ECOMORPH: SELF-SUSTAINING FORM

Lance Hosey, AIA, LEED AP
Director, William McDonough + Partners

Sustainable design emphasizes the particularities of place, yet at any given site the nature of place varies according to scale. Bioregional strategies consider larger-scale conditions such as macroclimate and ecosystems, taking into account general patterns of sun, wind, humidity, water, soil, materials, and flora and fauna. However, at the smaller scale of a building site, environmental factors can vary dramatically, depending on circumstances of form. Though larger regional patterns may give little indication of behavior at the smaller scale, designers tend to focus on the more general pattern, and the results may or may not be well adapted to the specifics of the site. Better environmental performance requires adapting to the more particular conditions.

One factor limiting this aim is that form is constrained by technique, since conventional construction materials and methods do not allow a great deal of flexibility. Recent technologies such as digital fabrication not only have given designers an unprecedented ability to explore novel geometry and construction techniques but also have removed traditional barriers between design and development. However, to date these techniques have been used mostly to liberate architects' fantasies about form and have not been applied explicitly to conserve resources. "Ecomorph" proposes an alternative model that brings new techniques to the age-old challenge of adapting design to the specificity of place. The result conserves resources through novel architectural form and therefore integrates sustainability with design.

Ecomorph: Self-Sustaining Form

Lance Hosey, AIA, LEED AP
Director, William McDonough + Partners

I. Introduction

Green building strategies divide into two broad categories—those that affect visible design and those that do not. The second list (thermal insulation, material content, water efficiency, etc.) has become more familiar, partly because these factors are easier to regulate and measure. But the first, which includes layout, massing, and fenestration, actually can have a greater impact on a building's performance. Smart engineers warn that the most effective mechanical system cannot compensate for poor solar orientation—if you face a building west, it's going to get hot. Architects can embrace sustainability by focusing on the thing they have always cared about most—the basic shape of buildings.

Form precedes technique as a green solution because it can have a significant impact on both resource conservation (including energy and materials) and human comfort but also because it is more easily adapted to place. The connection between form and performance is also a strong link between great design (by any measure) and green design. Yet, while technological solutions are driven by a clear process, architectural form still is driven mostly by the personal taste or preferences of the designer. Although the instincts of the design team should not be undervalued, we now have unprecedented opportunities to transform the process by creating form through intelligence, not intuition.

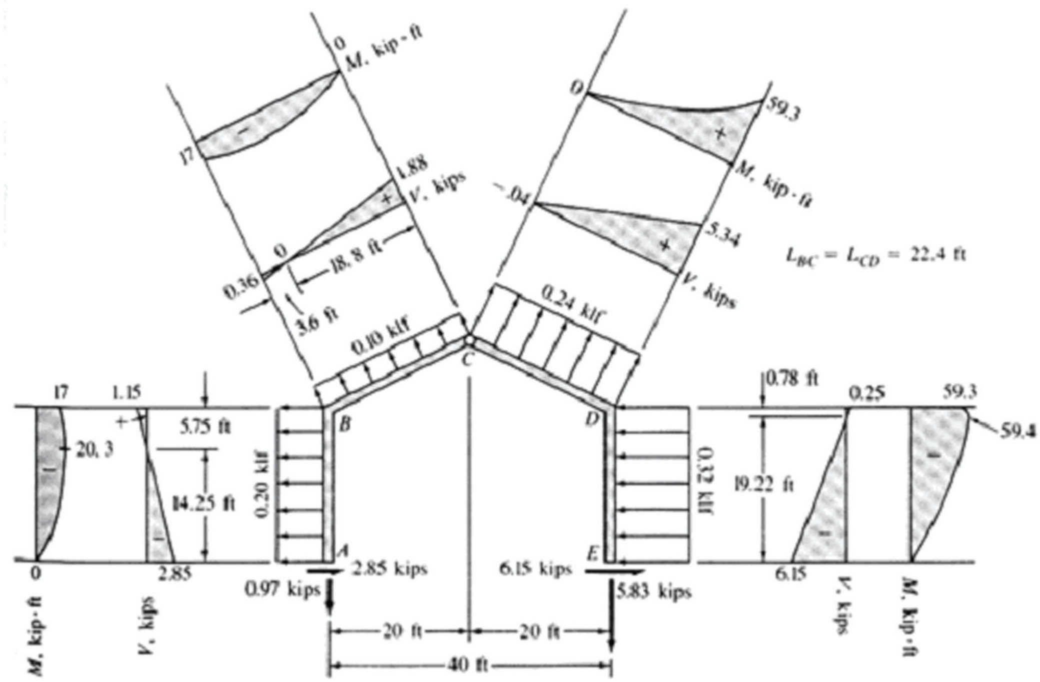


Figure 1. Sample moment diagram for a conventional gabled structure.

Challenges: FORM and TECHNIQUE

While sustainable design theory tends to dismiss modern architecture as disconnected from nature, ironically the two fields of thought share similar conceptual origins. For example, Louis Sullivan borrowed the modernist mantra “form follows function” from 19th-century biological theory, so the theoretical underpinnings of modernism were influenced by ideas about nature. (However, Darwin showed that through natural selection morphology occurs randomly and remains only if it ensures survival. In other words, form and function are more interactive than causal.) Yet, despite this rhetoric, modern architecture was highly inefficient; its fascination with simple geometry was never about efficient design—it was about efficient fabrication. Standard structural members (columns, beams, studs, etc.) typically are over-sized and poorly shaped. The rectangle, the most common shape in construction, is inherently inefficient for carrying loads (and in the case of mechanical ducts, for conveying air). We build orthogonally not to enhance performance but simply because production techniques such as metal extrusion favor simple forms. In this sense, the modernist edict should have been “form follows *industry*.”

Although sustainable design has rejected the mechanical inefficiency of modern architecture, it still conforms to conventional construction techniques, which suffer from myriad inefficiencies. Since World War II, industry- and developer-driven construction has favored standardization in order to increase economic efficiency at the expense of material efficiency. For example, the staple of contemporary residential and commercial construction alike—stud wall framing—only marginally improves on balloon- and platform-framing techniques developed in the 19th century. Wood framing is wasteful through the entirety of the process—from tree harvesting to lumber production to standardized dimensioning to application and eventual demolition. The “stick-built” house is an archaic form that continues to thrive purely because of customs, conventions, and habit.

Figure 2. .Regional form. Spiral growth plant in the rain forest; stacked growth plant in the cloud forest.

Opportunity: FORM

Because the goal of sustainable design and development is for human systems to work harmoniously with other living systems, culture strives to behave more like nature. Consider how nature produces form. In fauna and flora, morphology is determined by two factors: genetic (nature) and environmental (nurture). Figure 2 shows two plants, similar in size and frequency in Costa Rica. One grows in the rain forest, thick and lush with greenery competing for sunlight. The air drips with humidity. This plant's large, fleshy leaves provide maximum surface area to receive light and emit moisture, and they grow in a spiral pattern to allow every leaf as much light as possible. Now look at its cousin in the cloud forest, where the flora hugs the mountaintops to avoid getting whipped away by the wind. This plant's leaves are small to avoid too much exposure and evaporation, and they grow stacked above one another to create shade. The differences between these plants may be called *regional*: two different bioclimates separated only by altitude create very different forms in similar species.

Figure 3. Circumstantial form. Heliotropic sunflowers; gravitropic poppies.

The second type of form is *circumstantial*. If two specimens of one type of plant grow on opposite sides—one north and one south—of a tall tree, they may adapt to their conditions very differently, though their genetic codes give them virtually identical instructions. Heliotropism will tell them both to lean into the sun, but that direction varies. Similarly, if one grows on the side of a hill, it will right itself to grow vertically. If it loses some of its mass in a storm, over time it will adjust to its shifted weight. This is called gravitropism. In both cases, the circumstances of the plant are specific to that specimen, independently of the more general bioclimatic conditions.

Figure 4. Regional form. New England colonial; Virginia dogtrot.

Architectural form can learn from these examples. Regionalism includes bioclimatic considerations such as consistent patterns of rainfall, temperature and humidity. A New England colonial house is compact in order to conserve heat in winter, its roof pitch is tall to shed snow, and its windows are small to avoid cold drafts. A Virginia dog trot house lies low to avoid heat in the summer and opens in the middle to promote breezes. Different forms for different places. But the circumstances of two houses in the same climate may vary according to site orientation, breezes specific to that site, views, landscape, slope, shade, etc. Within one bioregion, a site on open, flat land requires a very different response than a site at the crest of a wooded slope, on a riverbank or lake shore, or in a dense inner city, and two separate urban sites can also differ greatly.

Regional form focuses on macroclimate, circumstantial form focuses on microclimate, and "Ecomorph" combines the regional and circumstantial. An *ecomorph* is a scientific term for a natural feature whose appearance is shaped by ecology, not by heredity or other predetermined factors. By adapting to its setting at two scales, Ecomorph responds to both climate and culture and therefore builds both natural and social capital in ways that generic form (e.g., the typical suburban commercial strip) does not.

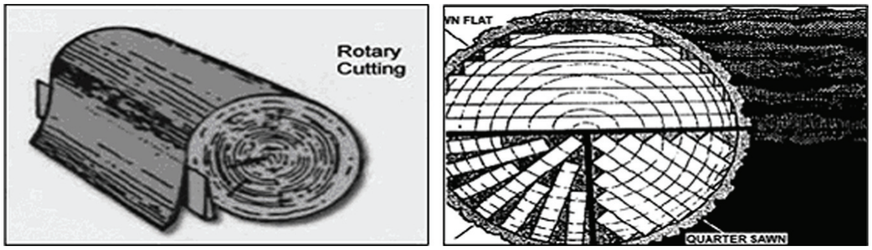


Figure 5. Two types of timber cutting.

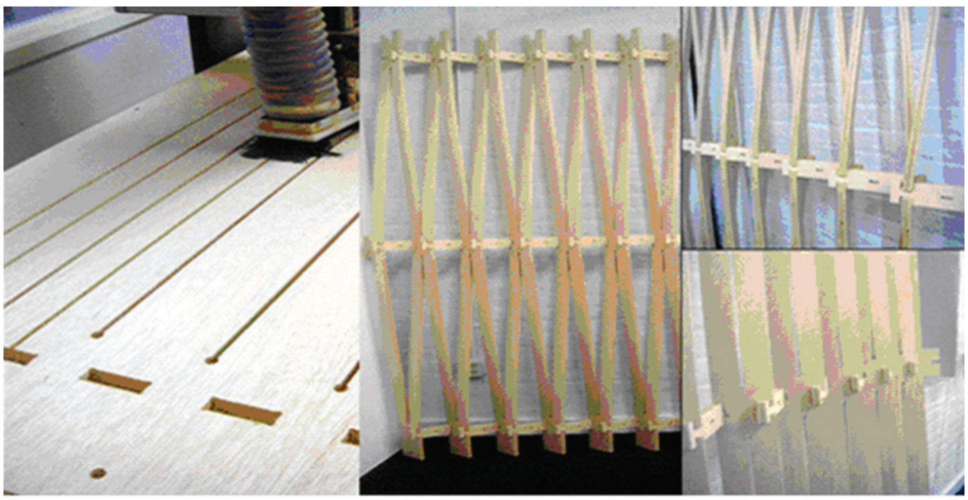


Figure 6. Sean Dorsy, Expandable Wall System.

Opportunity: TECHNIQUE

Fitting form more specifically to place requires innovative methods, and there are two types: adaptation and invention. Adaptation applies new approaches to conventional materials and methods. Invention proposes altogether new methods. Both can aid new forms.

Adaptation

Some materials, such as dimensioned lumber and plywood, come in specific sizes and shapes, so using them requires working with these predetermined forms. Emerging techniques such as digital fabrication (CAD/CAM) are redefining the relationship between design and construction, yet to date these techniques have focused on how to save time and cost and not on how to conserve natural resources. But these methods can be applied to produce more intelligent designs.

An example is the expandable wall system developed by Sean Dorsy, a recent architecture graduate of the Catholic University of America. As an alternative to the typical stud wall framing system, Dorsy's system is more efficient with materials through sourcing, design, and application. Because plywood is rotary sawn, it wastes less wood than dimensioned lumber. Using a CAD/CAM process with a CNC router, Dorsy saves every inch of standard 4x8 sheets, leaving nothing behind on the shop floor. Inspired by sources as diverse as Japanese paper cutting and cardboard pizza boxes, the prototype strategically unfolds the plywood to create an amazingly durable, origami-like frame that can be used as the innards of a partition or as an open room divider. Held together with clips instead of nails, it can be easily taken apart and redeployed, making it cheaper, lighter, stronger, more versatile and more attractive than stud framing.

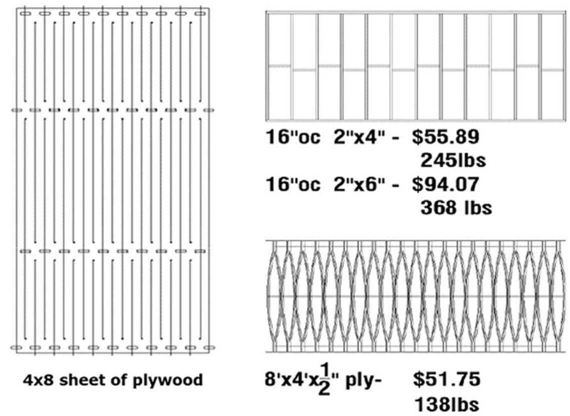


Figure 7. Sean Dorsy, Expandable Wall System.

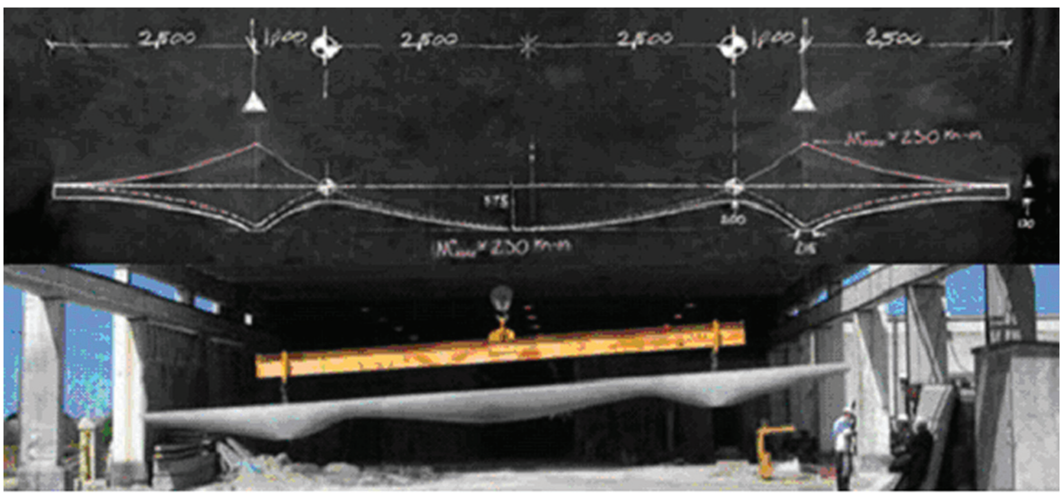


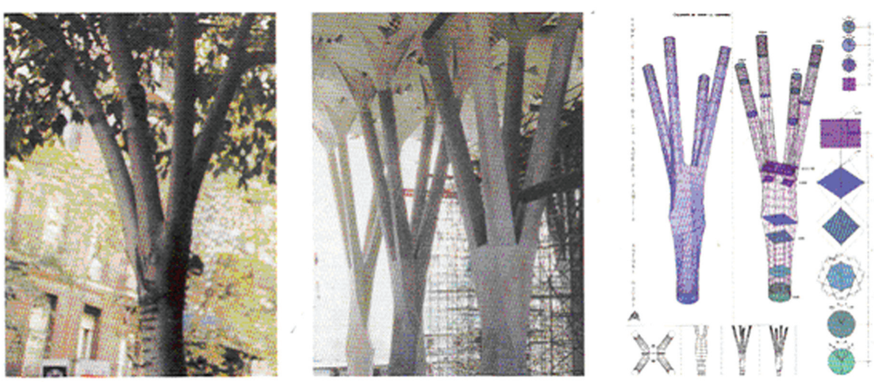
Figure 8. Moment diagram and fabric-formed concrete beam. Mark West, et al., C.A.S.T. (Centre for Architectural Structures and Technology), University of Manitoba.

Invention

Some materials, such as steel and concrete, are amorphous prior to fabrication, so they do not have predetermined form. Steel takes shape in a factory, prior to delivery, because the energy and effort that give it shape cannot be applied on site. Precast concrete is the same, though cast-in-place concrete is mixed on site and theoretically offers nearly infinite flexibility. The limiting factor in this case is not the material itself but the way it is installed, because the form is determined by the formwork. Recent developments with textile molds can achieve forms with concrete that are at once more complex and cheaper and easier to assemble.

Mark West and his students at the University of Manitoba have experimented with fabric forms to revolutionize concrete construction. For any given structural component, such as a beam, stress and strain are not consistent along its length. Yet, beams in both concrete and steel tend to be built as extruded section sized around the worst case scenario (the most demanding load). From a strictly environmental point of view, this is unnecessary and wasteful, because optimal performance requires varying the beam's shape in every dimension. West's fabric-formed beam solves this problem. Like an animal skeleton, material only goes where it is needed. It uses up to 300 times less volume and weight in formwork material and half the concrete of an equivalent rectangular beam. With such methods, form finally does follow function.

Figure 9. Thomas Jefferson, University of Virginia garden walls. Eladio Dieste, Church of Christ the Worker, Uruguay.



The trunk and branches of a tree

Branching columns in the church of the Sagrada Familia

Geometrical diagrams of the rectangular column in the nave of Sagrada Familia

Figure 10. Antonio Gaudi, Double-twisted columns, Sagrada Familia, Barcelona.

Synthesis: FORM and TECHNIQUE

What if we applied the example of fabric-formed concrete to entire building shapes? The idea in itself is not new—nearly two centuries ago, Thomas Jefferson used form to reduce material and increase strength in his famous serpentine brick garden walls at the University of Virginia. The undulating shape required only one layer of brick. South American structural designer Eladio Dieste applied the same idea about brick to every surface of Uruguay's Church of Christ the Worker.

Similarly, while conventional wisdom holds that the architecture of Antonio Gaudi was merely an expressive skin wrapping simplistic bones, in actuality his understanding of geometry was visionary. The twisted, tree-like columns of the Sagrada Familia, for example, are a *tour de force* of structure and material. Neither Jefferson nor Gaudi typically is thought of as "green," and their inspired examples seem to have escaped the notice of green designers today.

Figure 11. Plains Indians skin shelter. Inuit Igloo.

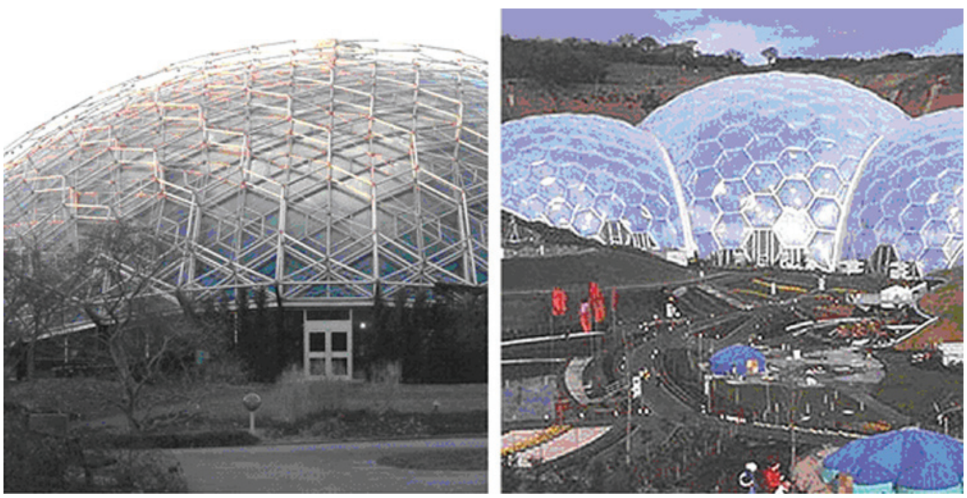


Figure 12. Buckminster Fuller, Geodesic Dome. Grimshaw Architects, EDEN project.

The product of such techniques may be called *self-sustaining form*—geometry that enhances structural and material integrity through the conservation of resources. Building traditions among indigenous cultures throughout history and across the world illustrate similar intelligence in simpler forms. The Inuit igloo and the skin- or bark-clad wigwam of the North American Plains Indians apply the same form—a dome—to opposite challenges of climate with very different materials. One uses heavy mass to keep heat in, and the other uses a thin membrane to keep heat out. Yet, they both use readily available, renewable materials for their regions.

The Japanese Pavilion at the 2000 Hannover Expo, designed by Shigeru Ban, Frei Otto, and Buro Happold, offers a similar but simpler approach to the concept of joined domes. First, the structure is comprised of compressed paper tubes instead of heavier, more expensive and energy-intensive materials such as steel. Second, the installation technique was extremely quick and simple. A diagonal lattice grid of tubes was laid flat on a series of scaffolds and simply pressed together with mechanical jacks. The domes took shape naturally as their ends secured in place. The resulting shapes are not half spheres but catenary domes—varying curve sections that are more efficient with structural loads than regular arcs are.

Figure 13. Japanese Pavilion, 2000 Hannover Expo.

Figure 14. Scale fabrication mock-up, Japanese Pavilion, 2000 Hannover Expo.

The Japanese Pavilion at the 2000 Hannover Expo, designed by Shigeru Ban, Frei Otto, and Buro Happold, offers a similar but simpler approach to the concept of joined domes. First, the structure is comprised of compressed paper tubes instead of heavier, more expensive and energy-intensive materials such as steel.

Second, the installation technique was extremely quick and simple. A diagonal lattice grid of tubes was laid flat on a series of scaffolds and simply pressed together with mechanical jacks. The domes took shape naturally as their ends secured in place. The resulting shapes are not half spheres but catenary domes—varying curve sections that are more efficient with structural loads than regular arcs are.

Type/Form	Driver	Pros	Cons
(Gabled) box	Habit/Industry	• Responds to convention • Efficient with current industry	• Inefficient with material, volume • Symmetrical
Dome (semi-circle)	Geometry	• Responds to convention • Efficient with surface, material	• Inflexible • Symmetrical
Catenary arch/vault	Physics	• Responds to gravity • Efficient with structural loads	• Symmetrical
Ecomorph (deformed catenary)	Ecology	• Responds to environment, place • Efficient with energy (sun, wind)	• Industry has not yet adapted

Table 1. Morphology of architectural forms. Assessment.

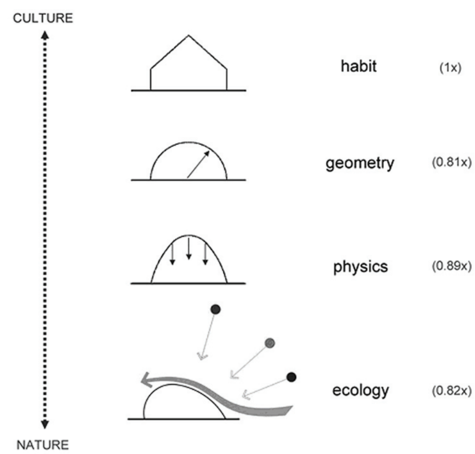


Figure 15. Morphology of architectural forms.

ARCHITECTURAL MORPHOLOGY: THE EVOLUTION OF FORM

All of these examples improve upon conventional construction through both form and technique. As Table 1 illustrates, typical gabled structures use materials poorly for conveying structural loads. But the form (a rectangle with a triangular hat) also encloses surface and volume very inefficiently. The form and technique of conventional structures is driven almost exclusively by habit or industry and not by material or spatial efficiency. As a result, they can never be optimal at conserving resources (both materials and energy).

Figure 15 outlines a matrix of building forms. The gabled box, ubiquitous because of age-old habits, responds only to industry's methods of production and culture's familiarity with simple shapes. The inefficiency of this form is evident in the fact that it doesn't occur in living things. By contrast, a semi-circle is nearly 20% more efficient in its ration of perimeter to enclosed area. In other words, all other factors being equal, a wigwam potentially uses only about 4/5 of the material of a typical house's envelope. Yet, while a pure dome may be perfect from a geometric standpoint, it is not optimal from a structural standpoint. Combing gravity with geometry, the most effective shape is the catenary. As an enclosure, the catenary arch or vault is not as efficient with perimeter as the semi-circle, but it still outperforms the gabled box.

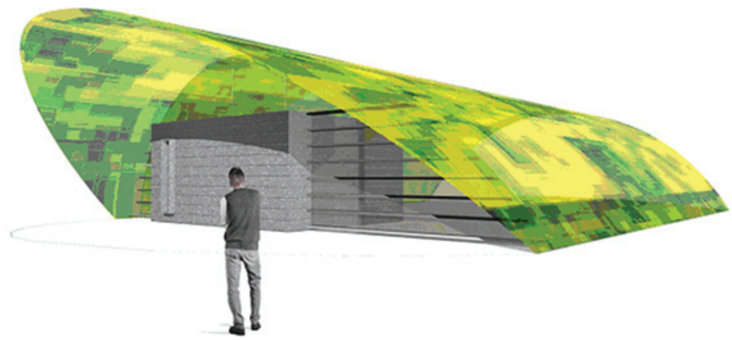


Figure 16. Lance Hosey, Ecomorph House. Perspective view.

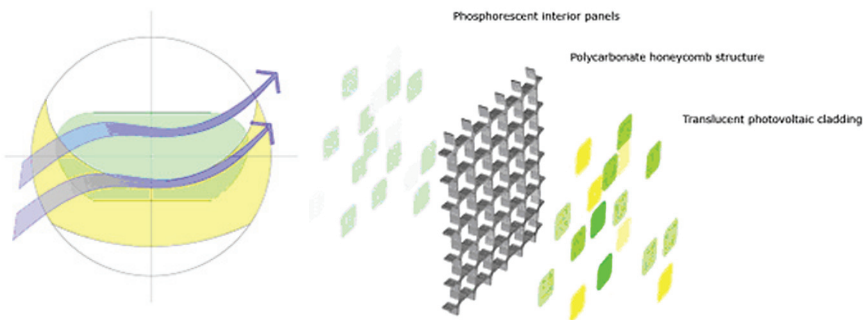


Figure 17. Ecomorph House. Plan and skin diagrams.

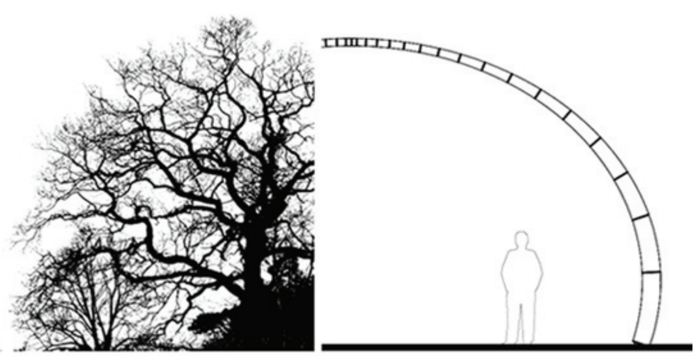


Figure 18. Ecomorph House. Sectional diagram of structural concept.

Figures 16-18 demonstrate this principle through the concept for an Ecomorph House, designed for a hot, humid climate. The shell-like form adapts to both sun and wind; the cross section is a warped catenary that conveys airflow, assuming a southerly breeze, and maximizes the south-facing surface area for the use of photovoltaic solar panels. The exterior cladding is translucent photovoltaic lenses, and the interior is phosphorescent panels that glow at night after receiving light all day.

The ends of the shell flare toward the north, both to shade the late afternoon light and to capture some breezes for interior ventilation. The structural frame is a polycarbonate honeycomb whose cells vary in size—what could be termed a "fractalized eggcrate"—recognizing that, like a tree, less material is needed at top than at bottom.

Figure 19. Foster + Partners, London Authority Building (City Hall).

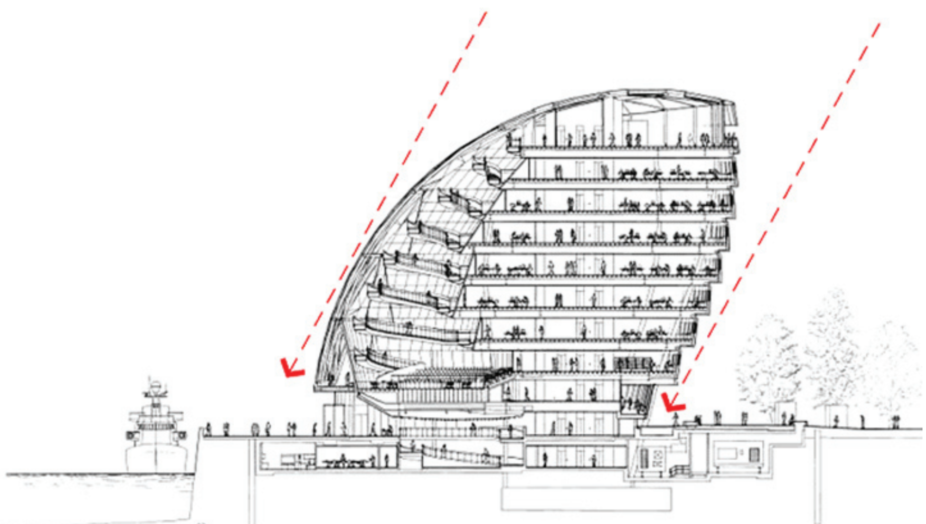


Figure 20. London Authority Building. Section showing sun angles.

The London City Hall, designed by Foster + Partners, shows a similar approach with an opposite form. The curvaceous envelope uses resources efficiently by optimizing the ratios of material to function and surface to volume. In this case, the tilt is toward the south, not away, in order to reduce the area of exposure to the sun and minimize heat loads. This strategy also maximizes the daylight reaching the pedestrian concourse on the north side.

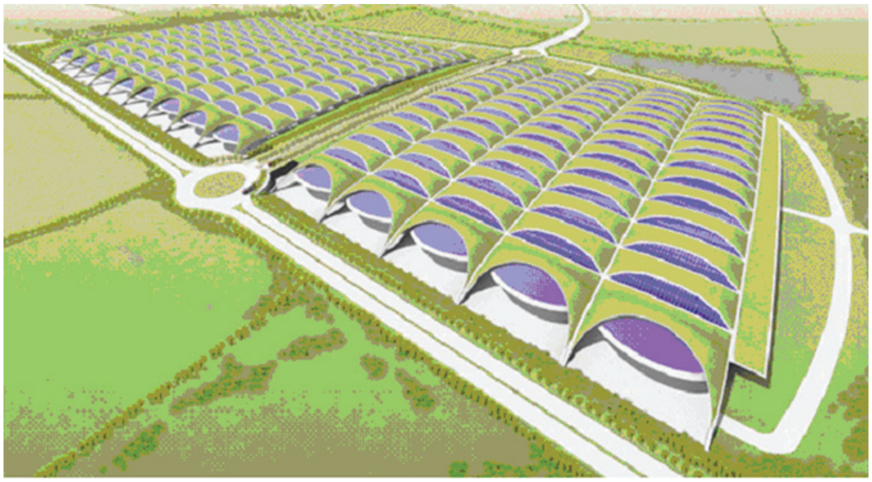


Figure 21. William McDonough + Partners, distribution center, England.

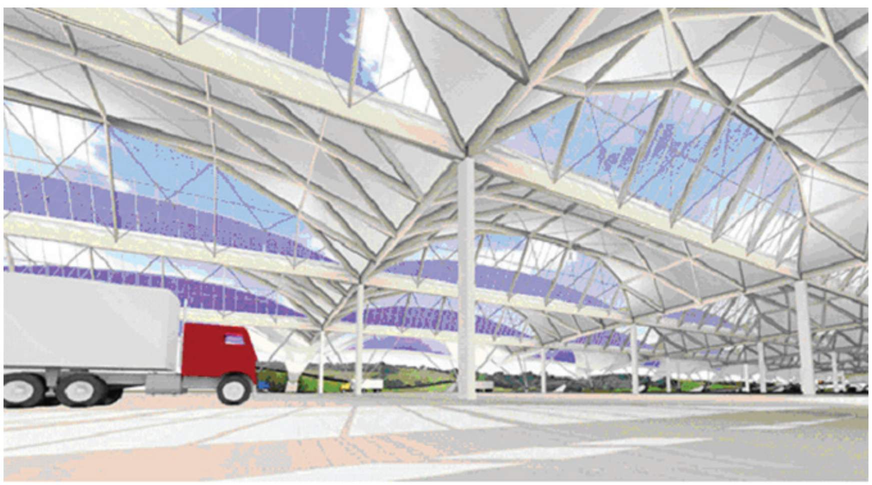


Figure 22. William McDonough + Partners, distribution center, England.

On a much larger scale, a project for a distribution center by William McDonough + Partners illustrates how to apply these principles to a modular strategy. A series of catenary vaults is sized to optimize the span and use as little steel as possible. The south-facing surfaces are clad in photovoltaics, and the north faces are clerestories. The remaining roofscape is planted, like a gently rolling meadow.

CONCLUSION

What makes these projects environmentally intelligent is precisely what makes them visually compelling. They demonstrate a direct relationship between form and performance and show that shape itself can aid sustainability in the sense that environmental educator David Orr describes—"the careful meshing of human purposes with the larger patterns and flows of the natural world." As industry develops new techniques, designers have an unprecedented ability to create intelligent forms fully adapted to the circumstances of climate and place. As a result, the lines between culture and nature blur, and design can emulate life as never before.