6. CREATING A DECISION SUPPORT SYSTEM FOR LIFE CYCLE ANALYSIS

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The only reason we now ship raw materials like bauxite or nickel or copper across the planet is that we lack the knowledge to convert local materials into usable substitutes. Once we acquire that know how, further drastic savings in transportation will result. In short, knowledge is a substitute for both resources and shipping.

Alvin Toffler
Power Shift, 1990

Life Cycle Design (LCD) establishes a design process which begins at the building's point of conception, and continues to its final disposition. The NIST Building, located at Montana State University in Bozeman, Montana highlights the importance of working knowledgeably with a region's resource base (virgin and by-products), and with a region's labor skills and businesses. In combination, these resources are integral to sustaining a region's environment and economy. This approach provides scientific and logical evidence to support the assertion that a region can best be sustained by regionalizing its resource dependencies rather than be guided by conclusions drawn from national and even international life cycle analyses. The Decision Support System (DSS) presented will cause a substantial shift in understanding building systems in general, and, more specifically, a shift in understanding the importance of both human and natural resource use.

In the Life Cycle Design approach, the procedure of Life Cycle Costing (LCC) becomes a subset of Life Cycle Economics. This procedure assumes that regional economics and ecological sustainability are the primary economic activities to which LCC is compared. These methods, together referred to as Life Cycle Design, purposely evaluate the catalytic actions promoted by the built environment to produce more responsible regional flows on the part of human activities relative to existing ecological parameters in the short and long terms. Assessing the impacts of any building subsystem (e.g. building material, energy system, water and wastewater system) from a life cycle perspective (a flow from source to re-source) and the total impacts that each stage has on the internal and external environment is referred to as Life Cycle Assessment (LCA). Life Cycle Design uses the knowledge gleaned from LCA and Life Cycle Economics (LCE) to compare options and choose a solution set that meets resource objectives in a manner that is culturally and scientifically appropriate.

LCD is based on several fundamental principles, as follows:

Principle #1: Recognize and incorporate self similarity and redundancy among living systems into the built environment. This phenomenon is most easily understood through the duplication of structure and function at many scales, i.e. biomes and watershed systems.

Principle #2: Promote the miniaturization of the life cycle including energy, mate rials, and water starting with the building and site, progressing only to larger scales of life cycle use as is necessary.

Principle #3: The production stage within the life cycle can only compete with more centralized larger scales if it becomes multipurpose and/or highly integrated.

Principle #4: Reducing the complexity of the life cycle enables it to relate more directly to the amount of information processable by all actors involved, from design and engineering integration to users and environmental impact.

Principle #5: Plan for an extended use phase of a building's life cycle through the separation of structure and shell and the admission of unpredictability in spatial dynamics.

Principle #6: Support regionalized economic loops by respecting tight knit life cycle integration. Each stage of the life cycle becomes a part of a region's economics.

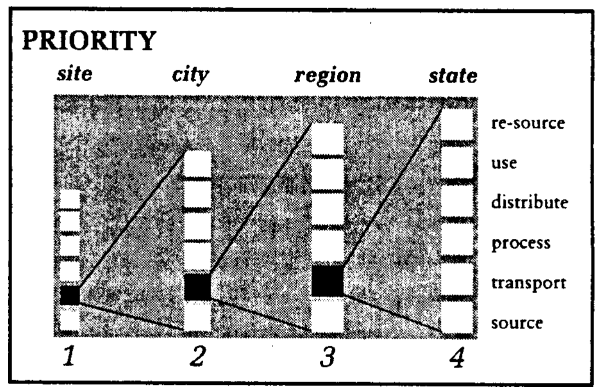
Principle #7: Create regionally relevant benchmarks through benchmark comparisons from similar environmental, technological and cultural conditions.

Principle #8: Link what are normally disparate databases regarding individual topics (e.g. regional economic vs. a building's life cycles) into a Life Cycle Design framework for decision making.

The following sections describe each principle more fully and link each to approaches used for the NIST Incubator project. It is assumed that a second phase of this work would enable more complete and measurable understanding of the findings at this point in the initial Life Cycle Design process.

Principle #1

Recognize and incorporate the natural tendency of self similarity and redundancy among all living systems into the built environment. This phenomenon is most easily understood through the duplication of structure and function at many scales, i.e. biomes, watersheds. This principle also states that priority should be placed on providing for the incorporation of all possible processes (or transformations) at the smallest possible scale thus relieving the burden of impact necessitated by the sole use of larger systems. Principal #1 also recognizes the principal of scales that contain processes and that are definable with boundaries. These boundaries are critical for the understanding of performance (or totality of life support needs provided) before one investigates the next boundary. The profound meaning of understanding boundaries is the essence of Life Cycle Planning and sustainably built environment. The intricacies of these scales, types, and relationships are addressed in other papers. If the reader wishes more familiarity with this concept, please contact this author. "Enhancing the Credibility of

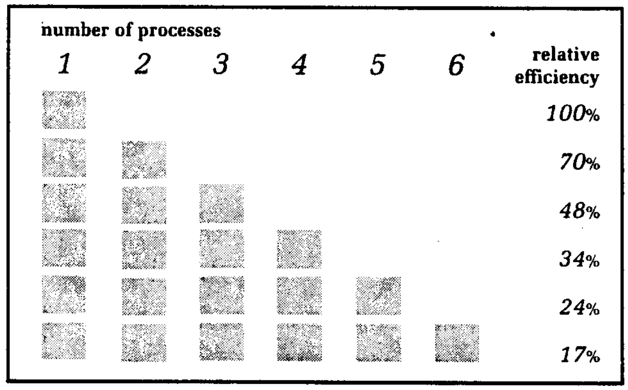


Ecology: Interacting Along and Across Hierarchical Scales," di Castri, Francesco, Dr., GeoJournal, Kluwer Academic Publishers, 1988. The NIST building provides much of its own renewably based energy for heating and cooling, its own waste water treatment, much of its own water .

Principle #2

Increasing efficiency through miniaturization of the life cycle within a regional or site context. This principle also requires the recognition of the Life Cycle sequence as a fundamental planning tool and that the processes within each life cycle overlap or serve in a multi-functional manner into another life cycle as described in Principle #1. The efficiency of life cycle process rises when fewer individual or separate transformations occur.

LIFE CYCLE SIZE



Energy efficiency as a function of the number of transformation processes

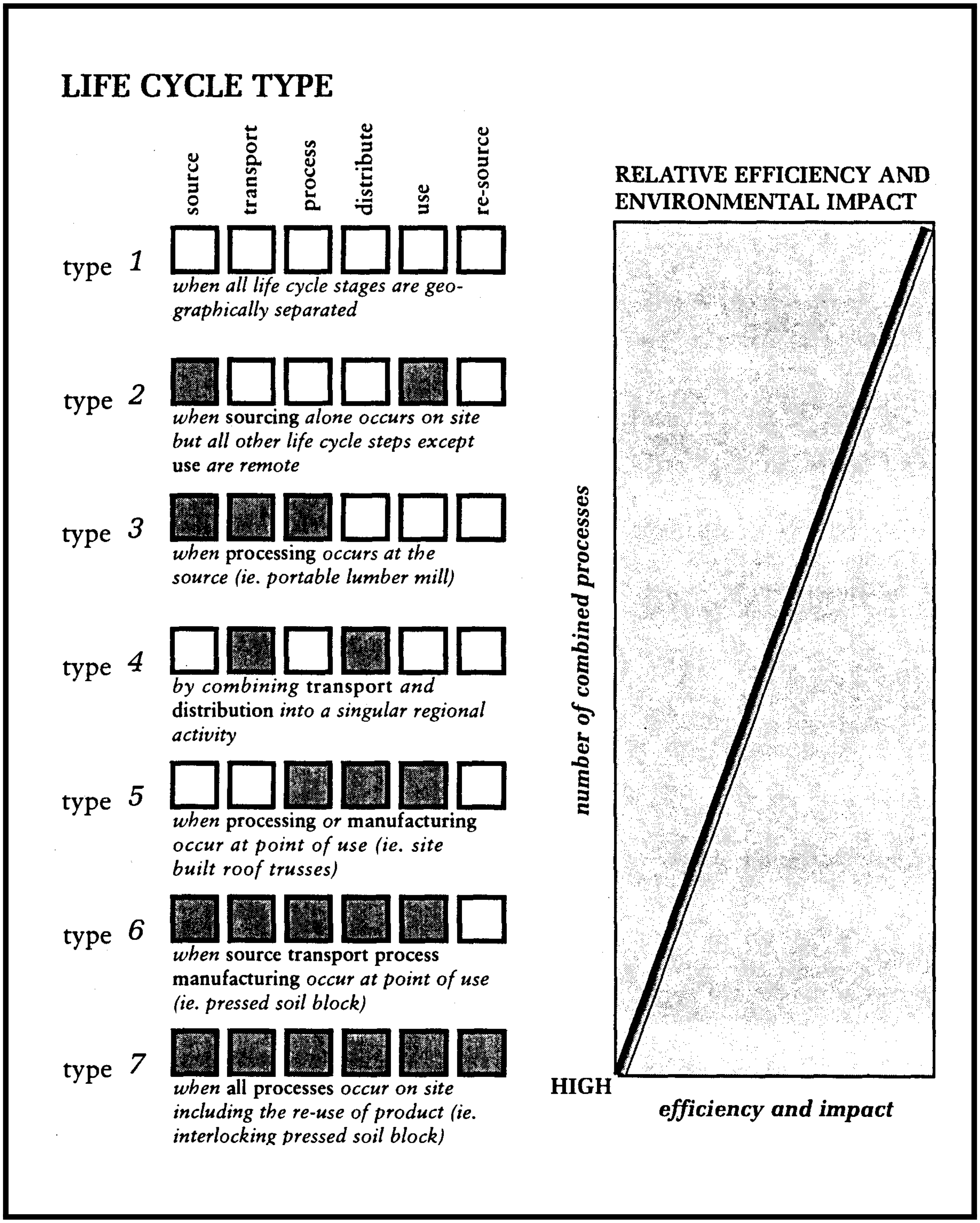
This efficiency increase has been demonstrated in both the energy and wastewater fields. See Ayers, Robert, "Industrial Metabolism", in Technology and Environment,

National Academy Press 1989

In the final report to NIST the sequences of life cycles assumed below would be compared to more conventional life cycle sequences and their boundaries. The objective of Principle #1 is to only develop alternative life cycle scenarios that technically exist or are close to commercialization. The examples used on the building illustrate in a brief format the life cycle used and the system it replaces. The NIST facility accomplishes the miniaturization principle through the utilization of on-site resources first. The various life cycle types incorporated can be generically summarized by types 2, *5,* 6 and 7. These types represent a departure from the normally disparate life cycle functions and affect the design in profound ways. For example, the on-site sourcing of energy, using the plentiful winter sun in Bozeman, spawns a number of design features as does the on-site availability of ground water and potential for wastewater using closed containment approaches and natural plant treatment indoors. The on-site or local sources required by these technologies can be spatially mapped, and appear at the scale of site, city, region and state boundaries. When a need is unable to be satisfied at one scale, the next larger scale takes effect. At a next step, life cycle boundary alternatives would be inter-compared with other life cycle boundaries to understand total effects. The impact procedure will occur later in our process when a full assessment of life cycle environmental impacts is done. Major material types in the NIST Project, other than some plant materials for landscaping, are all sourced off-site but within the city, region, state or multi-state area.

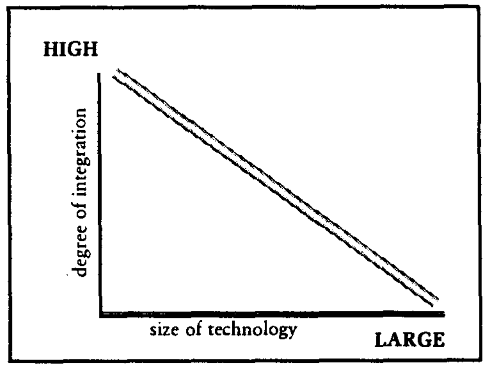
Principle #3

The technology of production and use at smaller scales can only compete with those at more centralized larger scales if they become multipurpose and highly integrated. There is a common belief that larger scale, centralized technologies are more efficient and environmentally superior to smaller scale operations due to effective centralized pollution control. However, trends show that with improved technology and enhanced integration between technologies, there is a greater possibility to achieve a balance in material and energy flows at all phases of the life cycle. Simply stated, integration is a more important concept in life cycle design than is conservation.



LIFE CYCLE TYPE
source
transport
process
distribute
use
re-source
type 1
when all life cycle stages are geographically separated
type 2
when sourcing alone occurs on site but all other life cycle steps except use are remote
type 3
when processing occurs at the source (ie. portable lumber mill)
type 4
by combining transport and distribution into a singular regional activity
type 5
when processing or manufacturing occur at point of use (ie. site built roof trusses)
type 6
when source transport process manufacturing occur at point of use (ie. pressed soil block)
type 7
when all processes occur on site including the re-use of product (ie. interlocking pressed soil block)
RELATIVE EFFICIENCY AND ENVIRONMENTAL IMPACT
number of combined processes
HIGH
efficiency and impact

At the NIST facility the most obvious applications of Principle #2 are the passive solar design features combined with material applications, where sourcing, (production), transport, processing, use and re-use or re-sourcing all occur within the confines of the building or site itself. If energy issues were treated separately, i.e. as a mechanical system divorced from the structure, neither the economics nor the efficiency would occur. Future LCD work on the building can develop a complete comparison at this scale, made by comparing a true cost accounting between energy types. In a similar manner, cisterns and on-site water catchment vs. centralized water supply, or aquatic wastewater treatment vs. the existing campus wastewater facility as a source of vegetative beauty and air scrubbing capacity by plant leaves. Proximity to the existing campus facility and thus normally its use would dominate the designers thinking but the amenities mentioned would not occur. Integrating purified wastewater with other site requirements, such as making sure the ground water level is up in the summer to enable the radiant cooling system to operate properly is an example of micro integration at the site level. Similar comparisons can occur between material LCD. For example, in a passive solar building, materials are as important for structural integrity as they are for mass. Similarly, cisterns can fulfill the dual functions of heat sink and water storage.



Principle #4

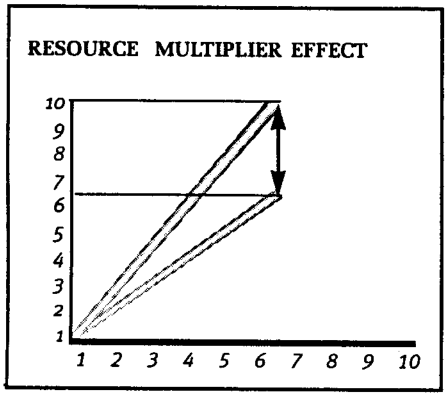
Reduce the complexity of the life cycle enables it to relate more directly to the amount of information processable by all actors involved, from design and engineering integration to users and environmental impact assessment.

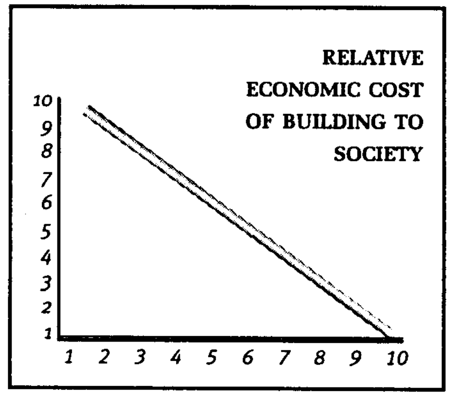
Working with simplified construction and mechanical systems aids both in information gathering and processing for environmental impact evaluation, and the ability to integrate one technology with another. The following graph summarizes the information and complexity issue:

The NIST Building incorporates this principle through its ability to summarize relatively simple systems for evaluation and effective integration. The ability to coordinate between the sizing of cisterns to heat sink issues and actually accomplish the task is far greater within the NIST complex than within the city of Bozeman or even the campus. The NIST building becomes a good example of whole system planning including the backup levels offered through accepting complexity at this relatively simple level instead of trying to tackle the entire city or region. (For example, water storage could be multi-defined as wastewater treatment holding tanks to exterior landscape holding ponds to the ground water, in addition to the cisterns mentioned earlier.) This is one of many examples now possible from an information/performance standpoint.

SOURCE	*SYSTEM*	*REGIONAL/NATIONAL L.C.E REPLACEMENT*	*LIFE CYCLE TYPE*
SCALE ONE	**SITE ENERGY**		
•solar radiation •ground water temperature	phonton sys light shelf passive heat active solar solar H_2O radiant cool	electric lighting (coal) electric lighting (wood/coal) electricity (coal) electricity (coal) electricity (coal)	type 4 type 4 type 5 type 6 type 6 type 6
SCALE ONE	**SITE WATER**		
•roof precipitation	catchment POT H_2O sys ponds	city water ground water	type 6 type 6
SCALE ONE	**SITE WASTE WATER**		
•road/path runoff	intersection vegetation	ground water	type 6
•human liquid waste	solar aquatic	waste water treatment plant	type 6
SCALE TWO	**CITY MATERIALS**		
•recycled newspaper	insulation	fiberglass	type 7
SCALE THREE	**REGION ENERGY**		
•Montana coal	coal fired power plant w. precipitator	natural gas	type 7
SCALE THREE	**REGION WASTE WATER**		
•ecologically suitable aquatic plants	solar aquatics	wastewater treatment plants	type 1
SCALE THREE	**REGION MATERIALS**		
•clay flyash	tile cement	national Portland cement	type 1 type 6, 7
SCALE THREE	**STATE MATERIALS**		
•straw	partition panels	gypsum wall board/wood studs	type 7

Principle # 5





Relative age of building in 40 year increments

Plan for an extended use phase of a building's life cycle. The principle relates to the length of time attributed to the use phase of a building, its environmental impacts, and the long term economic investment that a society places in the built environment. Design features such as flexibility, reuse, and material longevity lengthen a building's useful life which, in turn, can affect the useful life of a building's predominate materials. By building in an anticipatory manner, old buildings have paid for themselves in terms of embodied energy and other resource uses many times over. This principle reflects the disproportionately large investments made for rebuilding vs. for other investment practices which could reap greater social benefits. The diagrams above illustrate the resource and investment trends based on a structure's useful life.

The NIST building provides for an open space, almost barn like plan to accommodate flexibility within and, to some degree, outside the building. At the next stage of design development, the growth and form of one space type will be investigated relative to the next. Since cisterns are such a stationary element on the exterior, their position might be slightly shifted to allow for elongation growth. An important additional study will be made showing that, assuming Francis Duffy's information is correct, the embodied energy of materials for changes and additions could approach operational costs more quickly than is usually believed, since little analysis has been undertaken which relates building use change over time, and the energy and resource expenditures compared to operational cost from a mechanical equipment standpoint.

Principle #6

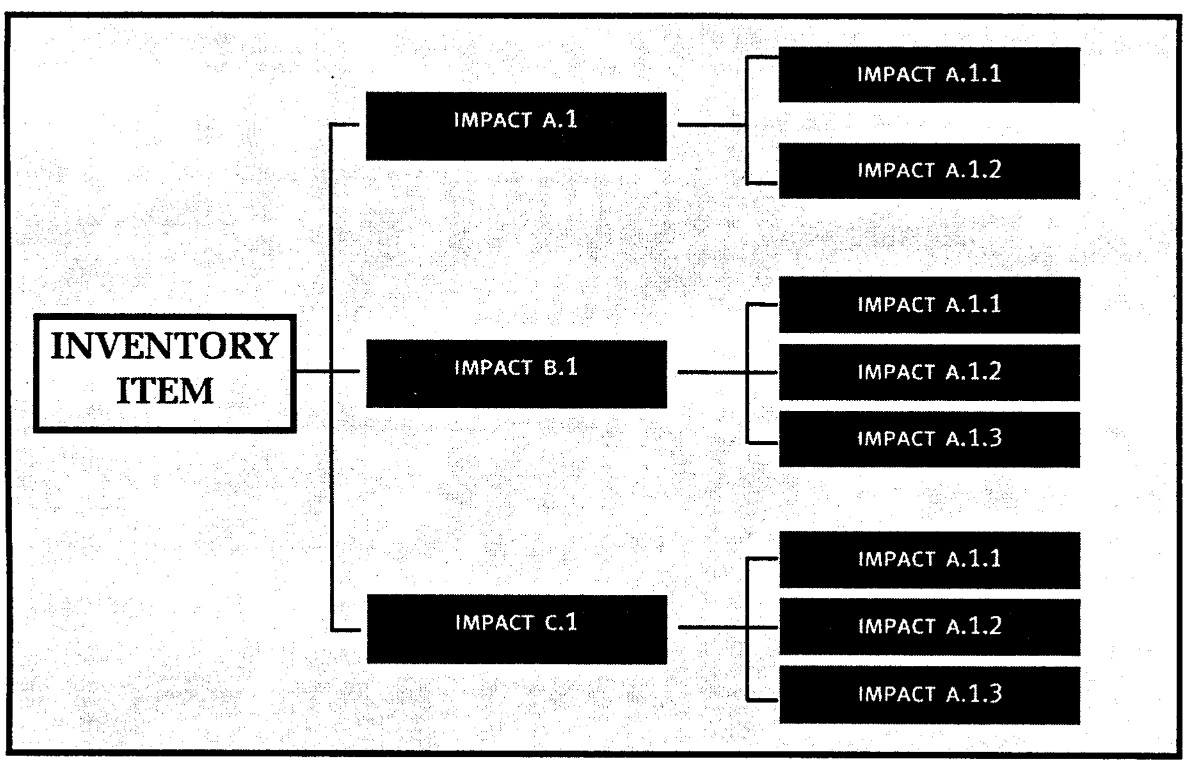
Support regionalized economic loops by respecting tight knit life cycle integration. Each stage of the life cycle becomes a part of a region's economics. Life Cycle Economics promotes the close alignment of economic benefits with the benefits of designing highly integrated material and energy flows where wastes are considered as valuable as virgin resources. Linking economics and ecology (as practiced by industrial ecologists, see Tibbs, Hardin, "Industrial Ecology," Whole Earth Review, Winter 1992) develops the "tightness" necessary to achieve healthy, ecological, and economical regions. Establishing a framework based on the life cycle format illustrates how impact analysis is minimized. The next step is to perform a traditional life cycle impact analysis, which parallels the

LCA methodology by evaluating each stage of the life cycle and the primary, secondary, and tertiary impacts. The resulting Multiple Impact Chain with Multiple Stressors and Multiple Impacts, illustrated below, is consistent with U.S. E.P.A. Guidelines (see Life Cycle Impact Analysis, Part I: Issues, EPA Contract Number 68-W9-0080).

The NIST Building's material selection matrix requires a more accurate life cycle costing than has been provided to date, not only relative to the point of use but also within the western Montana and northwest U.S. regions. The analysis for flyash cement assumes that it has lower embodied energy costs than Portland cement, even though the flyash is sourced over 170 miles while Portland cement is manufactured by ready-mix companies located down the street from the NIST site. The impacts of transporting bulk materials relatively long distances may offset other perceived benefits, especially when compared to local production. More information is needed relative to the long term chemical reactions of Portland cement as a CO_2 absorber as compared to its CO_2 emissions during manufacturing. Moreover, more information is needed to determine whether displacing the CO_2 emissions resulting from Portland cement manufacturing by using 97% flyash cement (now technically feasible) offsets enough CO_2 to make it environmentally preferable to transport flyash 170 miles to site.

Principle #7

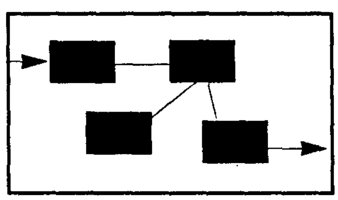
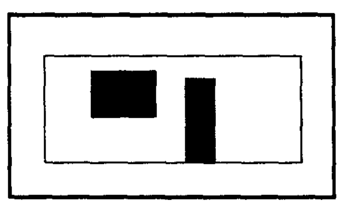
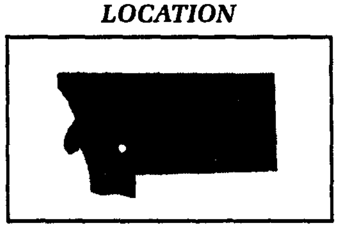
Create regionally relevant benchmarks through benchmark comparisons from similar environmental, technological and cultural conditions. It is unclear whether benchmarks



are relevant when comparing a building type to non-regionally derived best case scenarios. Two fundamental procedures are used to recognize benchmarks as performance goals for building: (1) Establishing state of the art practices or prototypes for comparison; (2) Comparing the new building effort to its regional condition. Whether it be building materials, energy sources and sinks, water, wastewater and/or other building processes, they can be designed in Life Cycle terms within a region's capacity to supply, transport, and absorb the constituents required for a building's construction, use and reuse. This type of benchmarking relies on five conditions:

a) an understanding of the throughput in total resource terms of the building from the building process through to demolition

b) the choosing of a boundary (i.e. scale of site, region, state) so that resource

TRADITIONAL DESIGN AND PLANNING	**BENCHMARK PLANNING PRINCIPLES**	***LIFE CYCLE DESIGN AND PLANNING***
benchmarking base case is compared to state of the art only within the bounds of existing technology performance with no goal outside to compare this performance to	***METABOLIC*** 	buildings metabolic activity is compare to existing human activity and it present relationship to ecological holding capacity
standard zoning has developed in the last 20 years into performance zoning but the spatial context has no environmental facsimile	***SPATIAL*** 	boundary of area becomes system limit for performance modeling both of human activity and environments capacity
standard geographic information placement is merely a database spatial benchmarking technique from which geographic analysis can be done–there is no overlying principle as to structuring information at the star that might lend itself more to environmental performance that could be critical in how data is collected as well as prioritized	***LOCATION*** 	place becomes connected to spatial patterns of similar ecological conditions in order to make performance and benchmark comparisons relative to the ability of life forms to provide the basic indexing for measuring the human to environment impact of a given condition

activity can be measured

c) the state of the existing natural environment (i.e. a region could be going through degrees of stress such as diseases that are destroying a forest)

d) the existing holding capacity of the environment (i.e. its sources, transports, and sink capacities)

e) are we directly or indirectly effecting the biological diversity of the boundary condition within which we work or can we effect by other actions

The preceeding diagram summarizes benchmarking principles that respect the principles outlined in this paper vs. other methods.

At present, the NIST Building uses typical per square foot benchmarking based on the experience of other buildings of similar size and footprint. However, depending on the boundary chosen to assess building impacts, it may be determined that, at the campus scale, there is an allowance for only a negative amount of energy per square foot. It may be that our actions at more regional scale when comparing metabolism to regional metabolism that we are offering some positive effect due to the fact that regional biological metabolism has not been meet and the fact that we might help certain forest conditions by utilizing deceased species of wood in the building. The issue of boundary must be more carefully studied at the next work level on the project.

From a landscaping and planting standpoint we could easily bring back more diversity at a higher plant level but if we consider the site itself as one of our first level boundaries we must remember that the building itself is taking up space and displacing not only existing higher plant diversity but the immense diversity offered in the soil by the various micro biota. Hopefully by introducing more density of high plant species more dense diversity of micro biota would also result.

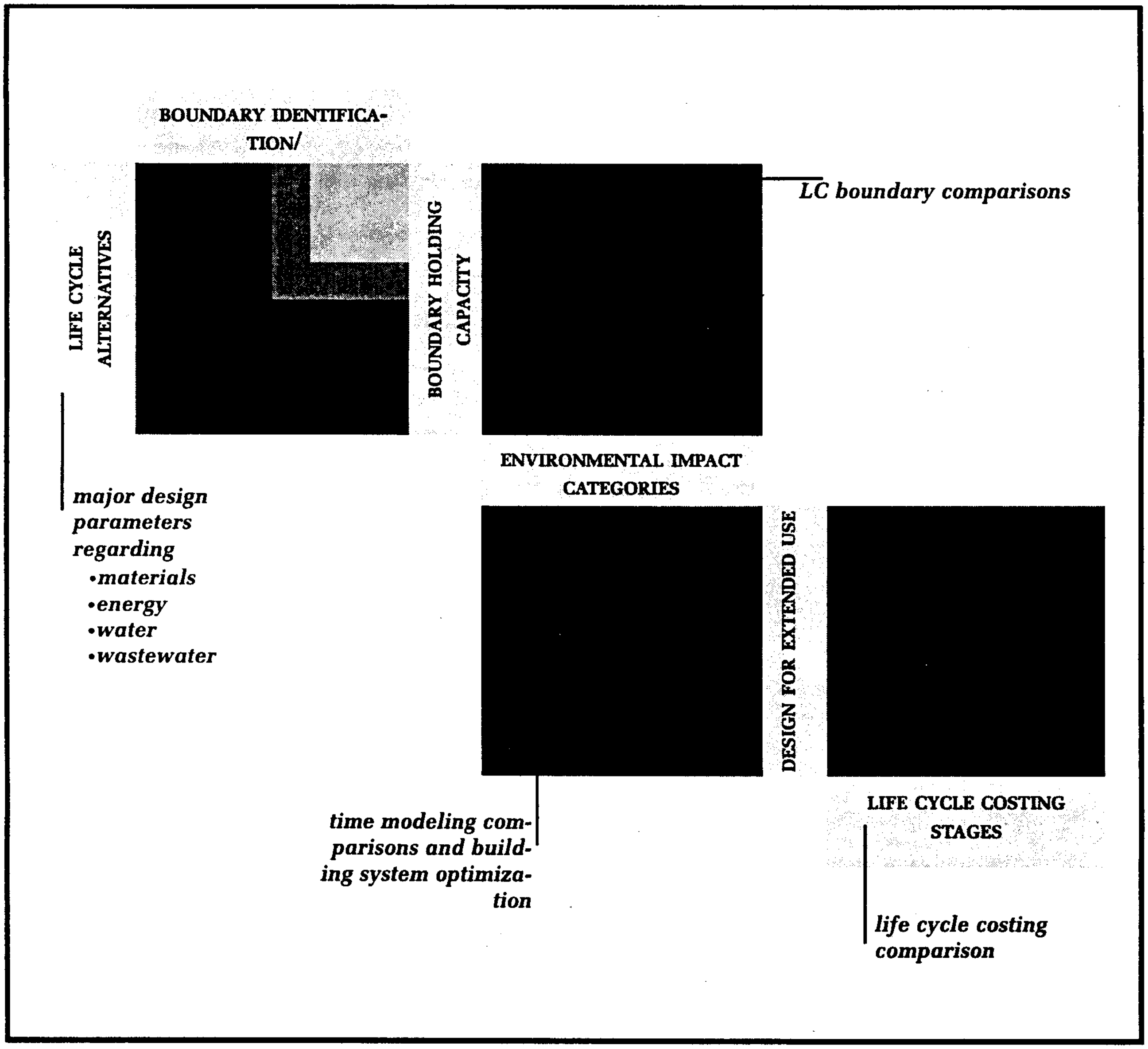
Principle #8

Link databases into a Life Cycle Design framework for decision making. This decision support system should be designed to: a) link spatial natural resource data to life cycle alternatives within prioritized performance boundaries; b) connect natural resources to economic activities; c) link natural and human resource bases with impact and ecological holding capacity criteria; d) show life cycle costing linked to the alternatives brought about by life cycle design. This procedure become possible by using interlocking relational field matrices and communicating through a variety of programming languages.

The Montana State University Building is well-positioned to be an incubator for proper design and engineering and an economic development incubator for the State of Montana. The building extends solar architecture into a comprehensive design methodology, with the potential to be transferred to projects across the U.S.. Moreover, by bridging architecture and economic development, new questions are asked and concerns are raised, thus complicating the design problem but making it infinitely richer. For example, how can the way a building is designed and engineered enhance a region's job creation potential, and, simultaneously protect the environment? The project also has the potential to identify opportunities to tap into the vast informational resources available to the region, by virtue of its university "anchor tenant," and use these resources for regional resource analysis, for example, by linking into satellite information systems to provide a better spatial frame of reference for resource planning.

A tremendous commitment both in time and resources is required to make this happen. Also crucial is rethinking, restructuring, and promoting fundamental design methods that have far too small an audience even today. So this project is far from done. The

FIELD MATRIX FOR LIFE CYCLE DESIGN



data is not yet linked, yet much of it could be. The procedure can no longer be one of checking off or shading empty boxes, but instead must acquire a precision, wherein options are identified and tradeoffs made based on knowledge consistent with what intelligent architecture should be.

Acknowledgements

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