II

RESEARCH ARTICLES

FRUGALITY AND ROBUSTNESS: NEGOTIATING ECONOMY AND ECOLOGY IN ARCHITECTURE

Ted Shelton, AIA[1]

ABSTRACT

This paper proposes an operational framework for developing an environmentally progressive mode of design practice. This framework, based on the concepts of frugality *and* robustness, *seeks to balance a project's first cost with the anticipated energy and material flows over its lifetime. Focusing on a conceptual rather than a computational basis for understanding issues related to green design, the framework is intended to provide an approachable "first step" for practitioners interested in developing an ethic of sustainability in their work.*

Frugality *is here understood as the conservation of resources by limiting or eliminating their use and* robustness *as the conservation of resources by deploying them in such a way as to maximize their usefulness over an extended time and varying circumstances. This paper outlines how, by embracing both* robustness *and* frugality, *a design professional might develop an environmentally progressive mode of practice while maintaining his or her professional responsibility toward the project budget; yielding an approach that is broadly applicable to a wide range of projects.*

INTRODUCTION

Design professionals wishing to pursue a greener mode of practice are faced with a deluge of information about how to accomplish this goal. However, it is seldom clear either how to deploy these strategies or technologies within the confines of the project budget or how to prioritize them in relation to one another during the design process. The pressure of project schedules, the safety of existing well-understood ways of working, the increasing demands of contemporary practice, and, paradoxically, the very size and complexity of the issue of sustainability, all conspire against even the most well-intentioned practitioner. Together these forces discourage the comprehensive reconsideration necessary to the greening of practice.

Perhaps the most common obstacle to the creation of green design is a concern (on the part of the client, the design professional, or both) that this will result in an unnecessary increase in the project cost. This concern is not without merit. A common approach to the harried practitioner's first "green" project is simply to select technologies that seem interesting or achievable—resulting in the superficial attachment of "green" items to an otherwise typical design. In these instances, the selected items—solar panels, green roofs, light shelves—become signs announcing the building's good intentions. Because this approach relies on an additive strategy rather than integrated rethinking of the project, it likely represents both an increased budget and limited environmental benefits—neither fully achieving the goal of a more sustainable project nor honoring the practitioner's obligations to the client.

Such an approach highlights the inherent difficulties—how best to begin the reconsideration of practice necessary for creating green design? This article proposes an operational framework, based on the concepts of *frugality* and *robustness,* for pursuing environmentally progressive design while simultaneously controlling project cost. This framework is meant to provide a "first step" for practitioners seeking to green their practice, while also outlining opportunities to expand their professional relationships with their clients. Much debate can and should be had over the metrics of sustainable design. However, for the sake of providing a straightforward argument and addressing the most common stumbling blocks, this paper focuses on just two: resource use (both material and energy) and project costs (initial and operational).

1. Assistant Professor, University of Tennessee, 1715 Volunteer Boulevard, Knoxville, TN 37996, USA. Phone: 865.974.3292; fax: 865.974.0656; email: tshelto4@utk.edu.

NATURAL ALLIES: A FRUGAL APPROACH

> The exact cost of my house, paying the usual price for such materials as I used, but not counting the work, all of which was done by myself, was as follows; and I give the details because very few are able to tell exactly what their houses cost, and fewer still, if any, the separate cost of various materials which compose them: -

Boards,	$8 03½,	mostly shanty boards.
Refuse shingles for roof and sides,	4 00	
Laths,	1 25	
Two second-hand windows with glass,	2 43	
One thousand old brick,	4 00	
Two casks of lime,	2 40	That was high.
Hair,	0 31	More than I needed.
Mantle-tree iron,	0 15	
Nails,	3 90	
Hinges and screws,	0 14	
Latch,	0 10	
Chalk,	0 01	
Transportation,	1 40	I carried a good part on my back.
In all,	$28 12½	

(Thoreau, 1973)

Ecology and economy are often seen as playing competing roles in the practice of architecture. Yet, when Henry David Thoreau set up housekeeping next to Walden Pond in order to commune with nature and learn its lessons, he considered the cost of his dwelling to be an important part of the endeavor. In fact, the first chapter of *Walden* is entitled "Economy" and includes the precise accounting of materials and costs listed above. While his simple home represented an act of expediency, his methods point to a certain correlation between economy and ecology in construction. Many of Thoreau's strategies—building simply and only as much as needed, reusing and recycling materials from other buildings, and taking advantage of the particulars of the site—are widely viable methods of reducing both cost and environmental impacts.

Such ideas are not without a more recent architectural pedigree. R. Buckminster Fuller often extolled the virtues of "doing more with less," and viewed his geodesic domes as materially and economically efficient structures that could be paid off as quickly as a car and would allow owners to live in close contact with the land (Krausse and Lichtenstein, 1999, pp. 330–331). While understanding the promise of prefabrication in a fundamentally different way, many of the architects of the Case Study Houses—Eames, Saarinen, Rapson, and Neutra to name a few—had similar goals. In fact, attempts to efficiently and cost-effectively deploy resources to allow people to dwell in contact with the natural world (or some representation of it) might be considered a subtext of the history of modern architecture.

The environmental awareness of Thoreau and these twentieth century architects does not precisely mirror current notions of sustainability. However, the relationship between one's connection to the natural world and the efficiency with which one builds provides a touchstone for the contemporary practitioner. The *frugality* of means suggested by this relationship, points to an intersection of intents wherein it is possible to simultaneously conserve both natural and monetary resources.

No matter how efficient, buildings represent sizeable mobilizations of both natural and financial resources. Therefore, the most significant decision with respect to a *frugal* design is whether or not to build at all. Choosing not to build maximizes both metrics here under consideration—no money would be spent and no natural resources consumed. Obviously, a mode of practice that puts a premium on not building poses difficulties for the design professions, which depend on construction to generate fees. While it may seem counterproductive to suggest that a client not build, to do so takes a broader view of the value of design services, placing a premium on problem solving skills and expansive thinking about the client's needs. Interestingly, such a proposal might actually open new income streams for design professions by expanding the services we offer beyond the design of buildings, interiors, and landscapes (and in turn, allowing an ecologically progressive mode of practice to inform these wider services). For example, a more efficient allocation of an existing facility, a small addition, and some creative programming that allows multiple functions to overlap in the same spaces, might serve the client's needs as well as a completely new building. Such a solution is eminently more environmentally and fiscally responsible, presents opportunities to become an advisor to the client on a myriad of facilities decisions, and most likely puts the advising firm on top of the selection list should a new facility ultimately be needed. There would also seem to be room here for creativity with respect to fees. It seems reasonable that the practitioner in such an instance be paid not only a fee for the design of the interior reorganization of the existing building and design of the addition, but also a percentage of the money saved with respect to the original budget.

Stewart Brand points out that the standard architectural contract creates a disincentive for controlling the project cost (and therefore, a disincentive for practicing *frugality*) by tying compensation directly to the cost of the building. He suggests that the design team and client agree to a set fee for the design of the project with the team receiving a bonus if the project is completed on time and in budget (Brand 1994, p. 190). While the idea of decoupling project cost and design fees is intriguing and could allow more freedom for design teams to adopt a more *frugal* approach to addressing their clients' needs, caution is necessary. There are many factors affecting budget and schedule (including the whims of the client) that are beyond the design team's control. Yet, developing legal mechanisms whereby design teams can address their clients' needs through means other than construction without suffering financial penalty would seem an important rung on the ladder towards practicing this ultimate form of *frugal* design.

The *frugal* predisposition to not build is tied to a preference for the land—the belief that nothing designed and constructed can be either as beautiful or as environmentally positive as undeveloped land. While the reader may draw his or her own conclusions about the aesthetic quality of an untouched field, the ecological portion of this view seems well founded. As architect W.G. Clark phrased it, this school of thought sees architecture as an act of, "replacement of what was lost with something that atones for the loss" (Jensen 2000 p. 10). This sentiment is tied to an understanding that construction is, regardless of how benign its final product, initially an act of destruction—the clearing of the site, the extracting of materials and their processing.

In their book *Cradle to Cradle,* William McDonough and Michael Braungart argue that this urge to "atone" for damage inflicted on the environment represents a limited way of understanding the effects of human production and urge a shift from seeking ways to limit our negative impacts to ways of producing positive ones (McDonough and Braungart 2002). This suggests the possibility of the *frugal* connection between cost and environmental benefit becoming unlinked in the area of construction—creating a situation whereby building more would actually yield higher environmental benefit. Yet, while this vision is an important goal for all of us in the environmental movement, the ability to produce a building that has a net positive ecological impact seems very far away indeed considering existing building technology—leaving us for now, only able to limit and atone for our harmfulness.

Once the decision to build has been made, the principle of *frugality* can be transferred to individual building systems. Optimizing a building's structure is an obvious first candidate for such scrutiny. (Though, the ensuing section on *robustness* will outline some arguments for saving money and material by oversizing the structure.)

As noted, Buckminster Fuller was nearly fanatical about optimizing structure, insisting that a true measure of how well a building had been designed was its weight (Krausse and Lichtenstein 1999, p. 135). Yet, some caution is necessary here. While some forms of non-traditional structures like space frames and Fuller's geodesic domes can be extremely miserly with their materials, they can often be quite expensive. Edward Cullinen's gridshell at the Weald and Downland Open Air Museum elegantly encloses a large space with a delicate tracery of thin oak strips (Figure 1). The possibility of using a renewable resource in such an evocative and efficient way is enticing. Yet, with a cost of £1.8 million for what is essentially a 1800 m^2 (19,375 ft^2) warehouse and covered workspace, and requiring a sizeable grant from the Heritage Commission for initial project research, it hardly seems affordable in most instances (Lowenstein 2002, p. 23, Weald and Downland Open Air Museum 2003). The price of such systems could decline dramatically if they were to become more commonplace, with a ready stock of components and larger pool of design and construction knowledge,

FIGURE 1. Interior view of gridshell at Weald and Downland Open Air Museum. © 2003 Tricia Stuth. Used with permission.

but until that time the cost conscious architect should only use them sparingly if at all. However, with traditional structural systems a *frugal* approach is much more straightforward. Here, cost efficiency and reduced material usage are nearly synonymous.

This *frugal* approach to structure is, in turn, easily transferable to other systems. Mechanical systems often represent many opportunities for saving resources and money. In his book *Factor Four*, Ernst von Weizsäcker tells how engineer Lee Eng Lock uses a critical eye to produce amazing results in air conditioning systems in Singapore. Through a combination of careful study of the size and nature of the demand, use of "oversized" heat exchangers, and elimination of friction in the system at every opportunity, he has created systems that use only 0.61kW of electricity per ton of cooling. "Lee's systems also provide much better comfort, take up much less space, are more reliable and generally cost less to build. They cost less partly because every part is exactly the right size, not too big. Elegant **frugality** is Lee's watchword. Energy, money, time, metal, every resource is used in just the right amount and place and manner" (emphasis added) (von Weizsäcker, et al. 1997, p. 53).

Lighting is another area where it is possible to think *frugally* about building systems. Apart from a few specialized building types, every project will employ some significant amount of glazing. This fact allows inventive design teams to use daylighting to limit the need for electric lighting. Simple strategies like placing windows higher in rooms or using a palette of light colors for interior surfaces can greatly increase illumination levels in a building and reduce the need for artificial lighting. In fact, placement of glazing can affect illumination levels far more than amount of glazing. Coupled with proper shade protection from the high summer sun, this strategy provides the building with a free source of light that contributes very little to heat gain in the building. This thinking can be extended to the placement of interior reflective surfaces. A small well-placed reflector can be nearly as effective for daylighting as a vast extent of white painted wallboard—allowing designers to be doubly *frugal*, eliminating the cost of much of the interior finishing while strategically locating what is left to limit both the initial and operating cost of the electric lighting systems.

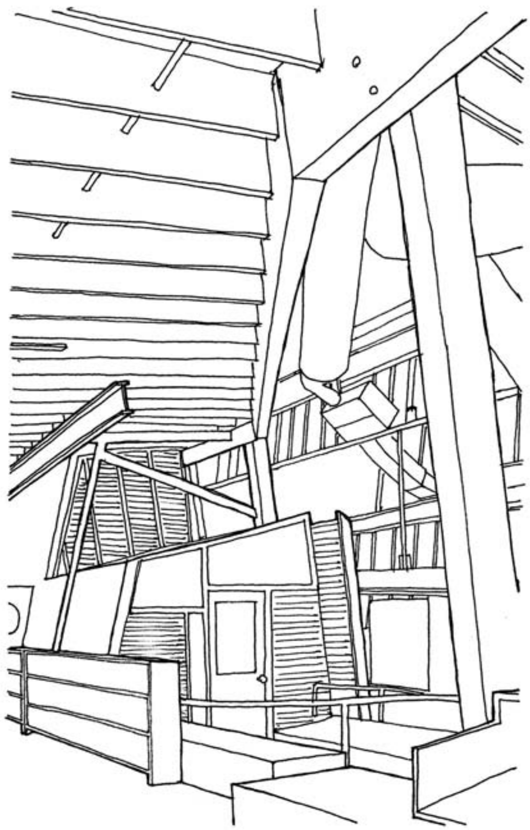
Rather than necessarily producing a kind of impoverished architectural expression, approaching design in this way naturally leads to an aesthetic that relies on the structure, services, and materials for its expression, with each part announcing its *raison d'être* by its placement within the composition. Patkau Architects have raised this type of careful consideration of the building's various pieces to an art form. Their Strawberry Vale School (Figure 2) just outside of Victoria, British Columbia is an exercise in purposefulness. White painted wallboard, rather than coating the entire interior of the building, is only employed where it is needed to reflect natural light. Floor coverings are used where they are needed for comfort and acoustics. Elsewhere, concrete floors suffice. The building's services and structure are apparent and reinforce the architectural language of the project. Coatings are only applied to materials likely to receive wear. All of this was accomplished, "within the limits of conventional public school construction," and to striking effect (Domus 1/1997, p. 13). *Frugality*, limiting what one builds and the amount of resources placed therein, is a good first step toward creating a cost- and environmentally-conscious project; but it need not sound the death knell for design.

ROBUSTNESS: WITHSTANDING THE TIDES

What of architectural beauty I now see, I know has gradually grown from within outward, out of the necessities and character of the in-dweller, who is the only builder, - out of some unconscious truthfulness, and nobleness, without ever a thought for the appearance; and whatever additional beauty of this kind is destined to be produced will be preceded by a like unconscious beauty of life. (Thoreau 1973, p. 47)

To only imagine an environmentally-progressive building as either as the latest high tech marvel that uses computer circuitry and countless systems to deliver low-energy comfort or as an otherwise ordinary building with solar panels bolted onto the roof is to overlook the concept of *robustness*. Such oversight is common, as *robust* characteristics tend to be largely invisible. In fundamental terms, a *robust* building gets the simple things right—things like insulation, orientation, air-tightness, and glazing. These basic ideas not only have the advantage of being considerably less expensive than a wind turbine or an integrated building management system, they are also more reliable. Dr. Nick Baker of Cambridge University illustrates the difference with this conceptual graph (Figure 3).

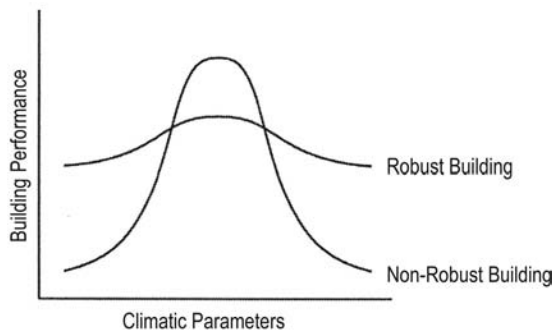
FIGURE 2. Interior view of Strawberry Vale School redrawn by the author from "Strawberry Vale School," *Domus*, January 1997, p. 15.



While the non-robust building, relying on complex technology, can provide better environmental performance, it can only do so over a narrow band of variables, with the possibility of precipitous fall off in performance outside of that range. The *robust* building, while never reaching the heights of performance achieved by the high tech building, has a more stable response over a wider range of variables. For instance, when a small-scale wind turbine is operating, it is supplying "free" clean energy to the building. However, when wind speed drops below the cut-in speed of the turbine, its contribution to the building's performance drops to zero. On the other hand, a building that uses strategically placed windows, light colored interiors, and a well insulated exterior wall to reduce energy demand for interior lighting and space heating will provide economic and ecological benefits over a very wide range of circumstances.

This is not intended to discount the possibilities of a high-tech approach, only to question where, in most cases, the best environmental use of money lies and to caution against the, "badly insulated, draughty

FIGURE 3. Diagram redrawn by the author from a seminar given by Dr. Nick Baker to the M.Phil. Programme in Environmental Design in Architecture at the University of Cambridge, 23 January 2003.



buildings bristling with eco-gimmicks" (Liddell and Grant 2002, p. 12). High tech options can work incredibly well, but they are not for buildings with meager budgets. Meanwhile, adopting a *robust* approach permits designers to practice environmental stewardship on nearly any project, as Dr. Bill Bordass notes:

> Green buildings can cost more—particularly where green features are tacked onto otherwise fairly conventional designs—but they need not: good buildings can be found at all price levels. For example a sound, robust, no-frills platform ("if in doubt leave it out") with a clear adaptability strategy may offer better value than a more highly-featured solution procured on the cheap. Well-integrated green schemes (without manifestly extravagant gestures) can be affordable if everybody is committed to getting a good package for what the client is prepared to spend. (emphasis added) (Bordass 2000, p. 2)

As with a *frugal* approach, a strong positive link between environmental progressiveness and fiscal responsibility is possible. Stewart Brand notes:

> Since about 30 percent of the operating costs in most buildings goes to paying for energy, significant money for maintenance, tuning, and remodeling of the building can be freed up by designing in energy efficiency through well-proven techniques—insulation, tightly crafted windows and doors, orientation to the sun, use of foliage (for summer shade), and appropriate color (light in hot climates, dark in cold). (Brand 1994, p. 190)

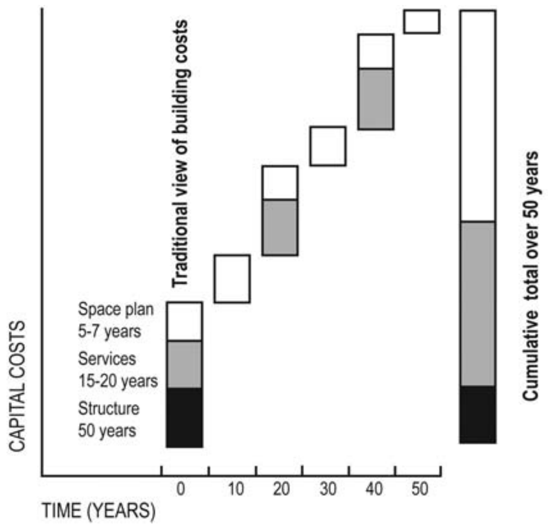
With *robustness* this link is created through a different mechanism than with *frugality*. Whereas the *frugal* approach conserves natural and monetary resources instantaneously by eschewing their initial use, a *robust* approach uses time to achieve its goals. While strategies such as providing the correct orientation or choosing a lighter interior color palette have little or no associated cost increase, others such as selecting better insulating windows, paying careful attention to the air tightness of details, or, as will be discussed later, providing stouter than necessary structure or enclosure can have a noticeable effect on the project budget. Therefore, a *robust* building must rely on its durability and responsiveness over time to demonstrate its full benefit.

This emphasis on time suggests that, when adopting a *robust* approach, designers must pay careful attention to the durability of materials and systems and to the client's needs. As a *frugal* approach brings to mind the adage that, the greenest material is the one you don't use, so a *robust* approach suggests that there is no material as wasteful as one mobilized in a design that is not responsive to the needs of the client. Likewise, the material and monetary flows associated with periodic updates can over time far eclipse those from the original construction (Figure 4) (Brand 1994, p. 13).

While it is true that, "buildings are always going to be inflexible or poorly adaptable in one way or another, given that social and technical change is ever-present and to some extent unpredictable," flexibility and adaptability remain worthwhile goals (Leaman et al. p. 1). A building that easily absorbs new uses and patterns of use without requiring extensive overhaul is preferable from both an economic and ecological standpoint to one that cannot absorb change.

Here, as with the *frugal* approach, are possibilities for design professionals to expand their relationships

FIGURE 4. Graph redrawn from: Brand, Stewart (1994) *How Buildings Learn: What Happens After They're Built,* New York, Penguin, p. 13. Originally: Duffy, Francis, and Alex Henney (1989), *The Changing City,* London, Bullstrode, p. 61.

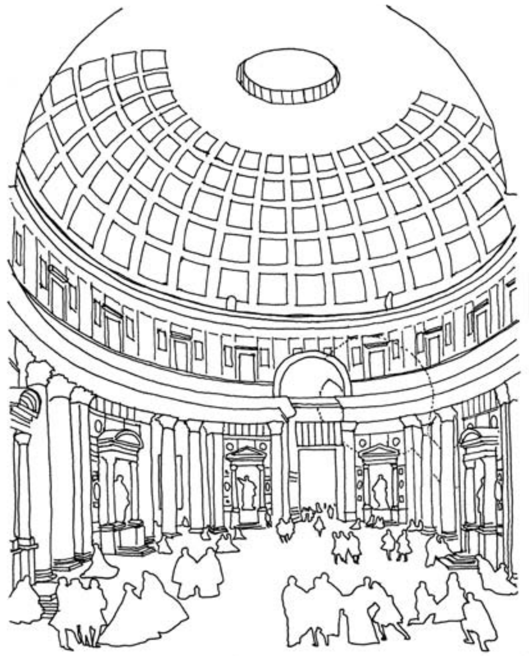


with their clients. Design commissions can become opportunities for providing much more than a one time service. By engaging the client's long range visions, the building becomes an integral part not only of addressing present needs but also of meeting future goals—demonstrating again that the value of design services goes beyond the provision of drawings for a single building and, in turn, becomes a prelude for an ongoing professional relationship.

Robustness also opens up possibilities for the design itself. Turning on ideas of solidity and timelessness, it suggests the use of durable materials and high quality construction techniques. As the epitome of a *robust* building, we could easily turn to the Pantheon (Figure 5). Lighted and conditioned solely by passive means, the expense of its construction and environmental impact of procuring its materials have certainly long ago been justified by its usefulness which has adapted not only to a change of religious affiliation, but also the rise of the modern tourist economy. (One might even detect a bit of *frugality* here in that the building utilizes marble on the lower interior surfaces and plain concrete far away from the occupants in the dome above.) While this example is admittedly extreme, it nonetheless emphasizes the possibility of a sturdier, more permanent architecture arising from a *robust* approach to economic and environmental concerns.

The difference between this way of thinking and the economizing of the *frugal* mode of thinking is striking. Undoubtedly, *robustness* will incur additional cost and require more materials when comparatively. Yet, these seemingly wasteful ideas effectively buffer the building against the waves of money and resources that are bound to wash through it in the course of its use. If we are to pursue the promise of both the *frugal* and *robust* approaches, the question then becomes how to reconcile them on a particular project.

FIGURE 5. Interior of the Pantheon redrawn by the author from Giovanni Paolo Panini.



DRAWING THE LINE: THE ROBUST/FRUGAL HYBRID

When faced with two such divergent models of how to achieve cost-effective sustainability, how is the design team to decide when each is appropriate? A critical part of the answer lies in understanding what Duffy calls, "the idea of the parallel and independent coexistence of different lifespans in the same building" (Duffy 1997, p. 75). That is, different parts of the building are modified or replaced at different rates. In a model originally developed by Duffy and later elaborated by Brand, each of these elements and its associated rate of change is identified. At the core is the structure—immobile, unchanging. Brand says of the structural elements, "these are the building" (Brand 1994, p. 13). Proceeding from there and ranging through the other elements with ever-increasing rates of change: the skin, the services, the space plan, and finally occupants' stuff (chairs, lamps, pictures, phones, etc.) (Duffy 1997, p. 75).

Taking this model as a guide, it becomes much easier to see which parts of a building might benefit from a *robust* approach and which might call for a *frugal* one. Components that are likely to remain for a long time and return the benefits of low energy and low materials operation and maintenance (structure and skin) are the best candidates for *robust* strategies. Meanwhile, pieces that will undoubtedly undergo many changes no matter how carefully considered (services and space plan) likely respond better to the *frugal* approach.

It is interesting to note, however, that in this hierarchy the services and the skin have divided loyalties of sorts. The skin, while largely unchanging and requiring durability, also plays the vital role of being the membrane through which the building exchanges energy with the environment. Thus, the design team cannot forget its role in insulating and collecting solar energy while seeking to make it longer lived. Likewise, the realization that building services are replaced more often than one might imagine (Brand estimates every 7 to 15 years) does not eliminate the need to carefully consider their impact on energy consumption and therefore on operational cost. We have already seen that an efficient mechanical system can cost significantly less than a conventional one. Indeed, this is a key point in the ability to achieve overall energy and cost savings when compared to a "conventional" building, as will be shown in a later section.

What emerges then is a picture of a building very much split between interior and exterior. Such a building would possess a tough, durable, *robust* shell and structural skeleton that can stand up to the forces of nature over long periods of time and therefore "pay back" investments of money and materials. Inside this would be *frugal* internal partitions and services systems, which are easily accessed, upgraded, and changed when needed. As mentioned above, two building components—the envelope and the building services—are critical to the creation of a hybrid building and thus demand special attention

UNDERSTANDING THE ENVELOPE

> [I]t cost me nothing for curtains, for I have no gazers to shut out but the sun and moon, and I am willing that they should look in. The moon will not sour milk nor taint meat of mine, nor will the sun injure my furniture or fade my carpet, and if he is sometimes too warm a friend, I find it still better economy to retreat behind some curtain which nature has provided, than to add a single item to the details of housekeeping. (Thoreau 1973, p. 67)

Perhaps nowhere else in the building do the opportunities for cost and resource savings come together as they do in the exterior envelope. Here, the design team can achieve significant energy savings with little or no additional cost through a fundamental understanding of radiation, heat transfer, and solar geometry coupled with a keen interest in holding the client's bottom line steady. As such, the building's envelope plays an important role in the notion of *robustness*. This is true in at least two ways. As the building's protective shell, the envelope's integrity can significantly temper the amount of maintenance (and therefore materials and money) required for its upkeep. In addition, as the membrane through which the building interacts with the climate, the envelope represents a frontier over which the design team must cast a watchful eye if the building is going to exhibit the properties we have already seen suggested by Baker—that is, a relatively high level of environmental performance, which varies little over a wide range of parameters.

While the envelope represents a tremendous opportunity to save resources through careful design and detailing, the risk also exists by which these good intentions may be thwarted. Unlike mechanical equipment which can be (and is expected to be) "balanced" and tinkered with or lighting systems whose functioning is readily apparent, the building's envelope is largely fixed and goes about its work quietly and unseen. In fact, we do not often consider it as performing work at all. Yet, its tasks are many: keeping water out, selectively admitting solar radiation (for both illumination and heating), holding heat in, and alternately allowing or preventing our access to natural ventilation. The envelope is a type of silent machine and its functioning is easily undermined.

A flashing is installed incorrectly over a window head, a pipe compresses an insulation batt, a weep hole is clogged, improper sealing creates air leaks, unnecessary framing increases thermal bridging. A lot can occur in the construction phase of a building that will compromise a building's monetary and resource efficiency for years to come. Yet, it usually takes catastrophe to alert us to failings in the building's envelope. Often, we will never know. Couple these dangers with the contractor's push to complete the envelope and get the building "dried in" and there is a strong argument for the design team to time site observations such that they receive a more detailed view of the exterior envelope than of other building components. It would also seem to suggest that it is important, through careful documentation and early meetings, that the contractor understand how the envelope is intended to perform.

SUBSTITUTION OF NATURAL SYSTEMS FOR BUILDING SERVICES

> I did not need to go out doors to take the air, for the atmosphere within had lost none of its freshness. It was not so much within doors as behind a door where I sat, even in the rainiest weather. (Thoreau 1973, p. 85)

For the vast majority of architectural history; there was no ventilation save what could be coaxed in through an opening, there was no warmth other than that imparted by the sun or a fire, and there was no water except what was carried from a nearby stream, well, or cistern. Building was connected to nature in a very intimate way. Yet, by the time Thoreau was enjoying the freshness of the air in his (at that time unfinished) cabin, technological changes were underway that would alter this cooperative relationship between nature and architecture into a confrontational one. At the time, these changes were exemplified by such innovations as the Franklin stove and the flushing toilet, but would eventually include air conditioning, electric lighting, and piped water and sewer services (Banham 1969). The ultimate symbol of this hostility toward natural forces is perhaps the ubiquitous glass-skinned, electrically lit, air-conditioned office tower that has become a fixture in many cities regardless of latitude or climate.

While modern society does not wish to return to the building technology and comfort levels of two or three hundred years ago, there is growing recognition of the many ways that natural systems can serve as substitutes for services that had come to rely on vast amounts of capital and resource investment.

This brings us to what is perhaps the high point of the convergence between economic and ecological thinking in architecture. By searching for ways to meet the occupants' (thermal and luminous) comfort requirements through natural processes, some designers are eliminating or significantly reducing systems that had previously been considered essential. This is a key component of what Paul Hawken refers to as "tunneling through the cost barrier." This is a way of bypassing the law of diminishing returns—through improvements to certain building components that diminish or eliminate the need for others. "Thick enough insulation and good enough windows can eliminate the need for a furnace, which represents an investment of more capital than those efficiency measures cost. Better appliances help eliminate the cooling system, too, saving even more capital cost" (Hawkin et al. 1999, p. 114).

To eliminate entire systems in this way requires integrated ways of thinking about the building along with cooperation between and expertise among the various members of the design team. For example, the architect's or interior designer's specification of a dark interior palette might require the electrical engineer to compensate by increasing the number or wattage of light fixtures, thus not only making the lighting system less cost- and resource-efficient than it need be, but also creating an increased cooling load. This will, in turn, be reflected in decreased efficiency in the mechanical design.

While it is possible, to some extent, to replace both lighting and plumbing systems with natural systems, the ability to "tunnel through the cost barrier" seems to nearly always hinge on the mechanical system. Most examples rely on the strategy of eliminating or drastically reducing the HVAC plant and distribution system in favor of some combination of a well insulated envelope, natural ventilation, and/or passive cooling and heating. Such a strategy can lead to both significant savings in initial investment and over the life of the building, while representing sizeable reduction in the use of energy and resources as well. Yet, clients, who are accustomed to the capability to achieve particular levels of humidity, temperature, air speed, and ventilation within very narrow ranges using mechanical means, may present a significant obstacle for the designer hoping to take this path. Therefore, when pursuing the breakthrough that will allow one to "tunnel through the cost barrier," serious discussions with both the project team and with one's client are necessary.

The potential of such an effort is demonstrated by the Croxton Collaborative's design for the headquarters of the National Audubon Society where the "tight thermal insulation and efficient lighting . . . resulted in the downsizing of [the mechanical equipment] by almost half" (National Audubon Society and Croxton Collaborative 1994, p. 92). These moves also resulted in reduced first cost associated with the mechanical system, reduced natural and monetary resources devoted to the system's ongoing operations, and produced an estimated $15,000 worth of office space for the society's use (National Audubon Society and Croxton Collaborative 1994, p. 101).

CONCLUSION: ECONOMY AND ECOLOGY IN ARCHITECTURE

Fear of a greatly increased project budget need not present a roadblock for designers wishing to pursue a more environmentally progressive mode of practice. The concepts of *robustness* and *frugality* can assist designers in understanding how their projects might become more resource efficient while avoiding unnecessary increases in project cost. The resulting conceptual framework can not only help in prioritizing various green design strategies, but might also present avenues for providing one's clients with expanded services.

To see economy not as the bane of green design but rather as its compliment opens up tremendous opportunities for the field. As Brian Edwards has noted:

> To be effective commercially, social and environmentally, sustainable design needs to give measurable benefits. It is not sufficient, especially in the rigorous field of commercial or educational buildings, to view green design as an act of faith or Utopianism. To persuade private developers and client in the public sector to risk new approaches and use new sustainable technologies there needs to be maximum benefit and minimum financial exposure. (Edwards 1998, p. 2)

As designers with an environmentally progressive ethic, we bear a responsibility to provide our clients with green design strategies that return both environmental and economic benefits. The new opportunities suggested by Edwards and the *robust/frugal* buildings arising from them represent a potentially sizable appropriation of financial resources toward more sustainable use of natural ones.

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