THE TEACHING OF COMPUTER ASSISTED SUSTAINABLE ARCHITECTURAL DESIGN

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ABSTRACT

Sustainable architecture is high-tech, energy and resource conserving architecture that sustains and increases the human and natural carrying capacity of the host environment. This paper presents a computer assisted design process to teach sustainable architectural design.

The energy performance of a base case building in each of four climates and cultures is presented. The climates are: Phoenix (hot-dry), Minneapolis (cold-dry), Boston (cold-humid), and New Orleans (hot-humid). Keeping the host climate, site, building size and function constant; but varying materials, shape and design concepts, each base case is iterated through a series of computer assisted re-designs to transform each base case building into an architecture representative of its regional climate and culture.

Traditional technologies and concepts produce traditional regional architecture. New technologies and concepts produce forms expressive of an emerging high-tech, high-touch, low energy society.

The paper presents computer generated work by the author and his students. It also presents an interim evaluation of the successes and difficulties of conducting a 'paper free' design studio.

INTRODUCTION

Building designers who ignore environmental constraints waste resources and destroy cultural and architectural contexts. Sustainable Architecture is defined as high-tech, high touch, resource conserving buildings and cities that sustain and increase the human and natural carrying capacity of the host environment.

The concept of the environment as our HOST is stressed. If our host cannot support us, we must leave. When we live beyond our limits we must change the way we live, or die. Worldwide degradation of natural environments and their capacity to support urban-industrial development threatens all life. We must learn to live better using less, or witness the decline of humanity and the destruction of it's natural support systems.
History tells of societies who temporarily tore the good life from some place on earth then died. Bleached marble mark the graves of Hellenic Greece. A few arches and highways litter once proud Rome.

A nation must develop resources to sustain its people. Mines are mined, farms are farmed, factories are built. This we have done. But, sustainable cultures must develop their people to sustain their resources. This we have yet to do.

As the forces that shape society change, its buildings and cities must change. The age of petroleum is dying. The authors of BEYOND OIL predict that the last oil well in the United States will be drilled sometime between 1993 and 2005. We are entering the post petroleum age of electronics and we are unprepared.

No where is the need for change more evident than in the United States. Our aging factories, built during World War II, are less efficient than the post war factories of Japan and western Europe. Our cities were constructed when energy was cheap; theirs when energy was expensive. With inefficient production and a high overhead, we cannot effectively compete in world market places. Our way of life cannot be sustained. Quality of life is dropping. We must change, or die.

Efforts to keep the good old days and ways are great. The 1970's OPEC embargo and the oil glut recessions of the 80's have been particularly destructive to our economy. Yet, these events have stimulated research in resource conserving architectural design. They have also stimulated advances in computers now available to architectural educators, researchers and practitioners.

An as yet weak but real change in architectural design concepts and techniques is being researched and developed in some schools of architecture. Computer graphic and analysis tools are being used to simultaneously evaluate the economic, cultural, spatial, thermal, and structural inputs essential to develop an architecture that expresses and sustains balanced human and natural ecologies. Where possible, technical constraints are simultaneously spreadsheeted or invisibly embedded into graphic programs.

THE DESIGN PROCESS

This design process is dependent upon:

a: an analytical understanding of the sustainable micro-climatic and environmental characteristics of the host site.
b: an awareness of resource conserving materials and technologies
c: the use of simplified computerized energy analysis programs, ( REENERGY is used in this illustration)
d: familiarity with any computer graphic design program, ( AUTOCAD is used in this illustration)
e: a disciplined willingness to accept the forms generated by the process as legitimate architectural design solutions.
THE PROCESS ILLUSTRATED

The process is illustrated using a base case building in four distinct climates. The climates are: Boston, (cold-humid); New Orleans, (hot-humid); Phoenix, (hot-dry), Minneapolis, (cold-dry). The base case is a 40,000 sq.ft., four story, brick clad office building. In the base case all materials, U. factors, CLFD's, areas, volumes and uses, HVAC heating and cooling plant types and efficiencies are constant. Only the climate data for each host site differs.

These characteristics are tabulated in Figure 1.

The physical characteristics of the base case office building is illustrated in Figure 2.

Bioclimatic diagrams, first developed at Princeton by Victor and Alidar Olgay and later further developed for use by the A.I.A. Energy Workshop program and others, are used to illustrate the climates for the four cities.

The bioclimatic diagrams indicate a need for a building that keeps people warm during the Minneapolis and Boston cold winters; and a building that keeps people cool during the New Orleans and Phoenix hot summers.

The diagrams indicate no need for interior air cooling during the summer months in Boston and Minneapolis. They also indicate that the host climates of New Orleans and Phoenix should require only a small amount of interior air heating during their mild winter seasons.
Figure 3. Boston Bioclimatic
A cold-humid climate requiring air heating day and night except during midday hours in June, July, and August. No summer air cooling is needed as monthly average temperatures seldom exceed the comfort zone.

Figure 4. Minneapolis Climate
A cold-dry climate requiring air heating day and night except during midday hours in June, July, and August. No summer air cooling is needed as monthly average temperatures never exceed the comfort zone.

Figure 5. New Orleans Climate
A hot-humid climate requiring interior air movement and cooling from mid-April through mid-October. Small amounts of air heating are required from November through February. Dehumidification is required for human comfort.

Figure 6. Phoenix Climate
A hot-dry climate requiring day and night cooling from April through October. Small amounts of interior air heating are required from October nights through March. Humidification is desired for human comfort.
It is stressed that the bioclimate diagrams indicate no need for air cooling in Minneapolis and Boston and only small amounts of air heating in New Orleans and Phoenix.

Using simplified energy analysis programs, the energy consumption rates are calculated for the base case building in the four cities. These are illustrated in figures 7, 8, 9, and 10.

It is evident that the base case building as designed ignores its host environments and climates. It is an energy hog building.
The average base case building requires air cooling in all climates. On the average, it must be heated below 12 °F and cooled above 30 °F. It will consume 18,248 gallons of oil and 732,643 KWH of electricity each year. If its primary energy comes from petroleum, it will require 66,620 gallons of #2 fuel oil each year.

Annual energy consumption data for the components of the four base case buildings are tabulated in Table 11.

These are energy hog buildings and yet they are typical. On the coldest day of the year in most U.S. cities the typical office building will be cooling, not heating, its inhabitants.

It will discharge hot air on the coldest days. These typical buildings destroy our climate, our environment and our cultures. This design insanity should not be sustained.

At this point in the design process the designer is asked to evaluate design strategies to reduce any and all building energy consumption rates. Design strategies as listed in the A.I.A. Energy Workbooks and strategies suggested by plotting the heating and cooling balance points on the host climate bioclimatic diagrams form the basis for successive design iterations of the base case design for each climate.

Figure 11. Energy Data. In successive design iterations several common design strategies are suggested. These are: shaping the form and altering occupancy schedules to utilize day lighting. Lighting loads are reduced from 2.5 watts to .7 watts per square foot. Equipment loads are cut from 1.5 watts to .7 watts per square foot by replacing electric with electronic equipment. Occupancy times and levels, where possible, are adjusted (i.e. flex times and or two shifts of 200 people as opposed to one shift of 400.)

Other common strategies are to reduce internally generated heat loads for all base case buildings in all climates to levels that do not degrade, and perhaps enrich their sustainable host environments.

On the other hand very different design strategies reflecting the unique climates of the host environments are successively iterated through the energy analysis computer program.
For example, in Boston and Minneapolis all glass is oriented to the south. Sun shading and day-lighting devices are installed to project day-lighting into the building at all times; shade the glass during the 'cooling season'; yet, permit direct solar heating during the 'heating season'. In both cases a selective amount of the building is earth sheltered to reduce infiltration and climate design extremes, (from 9 F and -12 F to 51 F and 44 F). An annual least energy consumption balance of internal heat and external loads determines the amount of earth shielding and the geometry of solar shading devices for each building. Where ideal south facing slopes are not available, earth sheltered structures in flat land are suggested. Ground earth temperatures are used to pre-condition and thus reduce ventilation heating and cooling loads. Exterior insulation and internal thermal mass strategies are suggested.

In New Orleans all exterior surfaces are completely shaded from April through October. The roof is shaded to lower solar gain and increase effective cloud cover. Exterior insulation and low density building materials are selected to reduce CIDF factors, lower building material thermal storage and reduce cooling and heating equipment operating times. Horizontal shading devices are used to increase air pressure on windward surfaces; window openings are shaped and sized and interior walls organized to maximize through ventilation. Ceiling fans are used to reduce air cooling demands.

In Phoenix, the harsh climate design extremes are lowered (from 34 F and 107 F to 70 F), by earth sheltering the building. (An above ground building of low density, high quality insulation materials would also be appropriate). A lattice shades all surfaces of the building from March through October. It permits solar gain from October through April and nightly dissipation of internal heat through deep sky radiation. Moderate ground temperatures are used to lower ventilation heating and cooling loads. Indigenous plants to lower summer and raise winter ground surface temperatures are used. Evaporative water processes, while viable, are discouraged as a strategy that degrades a scarce host environmental resource.

The above illustrative design strategies are arrived at through iterations of computer energy analyses and CAD sketches. The designer sketches a 'what if' architectural concept, then runs an energy analysis to verify the concept, then initiates a new 'what if' architectural concept and new energy analysis.

It is important that the energy analysis be easy and rapid for use by the designer. A simultaneous spreadsheet analysis producing instant 'bottom line' results is ideal for the conceptual design process. More sophisticated and accurate analysis programs should be used as the design is refined.

Examples of revised Building component rates of heat gains and losses based on the above strategies are illustrated in figures 12, 13, 14, and 15. It should be stressed that these graphs will change as operating parameters and design strategies change.
Figure 12. Boston Mod. 2 Rates

Figure 13. Minneapolis

Figure 14. New Orleans Mod 2

Figure 15. Phoenix Mod 2

Annual energy consumption data for the modified designs are presented in Figure 16. In all cases if 30% of available direct solar gain is recovered from passive thermal storage systems no fossil fuel energy is needed for heating. If natural ventilation is used, air cooling requirements are greatly reduced. It is again stressed that different operating parameters or design strategies will produce different energy rates and annual consumption demands.
The results are dramatic. Site energy per square foot per year drops an average of 90,000 BTUs per square foot per year. Source Energy drops an average of 200,000 BTUs per square foot per year. The modified designs use about 14% of the site energy and source energy. An average of 58,000 gallons of fuel oil is conserved by the average modified building each year.

From a building owner's viewpoint the revised designs mean an 84% reduction in annual energy operating costs. The owner can make better than average profits when office rentals are in demand and when there is an excess of office rental space, he can lower his rental rates far below that of average office buildings and still make profits while his competitors are forced out of business due to high energy overhead costs.

The natural resource savings are equally dramatic. In all of the sites sufficient solar energy is available to provide all necessary heating. The average building essentially needs electrical energy only for lighting, equipment and small amounts of cooling. The drain on the earth's resources drops to about 100,000 KWH per year. This is within the range of energy that can be provided by natural resources.

It is again stressed that the energy consumption data illustrated in figure 16 and the energy consumption rate diagrams of figures 12, 13, 14, and 15 are for illustration only. As any parameter of the design equation changes, the building forms, component heating and cooling rates and annual energy consumption loads and resource demands will also change.

From an architectural studio teaching viewpoint, the process provides a simplified almost 'painless' computer assisted process to guide the student architects search for architectural forms that respect their host environments, cultures and climates.

The architectural forms for the modified designs are illustrated in figures 17, 18, 19 and 20.
These schematic designs are beginning to become sustainable architecture. They do not degrade their host environments. Their wastes can be absorbed into sustainable host environments. Each of the modified designs, shaped as needed to better function within their host environments, begins to exhibit regionally and culturally recognizable characteristics generated by rational computer assisted design concepts and processes.

As the designer refines the design processes (hourly weather data, advanced skinsulations, selective glasses, advanced electronics etc.), and the analysis processes (more advanced energy analysis computer programs), the building form will change to meet the needs of its host environment, climate and culture.
This process produces high tech-high touch regionally expressive architectural forms. Even slight changes in climate, function, component technologies and culture can be expressed with subtle but real changes in the design.

Additionally, the designer may combine different functions within a building to balance its resource needs with its host environment. Excess heat generated by an office building during the day can be used to heat homes at night. The logic of combining offices, residences, and shops into one building, long enjoyed in most countries, is obvious. These cultural, resource and economic advantages foretell the design of mixed use buildings in sustainable communities as a major design effort of the next generation.

However, these changes can only occur with significant changes in university architectural design studios, then in professional practice and finally in our society.

Almost effortless computer analysis tools must be perfected and integrated into our existing intuitive, form conscious design studios. Few faculty and students can simultaneously engage in analytic and synthetic design processes. 'Intuitive' designers often lack rational analytic discipline and 'rational' designers often lack the intuition of 'gifted' designers.

Typical university intuitive paper design studio processes cannot attempt to solve the important architectural problems of society. Our profession and our society suffers this impotence. This must change.

Almost effortless computerized analytic and synthetic tools are needed to integrate cultural, environmental, technological and economical determinants of architectural form into the design process.

Successes and Difficulties In The Design Studio.

The process described in this paper has been used for approximately four years in a design studio at Texas A&M with increasing degrees of success. This process relies heavily upon the works of the many who have developed climate sensitive design concepts and computer assisted analysis programs. It is particularly indebted to the work of Victor and Alidar Olgyay and to The American Institute of Architects Energy Professional Development Program.

Difficulties: The constant changing of graphic design programs makes difficult the mastery of computer assisted conceptual design. It takes time for the linkages between our minds and our computers to become as invisible to the design process as the linkages between our minds and our pencils. As computer programs become more 'user friendly' this difficulty should lessen.

Students have difficulty in simultaneously performing analytic calculations while conceiving architectural forms. Simultaneously
spreadsheets on one computer while drawing on another is difficult. This difficulty may be eased by burying analysis tools in the graphic design program. We are now working on such a program.

The concept of the architect as an artist makes difficult the acceptance of new forms generated by rational processes. Too often students reject rational solutions for stylish preconceptions. The acceptance of architecture as a rational synthesis of not always understood and often conflicting constraints is and will continue to be strongly resisted by stylish academies. This may change as artists embrace computers and as the soft sciences harden.

Successes: Every student to date has developed an increased awareness and capability in architectural design. Their design processes are less painful, their solutions are more rational and also more sensitive to a wider range of constraints than the typical form driven studio.

In The Real World, it is obvious that sustainable architecture is enjoyed by countries and cultures that were shaped when energy was scarce. Such is not the case in the U.S. Our building codes and zoning laws must change to permit higher density, mixed use design concepts. These changes will come as the economic, cultural, resource, environmental and economic advantages of computer assisted integrated sustainable design become apparent. As these advantages become obvious, computerized design education will be followed by computerized architectural practice.

CONCLUSIONS: The apparent complexities of today's world has made difficult the architectural synthesis and expression of the many factors that shape our lives. Our best is not enough.

The petroleum age we are leaving centralized, politicized, urbanized and industrialized society. The inevitable forces shaping the electronics age we now enter will decentralize societies into smaller high-tech-low-energy, regionally expressive and sustainable communities. If one can work anywhere, one will choose to live in richly balanced sustainable human and natural environments.

As the forces that shape society change, the architecture of it's buildings and cities must change. Great change is upon us. We have the technology and the knowledge to sustain humanity; but do we have the will?

IF WE DO, the change will depend on computer assisted analysis and synthesis in university design studios, and then in the offices of architects practicing a more sustainable architecture.

IF WE DON'T... We study the ruins of other cultures who failed to sustain themselves. Who will study us?