Sustainable Architecture Module:

Introduction to Sustainable Design

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Fundamentals

Changing our Definitions of Growth and Progress

How do we measure economic success? Traditionally, we measure Gross National Product (GNP), which favors any economic activities and production, regardless of their true benefits and effect on long-term societal well-being. Even consumption, demolition, and waste that require further production are credited to a higher GNP. In industrialized, capitalistic societies, consumption is regarded as a virtue.

However, realizing the environmental threats, real or potential, to the quality of life, environmental movements have begun in virtually all sectors of industrialized countries, including business, manufacturing, transportation, agriculture, and architecture. Researchers are developing and refining methods of analyzing the true cost of an economic activity over its entire life cycle.

Developing countries tend to model their economic infrastructure after those of their industrialized counterparts. Today, economic activities in developing countries around the world, Pacific Rim countries in particular, are far more noticeable than two or three decades ago, and their share of the world economy is increasing. All quantitative economic indices such as per capita income, GNP, amount of foreign trade, and the amount of building construction indicate that their economies are strong and growing rapidly.

Measuring a country's GNP does not account for the loss of environmental quality — and quality of life — attributed to industrialization. In the United States alone, billions of dollars have been spent cleaning up an environment subjected to uncontrolled development. The ecological havoc created by the former Soviet Union is only now beginning to be fully understood. Developing countries would do well to learn from these situations, not emulate them.

Resource Consumption and Environmental Pollution

Resource consumption and economic status have a strong correlation. As the income level of a society increases, so does its resource consumption. This is true for societies of virtually any size, be they families, cities, or entire countries.

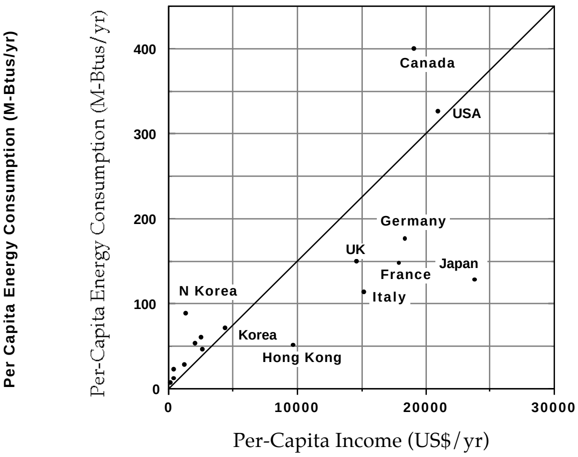


Figure 1: Correlations between per-capita incomes and per-capita energy consumption levels of selected industrialized and developing countries. [Source: Herman Daly, *Steady-State Economics* (Washington: Island Press, 1991).]

The correlation between per-capita income and energy consumption of various countries demonstrates this trend. As shown in **Figure 1,** industrial countries with higher incomes consume more energy per capita than developing countries. Among industrialized countries, the energy intensity of Canada and the United States is the highest, while Japan's is much lower. This implies that it is plausible for a society to establish resource-efficient social and economic infrastructures while raising its economic status. A society (household, community, city, or country) with such an infrastructure will be less susceptible to resource shortages, more reliable by itself, and thus more sustainable in the future.

The correlation between per-capita income and per-capita water consumption reveals a similar pattern (see **Figure 2**), as does the emission of environmental pollutants to the atmosphere (see **Figure 3**). Developing countries' energy use, water use, and share of global environmental pollution is expected to increase.

Sustainability in Architecture

The World Commission on Environment and Development has put forth a definition of "sustainability" as

> meeting the needs of the present without compromising the ability of future generations to meet their own needs.
>
> **— From *Our Common Future* (London: Oxford University Press, 1987).**

This definition of sustainability does not specify the ethical roles of humans for their everlasting existence on the planet. It also fails to embrace the value of all other constituents participating in the global ecosystem. The need for finding long-terms solutions that warrant continuing human existence and well-being is far more compelling than that of finding a proper terminology to describe the human need. In this respect, the debate on the terms "green," "sustainable," or "ecological" architecture is not terribly important.

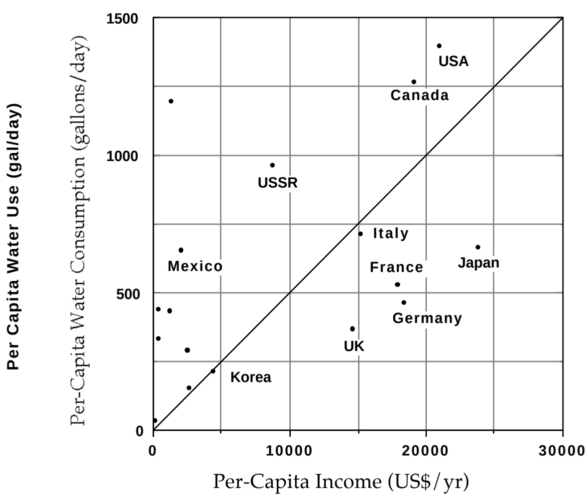


Figure 2: Correlations between per-capita incomes and per-capita water consumptions of selected industrialized and developing countries. [Source: Herman Daly, *Steady-State Economics* (Washington: Island Press, 1991).]

Architecture is one of the most conspicuous forms of economic activity. It is predicted that the pattern of architectural resource intensity (the ratio of per-capita architectural resource consumption to per-capita income) will generally follow the same patterns as shown in Figure 1, 2, and 3. A country's economic development will necessitate more factories, office buildings, and residential buildings. For a household, the growth of incomes will lead to a desire for a larger house with more expensive building materials, furnishings and home appliances; more comfortable thermal conditions in interior spaces; and a larger garden or yard.

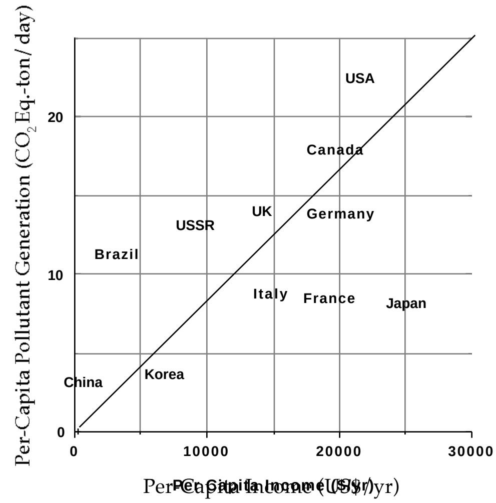


Figure 3: Correlations between per-capita incomes and per-capita pollutant production of selected industrialized and developing countries. [Source: Herman Daly, *Steady-State Economics* (Washington: Island Press, 1991).]

During a building's existence, it affects the local and global environments via a series of interconnected human activities and natural processes. At the early stage, site development and construction influence indigenous ecological characteristics. Though temporary, the influx of construction equipment and personnel onto a building site and process of construction itself disrupt the local ecology. The procurement and manufacturing of materials impact the global environment. Once built, building operation inflicts long-lasting impact on the environment. For instance, the energy and water used by its inhabitants produce toxic gases and sewage; the process of extracting, refining, and transporting all the resources used in building operation and maintenance also have numerous effects on the environment.

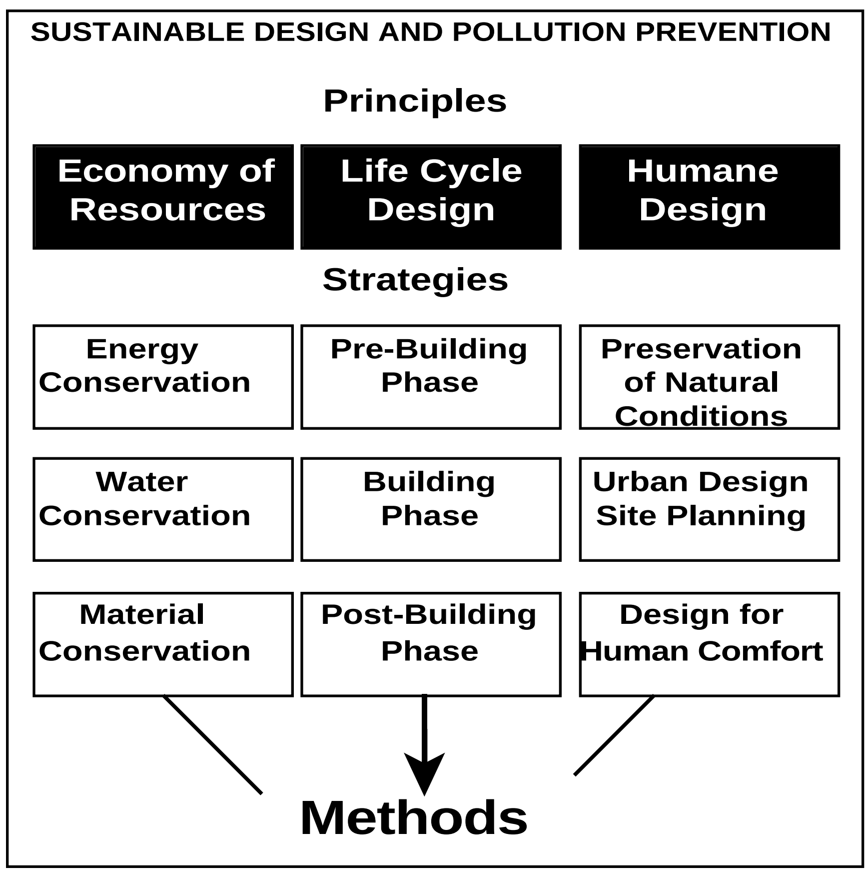
Architectural professionals have to accept the fact that as a society's economic status improves, its demand for architectural resources — land, buildings or building products, energy, and other resources — will increase. This in turn increases the combined impact of architecture on the global ecosystem, which is made up of inorganic elements, living organisms, and humans. The goal of **sustainable design** is to find architectural solutions that guarantee the well-being and coexistence of these three constituent groups.

Principles of Sustainable Design

To educate architects to meet this goal of coexistence, we have developed a conceptual framework. The three levels of the framework (Principles, Strategies, and Methods) correspond to the three objectives of architectural environmental education: creating environmental awareness, explaining the building ecosystem, and teaching how to design sustainable buildings. The overall conceptual diagram for sustainable design is shown in **Figure 4**.

We propose three principles of sustainability in architecture. **Economy of Resources** is concerned with the reduction, reuse, and recycling of the natural resources that are input to a building. **Life Cycle Design** provides a methodology for analyzing the building process and its impact on the environment. **Humane Design** focuses on the interactions between humans and the natural world. These principles can provide a broad awareness of the environmental impact, both local and global, of architectural consumption.

Figure 4: Conceptual framework for Sustainable Design and Pollution Prevention in Architecture.



Each of these principles embody a unique set of strategies. Studying these strategies leads students to more thorough understanding of architecture's interaction with the greater environment. This allows them to further disaggregate and analyze specific methods architects can apply to reduce the environmental impact of the buildings they design.

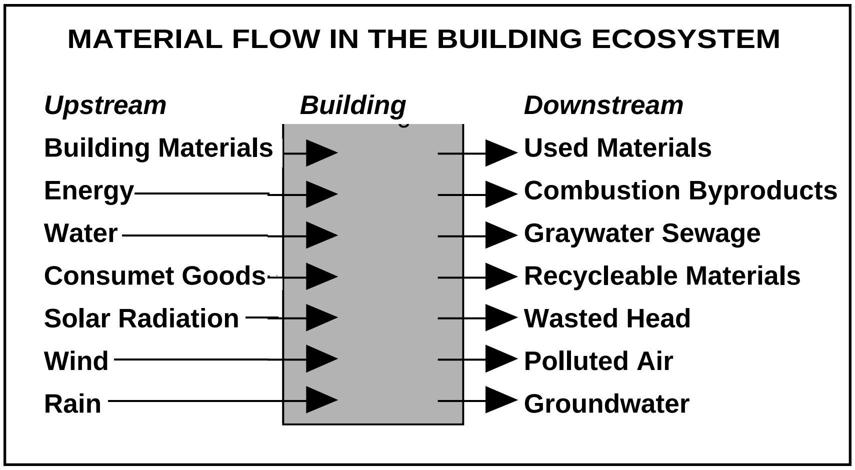


Figure 5: The input and output streams of resource flow.

Principle 1: Economy of Resources

By economizing resources, the architect reduces the use of nonrenewable resources in the construction and operation of buildings. There is a continuous flow of resources, natural and manufactured, in and out of a building. This flow begins with the production of building materials and continues throughout the building's life span to create an environment for sustaining human well-being and activities. After a building's useful life, it should turn into components for other buildings.

When examining a building, consider two streams of resource flow (see **Figure 5**). **Upstream**, resources flow into the building as input to the building ecosystem. **Downstream**, resources flow out of the building as output from the building ecosystem. In a long run, any resources entered into a building ecosystem will eventually come out from it. This is the *law of resource flow conservation*.

For a given resource, its forms before entry to a building and after exit will be different. This transformation from input to output is caused by the many mechanical processes or human interventions rendered to the resources during their use in buildings. The input elements for the building ecosystem are diverse, with various forms, volumes, and environmental implications.

The three strategies for the economy of resources principle are *energy conservation*, *water conservation*, and *material conservation*. Each focuses on a particular resource necessary for building construction and operation.

Energy Conservation

After construction, a building requires a constant flow of energy input during its operation. The environmental impacts of energy consumption by buildings occur primarily away from the building site, through mining or harvesting energy sources and generating power. The energy consumed by a building in the process of heating, cooling, lighting, and equipment operation cannot be recovered.

The type, location, and magnitude of environmental impacts of energy consumptions in buildings differ depending on the type of energy delivered. Coal-fired electric power plants emit polluting gases such as SO_2, CO_2, CO, and NO_x into the atmosphere. Nuclear power plants produce radioactive wastes, for which there is currently no permanent management solution. Hydropower plants each require a dam and a reservoir which can hold a large body of water; construction of dams results in discontinuance of river ecosystems and the loss of habitats for animals and plants.

Water Conservation

A building requires a large quantity of water for the purposes of drinking, cooking, washing and cleaning, flushing toilets, irrigating plants, etc.. All of this water requires treatments and delivery, which consume energy. The water that exits the building as sewage must also be treated.

Material Conservation

A range of building materials are brought onto building sites. The influx of building materials occurs primarily during the construction stage. The waste generated by the construction and installation process is significant. After construction, a low-level flow of materials continues in for maintenance, replacement, and renovation activities. Consumer goods flow into the building to support human activities. All of these materials are eventually output, either to be recycled or dumped in a landfill.

Principle 2: Life Cycle Design

The conventional model of the building life cycle is a linear process consisting of four major phases: design; construction; operation and maintenance; and demolition (see **Figure 6**). The problem with this model is that it is too narrowly defined: it does not address environmental issues (related to the procurement and manufacturing of building materials) or waste management (reuse and recycling of architectural resources).

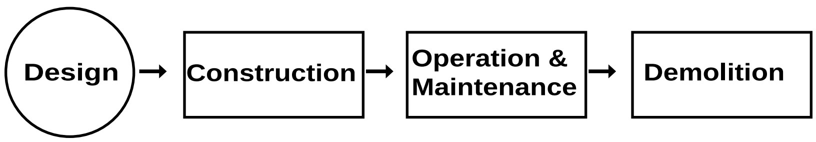


Figure 6: Conventional model of the building life cycle.

The second principle of sustainable architecture is life cycle design (LCD). This "cradle-to-grave" approach recognizes environmental consequences of the entire life cycle of architectural resources, from procurement to return to nature. LCD is based on the notion that a material transmigrates from one form of useful life to another, with no end to its usefulness.

For the purpose of conceptual clarity, the life cycle of a building can be categorized into three phases: *pre-building, building,* and *post-building,* as shown in **Figure 7**. These phases are connected, and the boundaries between them are not obvious. The phases can be developed into LCD strategies that focus on minimizing the environmental impact of a building. Analyzing the building processes in each of these three phases provides a better understanding of how a building's design, construction, operation, and disposal affect the larger ecosystem.

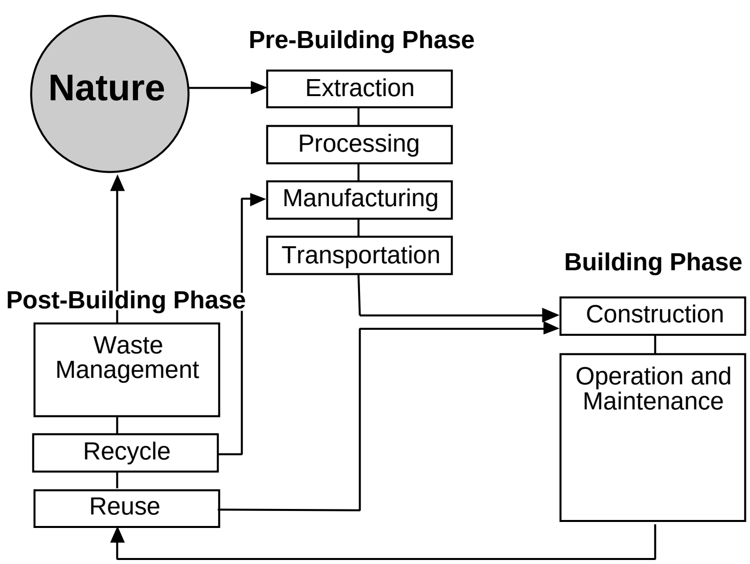


Figure 7: The sustainable building life cycle.

Pre-Building Phase

This phase includes site selection, building design, and building material processes, up to but not including installation. Under the sustainable-design strategy, we examine the environmental consequences of the structure's design, orientation, impact on the landscape, and materials used.

The procurement of building materials impacts the environment: harvesting trees could result in deforestation; mining mineral resources (iron for steel; bauxite for aluminum; sand, gravel, and limestone for concrete) disturbs the natural environment; even the transport of these materials can be a highly polluting activity, depending on their weight and distance from the site. The manufacturing of building products also requires energy and creates environmental pollution: for example, a high level of energy is required to manufacture steel or aluminum products.

Building Phase

This phase refers to the stage of a building's life cycle when a building is physically being constructed and operated. In the sustainable-design strategy, we examine the construction and operation processes for ways to reduce the environmental impact of resource consumption; we also consider long-term health effects of the building environment on its occupants.

Post-Building Phase

This phase begins when the useful life of a building has ended. In this stage, building materials become resources for other buildings or waste to be returned to nature. The sustainable-design strategy focuses on reducing construction waste (which currently comprises 60% of the solid waste in landfills[1]) by recycling and reusing buildings and building materials.

For more information on this topic, see *Recycling and Reuse of Building Materials.* This "Sustainable Architecture" module is available for a small fee from the Center for Sustainable Systems (formerly the NPPC; see the front page of this document for contact information) or **free of charge** on our website: www.umich.edu/~nppcpub/resources/compendia/architecture.html

[1] Sim Van der Ryn and Peter Calthorpe, *Sustainable Communities* (San Francisco: Sierra Club Books, 1986).

Site and Building Interactions

The LCD concept calls for consideration of the environmental consequences of buildings in all three phases of the life cycle. Each phase of building life cycle is associated with two groups of ecological elements: site and building (see **Figure 8**). The principal domain of architectural design is in the building phase, but sustainable building can be achieved by finding ways to minimize environmental impacts during all three phases of building life cycle.

	SITE: Elements of site ecology that exist within or in the vicinity of a building site, including sun-light, wind, precipitation, water table, soil, flora, fauna, etc. ...	BUILDING: Natural or manufactured resources, such as building materials, water, or energy ...
Pre-Building	... before construction.	... before they arrive at the site.
Building	... from the time construction begins through the duration of the building's useful life.	... from the time they arrive at the site for installation or operation though the duration of the building's useful life.
Post-Building	... after the building's useful life.	... after the building's useful life.

Figure 8: Ecological elements of Site and Building associated with the building life-cycle phases.

Principle 3: Humane Design

Humane design is the third, and perhaps the most important, principle of sustainable design. While economy of resources and life cycle design deal with efficiency and conservation, humane design is concerned with the livability of all constituents of the global ecosystem, including plants and wildlife. This principle arises from the humanitarian and altruistic goal of respecting the life and dignity of fellow living organisms. Further examination reveals that this principle is deeply rooted in the need to preserve the chain elements of the ecosystems that allow human survival.

In modern society, more than 70% of a person's lifespan is spent indoors. An essential role of architecture is to provide built environments that sustain occupants' safety, health, physiological comfort, psychological well-being, and productivity.

Because environmental quality is intangible, its importance has often been overlooked in the quest for energy and environmental conservation, which sometimes seemed to mean "shivering in the dark." Compounding the problem, many building designers have been preoccupied with style and form-making, not seriously considering environmental quality in and around their built environments .

Remember the performance factor of design. When a product saves energy, does it perform as well as what it is replacing? And how does it affect the performance of building occupants? For instance, early fluorescent lighting systems were more efficient than their incandescent counterparts; however, some fluorescents were known to buzz. The bulb might save $30 in annual energy costs, but if the noise irritated the employee working nearby, the employee's resulting drop in productivity could cost the employer a lot more, thereby wiping out any financial benefits gained from lighting energy conservation.

A general rule of thumb in such comparisons is that the annual energy bill of a typical office building amounts to around five hours of employee labor cost; therefore, any building energy conservation strategy that annually reduces productivity by more than five hours per employee defeats its purpose. This is not to say that energy conservation can't be financially beneficial, just that it should be kept in holistic perspective, taking other pertinent factors into account.

The following three strategies for humane design focus on enhancing the coexistence between buildings and the greater environment, and between buildings and their occupants,

Preservation of Natural Conditions

An architect should minimize the impact of a building on its local ecosystem (e.g., existing topography, plants, wildlife).

Urban Design and Site Planning

Neighborhoods, cities, and entire geographic regions can benefit from cooperative planning to reduce energy and water demands. The result can be a more pleasant urban environment, free of pollution and welcoming to nature.

Human Comfort

As discussed previously, sustainable design need not preclude human comfort. Design should enhance the work and home environments. This can improve productivity, reduce stress, and positively affect health and well-being.

Summary

To achieve environmental sustainability in the building sector, architects must be educated about environmental issues during their professional training. Faculty have to foster environmental awareness, introduce students to environmental ethics, and developing their skills and knowledge-base in sustainable design.

The current status of sustainable design in architecture is that of an ethic rather than a science. While a change of lifestyles and attitudes toward the local and global environments is important, the development of scientific knowledge-bases that provide skills, techniques, and methods of implementing specific environmental design goals is urgent.

To enhance environmental sustainability, a building must holistically balance and integrate all three principles — Sustainable Design, Economy of Resources, and Life Cycle Design — in design, construction, operation and maintenance, and recycling and reuse of architectural resources. These principles comprise a conceptual framework for sustainable architectural design. This framework is intended to help designers seek solutions rather than giving them a set of solutions. Specific design solutions compatible with a given design problem will emanate from these principles.

Methods for Achieving Sustainable Design

The ultimate goal and challenge of sustainable design is to find win-win solutions that provide quantitative, qualitative, physical, and psychological benefits to building users. There are many possibilities for achieving this seemingly difficult goal. The three principles of sustainable design — economy of resources, life cycle design, and humane design — provide a broad awareness of the environment issues associated with architecture. The strategies within each principle focus on more specific topics. These strategies are intended to foster an understanding of how a building interacts with the internal, local, and global environments. This section discusses methods for applying sustainable design to architecture.

Economy of Resources

Conserving energy, water, and materials can yield specific design methods that will improve the sustainability of architecture (see **Figure 8**). These methods can be classified as two types.

1) **Input-reduction methods** reduce the flow of nonrenewable resources input to buildings. A building's resource demands are directly related its efficiency in utilizing resources.

2) **Output-management methods** reduce environmental pollution by requiring a low level of waste and proper waste management.

Energy Conservation

Energy conservation is an input-reduction method. The main goal is to reduce consumption of fossil fuels. Buildings consume energy not only in their operation, for heating, lighting and cooling, but also in their construction. The materials used in architecture must be harvested, processed, and transported to the building site. Construction itself often requires large amounts of energy for processes ranging from moving earth to welding.

Energy-Conscious Urban Planning
Cities and neighborhoods that are energy-conscious are not planned around the automobile, but around public transportation and pedestrian walkways. These cities have zoning laws favorable to mixed-use developments, allowing people

to live near their workplaces. Urban sprawl is avoided by encouraging redevelopment of existing sites and the adaptive reuse of old buildings. Climatic conditions determine orientation and clustering. For example, a very cold or very hot and dry climate might require buildings sharing walls to reduce exposed surface area; a hot, humid climate would require widely spaced structures to maximize natural ventilation.

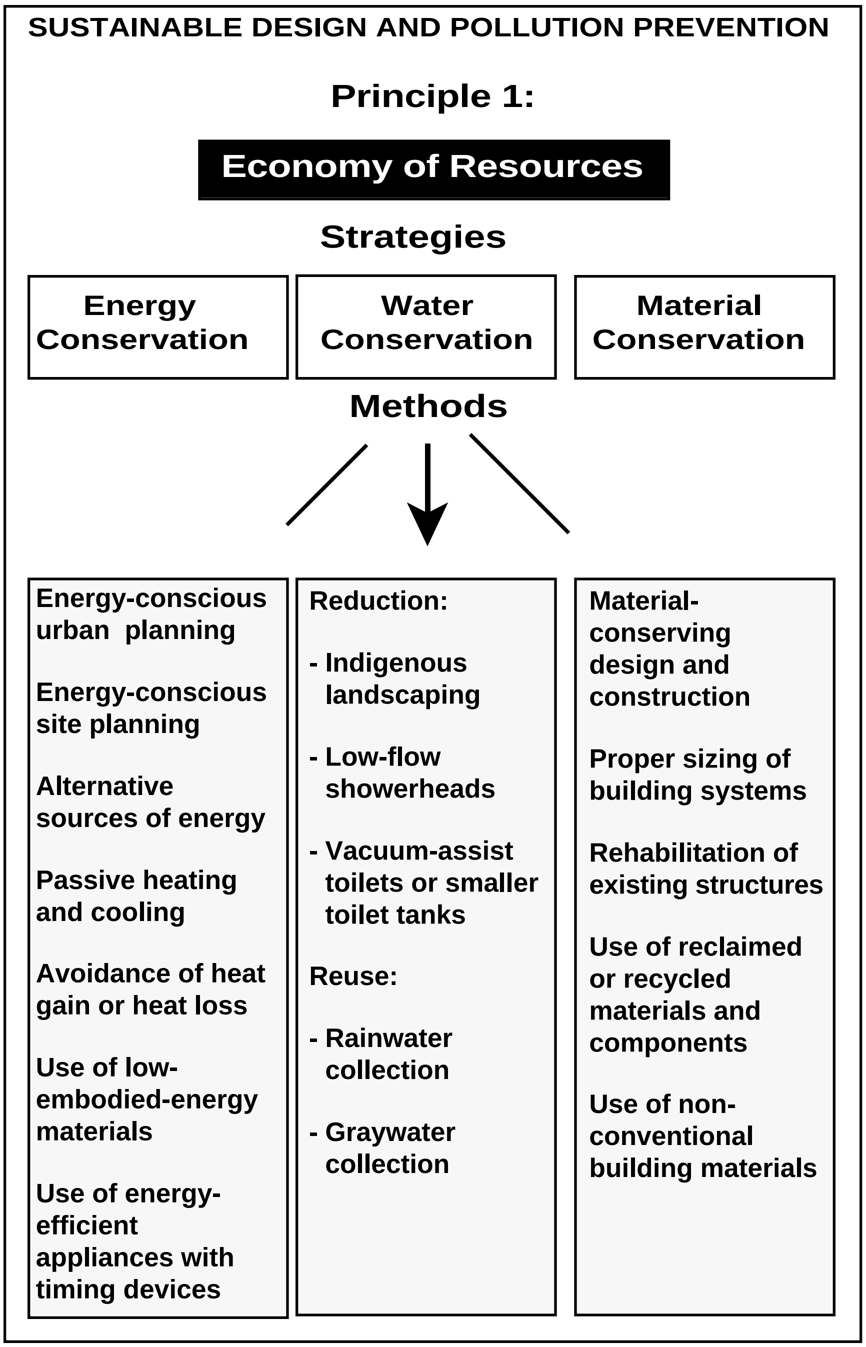


Figure 9: "Economy of Resources" methods of application.

Energy-Conscious Site Planning

Such planning allows the designer to maximize the use of natural resources on the site. In temperate climates, open southern exposure will encourage passive solar heating; deciduous trees provide shade in summer and solar heat gain in winter. Evergreens planted on the north of a building will protect it from winter winds, improving its energy efficiency. Buildings can be located relative to water onsite to provide natural cooling in summer.

Passive Heating and Cooling

Solar radiation incident on building surfaces is the most significant energy input to buildings. It provides heat, light, and ultraviolet radiation necessary for photosynthesis. Historically, architects have devised building forms that provide shading in summer and retain heat in winter. This basic requirement is often overlooked in modern building design. Passive solar architecture offers design schemes to control the flow of solar radiation using building structure, so that it may be utilized at a more desirable time of day.

Shading in summer, by plants or overhangs, prevents summer heat gain and the accompanying costs of air-conditioning. The wind, or the flow of air, provides two major benefits: cooling and hygienic effects. Prevailing winds have long been a major factor in urban design. For instance, proposals for Roman city layouts were primarily based on the direction of prevailing winds.

Insulation

High-performance windows and wall insulation prevent both heat gain and loss. Reducing such heat transfer reduces the building's heating and cooling loads and thus its energy consumption. Reduced heating and cooling loads require smaller HVAC equipment, and the initial investment need for the equipment will be smaller.

Aside from these tangible benefits, high-performance windows and wall insulation create more comfortable thermal environments. Due to the insulating properties of the materials, the surface temperatures of windows and walls will be higher in the winter and lower in the summer. The installation of smaller HVAC equipment reduces mechanical noise and increases sonic quality of the indoor space.

Alternate Sources of Energy
Solar, wind, water, and geothermal energy systems are all commercially available to reduce or eliminate the need for external energy sources. Electrical and heating requirements can be met by these systems, or combination of systems, in all climates.

Daylighting
Building and window design that utilizes natural light will lead to conserving electrical lighting energy, shaving peak electric loads, and reducing cooling energy consumptions. At the same time, daylighting increases the luminous quality of indoor environments, enhancing the psychological well-being and productivity of indoor occupants. These qualitative benefits of daylighting can be far more significant than its energy-savings potential.

Energy-Efficient Equipment & Appliances
After construction costs, a building's greatest expense is the cost of operation. Operation costs can even exceed construction costs over a building's lifetime. Careful selection of high-efficiency heating, cooling, and ventilation systems becomes critical. The initial price of this equipment may be higher than that of less efficient equipment, but this will be offset by future savings.

Appliances, from refrigerators to computers, not only consume energy, they also give off heat as a result of the inefficient use of electricity. More efficient appliances reduce the costs of electricity and air-conditioning. The U. S. Environmental Protection Agency has developed the "Energy Star" program to assist consumers in identifying energy efficient electronic equipment.

Choose Materials with Low Embodied Energy
Building materials vary with respect to how much energy is needed to produce them. The embodied energy of a material attempts to measure the energy that goes into the entire life cycle of building material. For instance, aluminium has a very high embodied energy because of the large amount of electricity that must be used to manufacture it from mined bauxite ore; recycled aluminum requires far less energy to refabricate. By choosing materials with low embodied energy, the overall environmental impact of a building is reduced. Using local materials over imported materials of the same type will save transportation energy.

Water Conservation

Methods for water conservation may reduce input, output, or both. This is because, conventionally, the water that is supplied to a building and the water that leaves the building as sewage is all treated by municipal water treatment plants. Therefore, a reduction in use also produces a reduction in waste.

Reuse Water Onsite

Water consumed in buildings can be classified as two types: graywater and sewage. Graywater is produced by activities such as handwashing. While it is not of drinking-water quality, it does not need to be treated as nearly as intensively as sewage. In fact, it can be recycled within a building, perhaps to irrigate ornamental plants or flush toilets. Well-planned plumbing systems facilitate such reuse.

In most parts of the world, rainwater falling on buildings has not been considered a useful resource. Buildings are typically designed to keep the rain from the occupants, and the idea of utilizing rain water falling on building surfaces has not been widely explored. Building envelopes, particularly roofs, can become rainwater collecting devices, in combination with cisterns to hold collected water. This water can be used for irrigation or toilet-flushing.

Reduce Consumption

Water supply systems and fixtures can be selected to reduce consumption and waste. Low-flow faucets and small toilet tanks are now required by code in many areas of the country. Vacuum-assisted and biocomposting toilets further reduce water consumption. Biocomposting toilets, available on both residential and commercial scales, treat sewage on site, eliminating the need for energy-intensive municipal treatment.

Indigenous landscaping — using plants native to the local ecosystem — will also reduce water consumption. These plants will have adapted to the local rainfall levels, eliminating the need for additional watering. Where watering is needed, the sprinkler heads should be carefully placed and adjusted to avoid watering the sidewalk and street.

Materials Conservation

The production and consumption of building materials has diverse implications on the local and global environments. Extraction, processing, manufacturing, and transporting building materials all cause ecological damage to some extent. There are input and output reduction methods for materials conservation. As with water, some of these methods overlap.

Adapt Existing Buildings to New Uses

One of the most straightforward and effective methods for material conservation is to make use of the resources that already exist in the form of buildings. Most buildings outlive the purpose for which they were designed. Many, if not all, of these buildings can be converted to new uses at a lower cost than brand-new construction.

Incorporate Reclaimed or Recycled Materials

Buildings that have to be demolished should become the resources for new buildings. Many building materials, such as wood, steel, and glass, are easily recycled into new materials. Some, like brick or windows, can be used whole in the new structure. Furnishing, particularly office partition systems, are also easily moved from one location to another.

Use Materials That Can Be Recycled

During the process of designing the building and selecting the building materials, look for ways to use materials that can themselves be recycled. This preserves the energy embodied in their manufacture.

Size Buildings and Systems Properly

A building that is oversized for its designed purpose, or has oversized systems, will excessively consume materials. When a building is too large or small for the number of people it must contain, its heating, cooling, and ventilation systems, typically sized by square footage, will be inadequate or inefficient. This method relates directly to the programming and design phases of the architectural process. The client’s present and future space needs must be carefully studied to ensure that the resulting building and systems are sized correctly.

Architects are encouraged to design around standardized building material sizes as much as possible. In the U. S., this standard is based on a 4'x8' sheet of plywood. Excess trimming of materials to fit non-modular spaces generates more waste.

Reuse Non-Conventional Products as Building Materials

Building materials from unconventional sources, such as recycled tires, pop bottles, and agricultural waste, are readily available. These products reduce the need for new landfills and have a lower embodied energy that the conventional materials they are designed to replace.

Consumer Goods

All consumer goods eventually lose their original usefulness. The "useful life" quantifies the time of conversion from the useful stage to the loss of original usefulness stage. For instance, a daily newspaper is useful only for one day, a phone book is useful for one year, and a dictionary might be useful for 10 years. The shorter the useful life of consumer goods, the greater the volume of useless goods will result. Consequently, more architectural considerations will be required for the recycling of short-life consumer goods.

The conventional term for consumer goods that have lost their original usefulness is waste. But waste is or can be a resource for another use. Therefore, in lieu of waste, it is better to use the term "recyclable materials." One way buildings can encourage recycling is to incorporate facilities such as on-site sorting bins.

Life Cycle Design

As discussed earlier, the Life Cycle Design principle embodies three strategies: pre-building, building, and post-building. These strategies, in turn, can yield specific design methods that will improve the sustainability of architecture. **Figure 10** shows how each method relates to the main strategies of Life Cycle Design. These methods focus mainly on reducing input. Consuming fewer materials lessens the environmental impact of the associated manufacturing processes. This then reduces the eventual output of the building ecosystem.

Pre-Building Phase

During the Pre-Building Phase, the design of a building and materials selected for it are examined for their environmental impact. The selection of materials is particularly important at this stage: the impact of materials processing can be global and have long-term consequences.

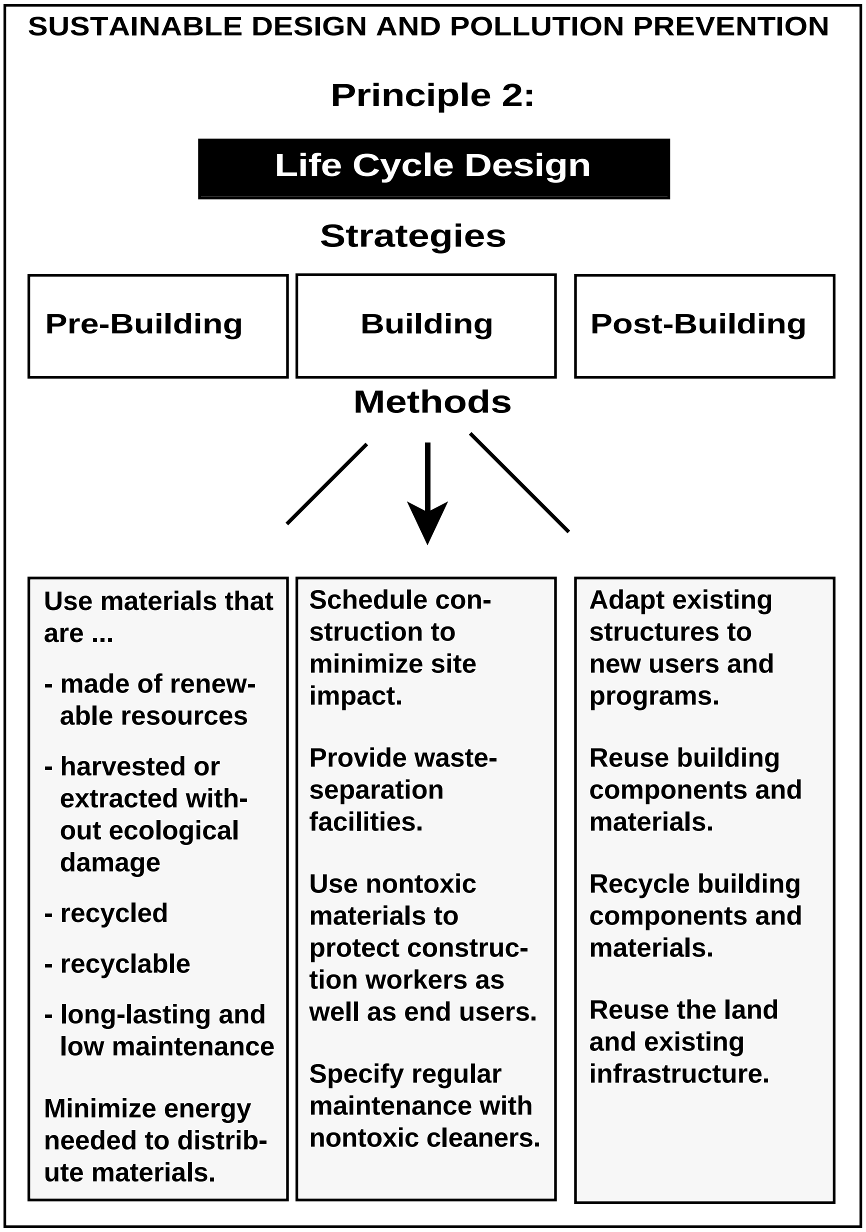


Figure 10: "Life Cycle Design" methods of application.

Use Materials Made From Renewable Resources

Renewable resources are those that can be grown or harvested at a rate that exceeds the rate of human consumption. Using these materials is, by definition, sustainable. Materials made from nonrenewable materials (petroleum, metals, etc.) are, ultimately, not sustainable, even if current supplies are adequate. Using renewable materials wherever possible reduces the need for nonrenewable materials.

Use Materials Harvested or Extracted Without Causing Ecological Damage

Of the renewable materials available, not all can be obtained without significant environmental effects. Therefore, the architect must be aware of how various raw materials are harvested and understand the local and global ramifications.

Use Recycled Materials

Using recycle materials reduces waste and saves scarce landfill space. Recycled materials also preserve the embodied energy of their original form, which would otherwise be wasted. This also reduces the consumption of materials made from virgin natural resources. Many building materials, particularly steel, are easily recycled, eliminating the need for more mining and milling operations.

Use Materials with Long Life and Low Maintenance

Durable materials last longer and require less maintenance with harsh cleansers. This reduces the consumption of raw materials needed to make replacements and the amount of landfill space taken by discarded products. It also means occupants receive less exposure to irritating chemicals used in the installation and maintenance of materials.

Building Phase

The methods associated with the Building Phase strategy are concerned with the environmental impact of actual construction and operation processes.

Minimize Site Impact

Careful planning can minimize invasion of heavy equipment and the accompanying ecosystem damage to the site. Excavations should not alter the flow of groundwater through the site. Finished structures should respect site topology and existing drainage. Trees and vegetation should only be removed when absolutely necessary for access. For sensitive sites, materials that can be hand-carried to the site reduce the need for excessive road-building and heavy trucks.

Employ Nontoxic Materials

The use of nontoxic materials is vital to the health of the building's occupants, who typically spend more than three-quarters of their time indoors. Adhesives used to make many common building materials can outgas — release volatile organic compounds into the air — for years after the original construction. Maintenance with nontoxic cleansers is also important, as the cleaners are often airborne and stay within a building's ventilation system for an extended period of time.

Post-Building Phase

During this phase, the architect examines the environmental consequences of structures that have outlived their usefulness. At this point, there are three possibilities in a building's future: reuse, recycling of components, and disposal. Reuse and recycling allow a building to become a resource for new buildings or consumer goods; disposal requires incineration or landfill dumping, contributing to an already overburdened waste stream.

Reuse the Building

The embodied energy of a building is considerable. It includes not only the sum of energy embodied in the materials, but also the energy that went into the building's construction. If the building can be adapted to new uses, this energy will be conserved. Where complete reuse of a building is not possible, individual components can be selected for reuse — windows, doors, bricks, and interior fixtures are all excellent candidates.

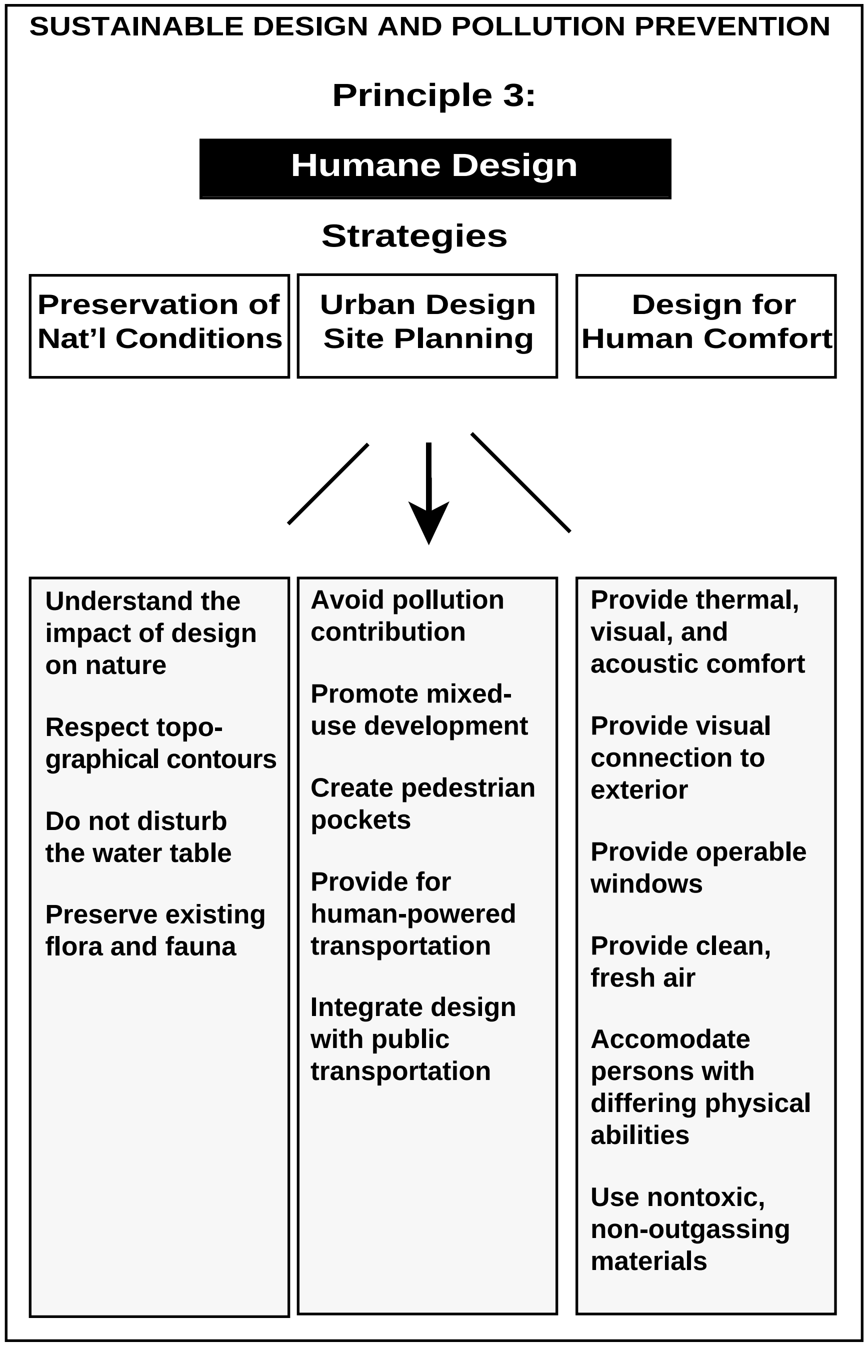
Recycle Materials

Recycling materials from a building can often be difficult due to the difficulty in separating different substances from one another. Some materials, like glass and aluminum, must be scavenged from the building by hand. Steel can easily be separated from rubble by magnets. Concrete can be crushed and used as aggregate in new pours.

Reuse Existing Buildings and Infrastructure

It has become common for new suburbs to move farther and farther from the core city as people search for "space" and "nature." Of course, the development of new suburbs from virgin woods or fertile agricultural fields destroys the very qualities these suburbanites are seeking. Moreover, in addition to the materials for new houses, new development requires massive investments in material for roads, sewers, and the businesses that inevitability follow. Meanwhile, vacant land and abandoned structures in the city, with its existing infrastructure, go unused, materials wasted.

Figure 11: "Humane Design" methods of application.



Humane Design

As described in the introduction, this principle embodies three strategies: preservation of natural conditions, urban design and site planning, and design for human comfort. These strategies, in turn, yield specific design methods that will improve the sustainability of architecture. **Figure 11** shows how each method relates to the three strategies of Humane Design. These methods focus primarily on improving the quality of life for humans and other species.

Preservation of Natural Conditions

Respect Topographical Contours

The existing contours of a site should be respected. Radical terraforming is not only expensive but devastating to the site's microclimate. Alteration of contours will affect how water drains and how wind moves through a site.

Do Not Disturb the Water Table

Select sites and building designs that do not require excavation below the local water table. Placing a large obstruction (the building) into the water table will disturb natural hydraulic process. If the water table is exposed during construction, it will also become more susceptible to contamination from polluted surface runoff.

Preserve Existing Flora and Fauna

Local wildlife and vegetation should be recognized as part of the building site. When treated as resources to be conserved rather than as obstacle to be overcome, native plants and animals will make the finished building a more enjoyable space for human habitation.

Urban Design and Site Planning

The methods associated with the Urban Design and Site Planning strategy apply sustainability at a scale larger than the individual building.

Integrate Design with Public Transportation

Sustainable architecture on an urban scale must be designed to promote public transportation. Thousands of individual vehicles moving in and out of area with the daily commute create smog, congest traffic, and require parking spaces.

Promote Mixed Use Development

Sustainable development encourages the mixing of residential, commercial, office and retail space. People then have the option of living near where they work and shop. This provides a greater sense of community than conventional suburbs. The potential for 24-hour activity also makes an area safer.

Design for Human Comfort

Provide Thermal, Visual, and Acoustic Comfort

People do not perform well in spaces that are too hot or too cold. Proper lighting, appropriate to each task, is essential. Background noise from equipment or people can be distracting and damage occupants' hearing. Acoustic and visual privacy also need to be considered.

Provide Visual Connection to Exterior

The light in the sky changes throughout the day, as the sun and clouds move across the sky. Humans all have an internal clock that is synchronized to the cycle of day and night. From a psychological and physiological standpoint, windows and skylights are essential means of keeping the body clock working properly,

Provide Operable Windows

Operable windows are necessary so that building occupants can have some degree of control over the temperature and ventilation in their workspace.

Provide Fresh Clean Air

Fresh air through clean air ducts is vital to the well-being of building occupants. The benefits of fresh air go beyond the need for oxygen. Continuous recirculation of interior air exposes people to concentrated levels of bacteria and chemicals within the building.

Use Nontoxic, Non-Outgassing Materials

Long-term exposure to chemicals commonly used in building materials and cleaners can have a detrimental effect on health.

Accommodate Persons with Differing Physical Abilities

One aspect of sustainable design is its longevity. Buildings that are durable and adaptable are more sustainable than those that are not. This adaptability includes welcoming people of different ages and physical conditions. The more people that can use a building, the longer the building's useful life.