Environmental Building Design: Forms of Emergy

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ABSTRACT
The proposition that self-organization for maximum power could offer criteria for environmental building design is compelling, but what forms of building does this indicate? The use of emergy analysis overcomes the discounting of environmental energies, but the literature on emergy and building design suggest two quite different scales of objectives that might be considered. The first is to optimize buildings or their components to achieve a thermodynamic minimum, following the examples of Pulselli et al (200&). However both R.A. Adams (1988) and T. Abel (2007) make the point that buildings are tools of larger social processes and their value must be evaluated according to those hierarchies. This approach opens the topic of sustainable design to its proper scope, the hierarchy and expression of power.

POWER OF BUILDINGS
Where would we be without buildings? They provide the environments that make most other human achievements possible and have been integral to every stage of civilization, enabling and then symbolizing each new form of production and social organization. Early agricultural states built pyramids and temples, global metropolises build glass skyscrapers and museums, and if new sources of energy are successfully developed, we can expect radically new kinds of “buildings” in space or on other worlds. The expectation is that human civilization will continue to grow in power and complexity unless, or until, it encounters an insurmountable limit. In the view of systems ecology, buildings are tools in a vast evolutionary process of self-organization, whose overarching goal is to maximize their power. (Lotka, 1922, Odum, 1983, Abel, 2007)

Maximum power is not a simple concept. It seeks the prosperity of both individual buildings and of the whole biosphere, rewarding cooperative exchanges as much as competition. The principle has been inferred from the behavior of successful ecosystems, which support larger populations and obtain more work from available resources by creating a rich hierarchy of niches and intricately indirect forms of interdependence. Put more directly, the goal of environmental building design is to develop arrangements that reconcile the local with the global. We still lack a true “science of sustainability” with which to achieve that goal, but systems ecology provides the best guide, making the principles of successful eco-systems intelligible and the networks of exchanges visible.

In common usage, the terms energy and power are interchangeable, but the distinction is critical. In formal terms, energy is the capacity to do work, while power is the rate at which energy can be converted to work. Odum (1996) demonstrated that maximum power occurs at intermediate levels of efficiency, which is not as abstract as it sounds. In everyday circumstances we constantly trade energy for power, wasting a bit of energy to accomplish work at a useful rate. The slower we drive a car, for example, the greater the fuel efficiency, but what good does it do to drive at walking speeds? We drive fast enough to make the extra expenditure seem worthwhile.

However the literature on the application of systems ecology to buildings suggests quite different scales of maximum power objectives (Brown, 2003, Pulselli, 2007, Meillaud, 2005). The first objective, at the individual building scale, is similar to the automobile example. Buildings would be much more efficient if they delivered services at a lower rate, but we seek the minimum expenditure that will maintain contemporary power standards for heating, cooling, lighting, information flow, and
so on. Emergy analysis helps us understand the full network of natural and human work required to deliver those services and the tradeoffs between building construction and operation required to minimize waste at a particular power level, but it also makes visible the larger dimensions of the question. Buildings of greater efficiency ultimately make energy available for other uses, which can support more people, larger buildings, or be used for other kinds of expenditures.

So the larger scale of objective would be to maximize the power of the ecosystem in which the building operates. In other words, the energy “wasted” by an individual building can support other processes in a mature ecosystem, creating greater opportunities for interaction and greater overall prosperity. Emergy analysis can help reveal the interconnections of that prosperity, but it also requires a full account of the social and economic arrangements. As Odum (2007) and Abel (2007) have argued, economic hierarchies are a significant feature of social self-organization, so we must also understand the material and symbolic role of architecture in those hierarchies.

**ARCHITECTURE**

If we examine the latest crop of net-zero energy buildings—the headquarters for MASDAR in Abu Dhabi (2009) or the Bullitt Center in Seattle (2012)—they show a distinct family resemblance. Their flat roofs are covered with photovoltaic panels that are extended to the maximum area allowed on the site in a clear expression of the formula for calculating net-zero, that is, the environmental energy captured on-site exactly meets the operating energy demands of the building. Much of the value of net-zero buildings derives from just such a visible form of expression. It provides an environmental “style” of the kind expected by editors, commentators, the general public, and especially by clients, who want visible evidence of their investment and of the reduced environmental footprint of their building. The problem with this formulation is twofold: it only addresses the energies required to operate the building—to provide heating, lighting, cooling, and electric power—and so neglects all the energies required to manufacture and maintain the buildings, and it also discounts the value of renewable, environmental energies, counting them as free. At the end of the day, the net-zero formula produces the architectural style of a net-zero utility bill.

The act of “reading” and interpreting the signs of architectural energy performance is a complex cultural process. Such indicators can be used accidentally, incorrectly, or even deceptively as “greenwash,” and because buildings last longer than the cycles of cultural fashion or technological change, the meaning and value of a specific indicator may shift. As a rule, contemporary architects distrust the use of explicit stylistic strategies for all those reasons, but it is precisely through descriptions of style that policy makers and the general public have been taught to understand and evaluate architecture. Style plays a complex role in cultural self-organization, so we have to explore the connection of the term to energy.

**Energy Forms**

Richard Adams coined the term “energy form” (1988) to describe the full range of material and social structures “capable of doing work” in order to help him understand the dynamics of cultural evolution, and to overcome the narrow focus on fuels or their scarcity. The term energy form is provocative to architects, for whom the relation between form and function has been a topic of debate for nearly two centuries, since roughly the beginning of the modern period and the explosion in populations of people and buildings (DeZurko, 1957; Collins, 1965; Rykwert, 1980). What had previously been a matter of slow evolution over many generations—types and styles of buildings—became a matter of rapid change and contentious debate. The modern meaning of style was linked initially to the development of artistic connoisseurship and then to broader accounts of socio-cultural change and evolution. Like styles in clothing and cuisine, what was originally a feature of specific peoples or places became a matter of choice, and then of purposeful variety, and eventually of diffusion research and “branding.” Accounts of the adoption or diffusion of new products and technologies have grown from an academic research topic to strategies for marketing campaigns. (Everett, 1995)
The idea of function in architecture had itself been largely translated from developments in biology. Gottfried Semper’s reading of the comparative anatomy of Georges Cuvier in the early nineteenth century (Cache, 2002; Mallgrave, 1996) is a key example, and leads along many pathways to Louis Sullivan’s well known formulation “form ever follows function.” (Sullivan, 1896) The implicit purpose of such formulations was to provide architects with a formula to navigate the accelerating changes in their work and so required an account of the evolution of architecture. Through the 19th and 20th centuries, architectural types and styles were examined as the visible evidence of the process of evolution in the built environment, just as species were the visible evidence in biology or genre in literature. Simple concepts of function, based on structural efficiency, methods of construction, or kinds of use, initially provided a compelling theory for the mechanism of evolutionary change, but ultimately proved inadequate to the full complexity of cultural change. (Collins, 1975; Fernandez-Galiano, 2000)

Adams originally studied with Leslie White, who had reduced the whole matter to a baldly deterministic proposition in the 1940s: “We may express this concisely and succinctly with the following formula: \( E \times T \times C \), in which \( C \) represents the degree of cultural development, \( E \) the amount of energy harnessed per capita per year, and \( T \), the quality or efficiency of the tools employed in the expenditure of the energy.” (White, 1949) Adams sought a more nuanced, less deterministic version of that proposition, based on the increased understanding of non-linear thermodynamic systems. As Adams explained his concept,

“Energy is seen both in the broader context of including all mass-energy forms relevant to the doing of work and as a major variable in the evolution of life in general and therefore the human species in particular. Any form of energy, or ‘energy form,’ whether solar, biochemical, human, mechanical, nuclear, neural, or what you will, that operates in societal contexts can be seen on the one hand as an object to be controlled and manipulated by man and on the other as an independent variable in which human activities merely form a part.” (Adams, 1988)

Adam’s distinction helps explain the two scales of objectives as experienced by designers, who determine the specific forms of buildings, but must operate within larger “energy forms” beyond their professional reach. It poses a fundamental dilemma of environmental building design, whose claims can only be tested over generations. Adams described this difference in a comparison between the proximate causes used in functional biology and the selection explanations offered by evolutionary biology. “Selection explanations are used precisely because natural process is stochastic and accidental, composed of unpredictable assemblages with often wildly unpredictable consequences.” The optimization of building emergy use can be subject to functional analysis and proximate causal explanations without resorting to selection explanations, but different strategies and techniques are required to reconcile design projects with the indeterminate process of cultural evolution.

**Glass Walls**

Buildings are bioclimatic engines that modify the local climate to make them useful for human activities. They transform energy in a variety of forms to support the activities of occupants. In the last two hundred years, buildings have increased their capacities in virtually every dimension, from the work required to obtain, prepare, transport, and assemble the highly-refined materials of their construction to their capacity to regulate their internal climates and to deliver even more highly refined flows of information and entertainment. This period has been a classic growth-phase, with the rapid proliferation of relatively inefficient buildings of increasing size and variety, as the work of construction and operation has shifted from the limited reservoir of renewable flows and human power to the much greater capacities of fossil fuels. Through the nineteenth and twentieth centuries, many new types of buildings emerged with dramatic new capacities.

While data on historic building energy usage is far from complete, the evidence shows a steady increase in building energy use and energy intensity (per unit area) from the early nineteenth century until the energy supply crisis of the mid-1970s. In a recent paper, Oldfield et al charted five “energy generations” of tall buildings in New York, beginning in the 1880s, with each generation representing
an increase in scale, capacity, and intensity made possible by the mobilization of ever greater flows of power. (Oldfield, 2009)

The first phase began in the post-Civil War period with the early “skyscrapers,” which although taller, were still fundamentally climate-driven buildings that only provided central heating. They largely relied on daylighting for illumination and ventilation for cooling, both provided by windows, which effectively limited the depth of typical floor plates. With the growing density of New York in the early twentieth century, the city passed a progressive zoning law in 1916 to guarantee the availability of daylight in all buildings. The effect was to make new buildings even taller and more slender, increasing their ratio of surface area to volume, and thereby increasing the vertical transportation and heating requirements, both paid for with increased fuel consumption.

More dramatic increases occurred through the following decades as new technologies provided new services such as air conditioning and efficient fluorescent illumination that reduced the importance of windows and freed buildings to increase in bulk. New techniques of manufacturing and assembly made all-glass building skins possible, so while the bulkier buildings had reduced surface areas, those glass surfaces required more power to manage their environmental effects. Taken together with the new requirements for air conditioning, lighting, and telecommunications, the buildings of the 1950s to 1970s demanded steadily increasing amounts of power to operate. The use of steel for structural frames, aluminum and glass for curtain walls, the development of lighter-weight, disposable assemblies for interiors, and the increased speed of construction dramatically increased the work, energy, and materials involved in building construction and maintenance.

Whether we call them types or styles of buildings, each of these “energy-generations” is now imbued with cultural associations that are broadly recognizable, even if their connection to energy consumption is not explicit or widely understood. The all-glass high-rise, in its size and in its specific palette of materials, signals a civilization of unprecedented wealth derived from the unleashing of fossil-fuel reserves. These are energy-forms that represent a particular maximization of power, and which serve both as goals for societies without such power and as central emblems of newly global cities. The boom of the post-war period was slowed by the energy shocks of the 1970s, and not surprisingly the all-glass wall became a central issue in the next generation of buildings.

The initial reaction to the energy supply crises was simple conservation—re-setting thermostats, decreasing ventilation rates, lowering light levels, altering work schedules, and so forth—effectively reducing the power of services delivered by buildings. But more efficient approaches were quickly developed, reducing energy consumption, but continuing the increase in capacities and services provided (especially information delivery and feedback). The multiple inefficiencies of all-glass curtain walls were revealed in many studies, and wall-to-window ratios were even regulated in some building standards. But as the period of crisis and high fuel costs passed, the all-glass wall was transformed by the development of “smarter” glass assemblies, and shifted from a sign of conspicuous consumption to an emblem of more efficient high-powered buildings.

**Efficiency**

A critical element of the increases in building efficiency was the development and adoption of energy performance codes. ASHRAE Standard 90 was the first building energy standard, developed in the mid-1970s, and it established energy consumption goals that were 50% lower than contemporary norms. With energy costs still quite low since that time, most buildings have been built more-or-less exactly to the performance requirements in effect at the time of their construction. With increased awareness of environmental topics, global climate change most recently, there has been a push to further improve building energy performance. The standard set by ASHRAE has been incrementally reduced over the last 30 years, with more recent calls to reduce it by 30% below current consumption norms. But each reduction sharpens the question, how efficient should we make contemporary buildings, how much waste is acceptable?

Building performance standards are intended to regulate the fuels purchased annually to support the operation of buildings. It is in this context that net-zero energy buildings have been developed, and
they represent the logical conclusion of performance standards based on annual operating energy. However operating energy represents only part of the power flow required to construct and maintain contemporary buildings. Before we can even set performance goals, we have to establish the boundary of analysis and the metric on which it will be based. The new voluntary standards, in particular the LEED suite of standards first introduced by USGBC in 1998, have addressed part of that question. They explicitly include a wide variety of environmental costs, but they lack a rigorous metric with which to reconcile the costs and effects of different environmental impacts.

It is this shortcoming that emergy analysis can mostly readily overcome, providing a common measure of the different fuels and forms of work involved in the construction and operation of buildings, and accounting for work of “free” environmental services. Unfortunately there are only a few detailed studies of emergy use in the construction industry, so the first challenge is the development of more comprehensive accounting. (Odum, 1996, Buranakarn, 1998; Brown, 2003; Meillaud, 2005; Pulselli, 2007, Srinivasan, 2011). Much of that work will require the translation of data on building fuel usage into emergy terms, and adapting the growing body of life-cycle and embodied energy research to emergy terms.

In their 2007 article Pulselli et al identified the three principle components of building emergy use, manufacturing and construction, maintenance and repair, and annual operation including heating, cooling, lighting, etc. The boundary of analysis is drawn around the building, but to combine these different elements requires the definition of a useful life over which to amortize the investment of construction. With that refinement, an effective annual emergy flow can be determined and the building scale design goal is then to minimize the fuels, services, and materials invested to enable the building to appropriately capture renewable energies.

The challenges to this method are similar to those faced by all current standards, which begin by determining the norms for different building types and using them to set goals. Developing standards from norms is quite typical, but generally leads to the kind of incremental approach we have seen with building standards in the last few decades and highlights one of the strongest appeals of using emergy accounting as a physically-based, thermodynamic standard. Once the spatial and temporal boundaries of analysis are established, a thermodynamic minimum for that particular construction can be established.

But this procedure raises a number of challenging questions. The first of which is shared with all contemporary energy codes, which are typically normalized to the area or volume of the building, and so describe the relative efficiency of the building assembly, but conceal any of the effects of size. A building of 150 square meters occupied by a family of four could have the same Emergy Use Intensity as the multiple houses of a wealthier family (sej/m2, sej/m3). The alternative is to normalize the emergy flow to the numbers of people that use or occupy the building (sej/person), and that makes evident the dramatic inequities that exist among individuals and reminds us that people, not buildings, are the real engines of consumption. The deeper issue, that calls the simple use of emergy minima or building efficiencies into question, is the spatial and temporal scales at which the maximum power principle actually operates.

**Design**

Buildings are complex tools used by people in various social and economic arrangements, and whose value is established according to the hierarchies that emerge in those arrangements over time. Odum’s fifth principle of thermodynamics argues that such hierarchies develop in self-organizing systems to maximize their overall power and complexity. This principle would suggest that building performance standards should be based on social and economic positions. Although this seems a radical proposal, we already accept dramatically different amounts of building energy consumption based on the wealth and position of the people or institutions. In Adams’ terms, we must learn to see energy in all its forms, in its material and symbolic forms. This opens sustainable design to its proper scope, the hierarchies and expression of power, but can we translate it into a design principle or do we merely risk freezing transient social advantages?
A larger goal of environmental building design is to help prevent the more dramatic “selection” techniques of self-organization: catastrophic population collapse through famine, disease, and war. More efficient or high-performance buildings are merely tools in the overall process of human self-regulation, and have to be evaluated in their contribution to social and economic hierarchies. Put more simply, our commonsense judgments about wealth—how much is too much—can be understood as techniques with which to regulate social hierarchies and ensure that they serve the common good. As we reconsider our current forms of building, tabulating the total environmental cost of spectacular assemblies like the all-glass wall, the common good is the final objective and metric.

REFERENCES