehensive performance evaluation and assessment based on life cycle assessment, comparative risk assessment, and industrial ecology [3, 7, 8, 12-21].

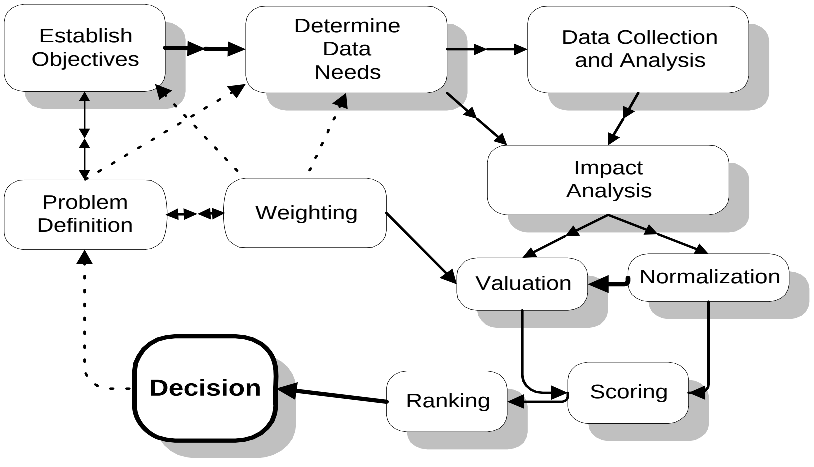

Figure 1. (SEABEP) Decision Model

Each step in the SEABEP process is important. The weighting step, while fundamental, is generally absent from most methods. When explicit weighting of environmental problems is absent, all problems are implicitly weighted either equally or their relative weights reflect *ad hoc* choices of the decision-maker. Industrial ecology and even life-cycle assessment approaches tend to avoid weighting, although Lindeijer has advocated that weighting be included [22]. Approaches that award points to guide design-for environment (such as BREEAM) have implicit weighting, but no systematic basis for the weighting (if any exists) is described. The EcoIndicator approach includes explicit weighting and details of its derivation [20-21]. Because it is limited to a European context and analysis, it tends to undervalue global environmental problems and emphasize European ones.

Weighting environmental problems should be done on a global scale and on a local or project scale [22]. The scale will affect the results. It is important that both global and project-specific weightings be applied and that any conflicts be addressed. The first four criteria shown in Table 3 were adapted from EPA's Science Advisory Board (*Reducing Risk*) [13] and the fifth was added by us to account for the building context. These criteria were applied to develop the generic global weightings shown in Table 4. The global weightings provided in Table 4 can be used as "default" values, or an original set can developed by the project team. The local or project specific weightings must be developed by the project team.

THE SPATIAL SCALE OF THE IMPACT (Global, regional, local - large worse than small)
THE SEVERITY OF THE HAZARD (More toxic, dangerous, damaging being worse)
THE DEGREE OF EXPOSURE (Well-sequestered substances being of less concern than readily mobilized substances)
THE PENALTY FOR BEING WRONG (Longer remediation times of more concern)
THE STATUS OF THE AFFECTED SINKS (An already overburdened sink more critical than a less-burdened one. Sinks = receptors, or environmental compartments).

Table 3. Criteria for Weighting Environmental Problems

The valuation of various environmental problems requires construction of a problem list that is both comprehensive and not too detailed. The proposed list and "strawman" generic weightings in Table 4, together with a set of either locale- or project-specific weights (developed by those involved in a specific project) can be used in quantitative ratings for environmental decision-making.

Environmental Problem Category	*Weighting*
Habitat destruction / deterioration (Biodiversity loss)	90
Global warming	80
Stratospheric ozone depletion	90
Soil erosion	20
Depletion of freshwater resources	10
Acid deposition	25
Urban air pollution / smog	25
Surface water pollution	25
Soil and groundwater pollution	35
Depletion of mineral reserves (esp. oil and some metals)	50

Table 4. Weightings for ten environmental (ecological) problems

A similar set of weights could be developed for a list of environmental problems with direct human impacts, such as indoor air pollution, worker exposure to toxic chemicals, etc., or, ideally, a single weighting system integrating both ecological and human health environmental problems could be used. An integrated list will require further development to achieve consensus on individual, value-based concerns.

Sustainability Criteria for Design Analysis

There are several possible approaches to developing sustainability criteria. Each has its shortcomings, either involving the need for scientific knowledge or data that aren't available or requiring value-based judgments that vary among individuals, cultures, and locations. Nevertheless, each approach leaves "transparent" the basis for the criteria and, therefore, can easily be revised by applying new or different data, knowledge, or value judgments for a particular project. Among the bases considered here are socio-ecological indicators [23], ecological carrying capacity [18], and I=PAT [24] among others. The last two are similar in that they both establish acceptable levels of consumption and pollution-generation based on assumed levels of sustainable environmental impacts. The first is different and will be discussed later.

By calculating the effects of combinations of projected population growth rates, per capita consumption rates, and environmental impacts per unit of consumption, one can assess in gross terms the seriousness of the coming crisis. Projected global population growth and consumption form the basis for estimating the level of environmental impacts to be addressed by technological improvement and/or reduced consumption. In 2050, projected population is 1.3 billion and 8.7 billion in industrialized and developing countries respectively.' Assuming a 2.5% and 3.5% annual growth rates in consumption in industrialized and developing countries respectively results in a doubling and a quadrupling of consumption in industrialized and developing countries respectively. The result is a 350% increase over current consumption levels.

If current levels of environmental stressors (e.g., greenhouse gas emissions, soil erosion, acid deposition, mineral consumption, etc.) are approaching the limits of the earth's carrying capacity, then significant reductions in these stresses will be required to accommodate expected growth in population and consumption. A major uncertainty that limits this approach is the insufficiency of scientific data on environmental problems other than for global climate change and ozone depletion. Even the seriousness of these environmental problems remains controversial, if not among most scientists, at least among policy-makers in industrialized countries [24]. Other problems such as soil erosion, habitat destruction and biodiversity loss are subject to political and regional differences and insufficient scientific knowledge. Most other global environmental problems are also insufficiently characterized from a scientific perspective.

Determinations of sustainable impacts require value judgments often considered outside the purview of scientists. However, such value judgments are implicit in many of the requisite components of human or ecological risk assessment [25]. By ignoring them, scientists are accepting values, not avoiding value based methods. The issues of social, generational, and genetic justice are at the heart of any risk assessment and are identified by Azar *et al* as indicators of their fourth socio-ecological principle (discussed below) [23]. These issues are important to any effort to define sustainability criteria or prioritize environmental goals. Perhaps this is why most definitions of sustainability are either vague or non-quantified.

A different approach, proposed by Holmberg *et al* in Sweden avoids focusing directly on environmental impacts because, the authors assert, impacts are complicated, delayed, and difficult to assess [23, 26]. These Swedish authors argue that there are anthropogenic actions that affect the environment for which establishing acceptable rates based on four simple principles is reasonable. These four principles are the basis of several indicators for each. These indicators, shown in Table 5, given by Azar *et al* as mathematical formulas [23], can be used to calculate criteria for most technologies including building technologies. The criteria from Table 5 can be applied as sustainability criteria to develop targets for decisions affecting the environmental impacts of a building material or product, a whole building, or collection of buildings. The target values can be used in the "normalization" phase of methods based on life cycle assessment or as "benchmarks" in other evaluation methods.

Principle 1: Substances extracted from the lithosphere must not systematically accumulate in the ecosphere	$I_{1.1}$: Lithospheric extraction compared to natural flows
	$I_{1.2}$: Accumulated lithospheric extraction
	$I_{1.3}$: Non-renewable energy supply
Principle 2: Society-produced substances must not systematically accumulate in the ecosphere	$I_{2.1}$: Anthropogenic flows compared to natural flows
	$I_{2.2}$: Long-term implication of emissions of naturally existing substances
	$I_{2.3}$: Production volumes of persistent chemicals
	$I_{2.4}$: Long-term implication of emissions of substances that are foreign to nature
Principle 3: The physical conditions for production and diversity within the ecosphere must not systematically be deteriorated	$I_{3.3}$: Transformation of lands
	$I_{3.2}$: Soil cover
	$I_{3.3}$: Nutrient balance in soils
	$I_{3.4}$: Harvesting of funds
Principle 4: The use of resources must be efficient and just with respect to meeting human needs	$I_{3.3}$: Transformation of lands
	$I_{3.2}$: Soil cover
	$I_{3.3}$: Nutrient balance in soils
	$I_{3.4}$: Harvesting of funds

Table 5. Socio-ecological indicators based on socio-ecological principles from [23]

DISCUSSION AND CONCLUSION

Designers must be aware of the impacts of buildings on the larger environment. These will include impacts on biodiversity, global climate, and ozone depletion, on the availability and quality of soil, air, and water, on natural resource depletion, on waste generation, and on mineral (including energy source) consumption,. Some of these will ultimately, although perhaps imperceptibly, affect the building itself and its users. Therefore, each building must be planned and designed as though it were being replicated a million times over so that the consequences of its impacts on the global environment and, in a very real sense, its own environment are taken seriously.

"Sustainable Design" Guidance

Table 6 presents examples of design strategies that integrate both indoor (project) and general environmental considerations. A systematic approach to evaluating building environmental performance will support an emphasis on one or more of these design strategies.

Resource conservation. Selecting building materials and products that are extremely durable and can be expected to perform well over an extended useful life.

Pollutant source control. Eliminating or controlling pollution at the source is generally four times as cost effective as removing pollution from air, water, or soil. Typically, low-emitting products result from production processes involving lower exposures of the manufacturing workers as well.

Energy conservation. Energy conservation will reduce potential emissions of greenhouse gases at power plants, and acid-forming emissions that contribute to acid deposition.

Energy efficiency. Where energy-consuming devices are required, efficient appliances should be used. The ratio between the best and worst products may be 2-to-1 or even 3-to-1.

Ventilation. Adequate ventilation and filtration will control pollutants that reach the indoor air by reducing and removing them through dilution, exhaust (local, general), and air cleaning.

Overall design. Design for the whole person: The human body and mind integrate all the factors in the physical, chemical, biological, and psychosocial environment. A good building lasts longer.

Table 6. Design strategies integrating indoor and general environmental considerations

An approach has been described that includes assessing the contribution of buildings to the total anthropogenic environmental burden, weighting various environmental problems, adopting principles for determining sustainability, and establishing targets based on sustainability criteria. These elements used together with other methodologies will improve the methods' comprehensiveness in informing decisions to optimize total building environmental performance.

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