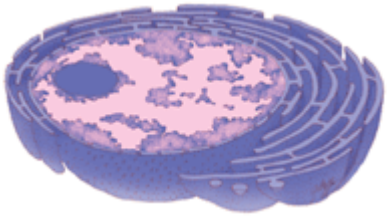
THE ECOVILLAGE as a LIVING CELL

~ Biological Structures and Metaphors ~



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OVERVIEW

We are living in an exciting Age. A convergence of prophecies and predictions from many different sources points to these times as a critical transition zone for humanity, in particular, and the Earth more generally: There is Millennium fever; there is a segment of society waiting for the Apocalypse and associated Rapture; there is the Hopi prophecy of a coming 'Fourth World;' the accurate Mayan calendar suddenly ends in the year 2012; the Age of Aquarius is dawning; Nostradamus, Zion, Babylon, the Pleiades, Sirius, and the New World Order, etc.

A purely scientific evaluation of the momentum of the day may also lead to a similar conclusion: a major transformation is pending because the confluence of so many signals is indicating that human systems are fundamentally altering natural systems, globally, causing uncertain chaotic disequilibrium; business cannot be carried on as usual. The Earth is heating up – sea levels are rising, glaciers are receding, and a large chunk of Antarctica is slipping into the ocean. Precious topsoil is being blown away or washed into the sea as deserts continually expand and marginal lands are salinized. Aquifers are depleted and lakes and rivers are poisoned as freshwater supplies are squandered. Forests are cleared and wetlands are paved over as multitudes of living creatures go extinct from loss of habitat. Billions of years of genetic diversity is cashed in for quarterly profit earnings. The new global economy that requires ever-increasing growth is running into the serious and real resource limitations of a finite Earth. Genomes are patented as biotechnology introduces new, manufactured life-forms that have not been integrated into the Web of Life, with consequences unknown. Exponentially intensifying human population pressure – the root cause of all these problems – leads to poverty, scarcity, a perpetual state of war, and a sense of dis-ease. Indeed, an objective analysis of the 'state of the world' must conclude that we are in a crisis situation: a major re-evaluation of humanity's role in the world is in order. This sort of needed discussion is currently taking place in many quarters around the globe under the heading of 'sustainability.'

Sustainability will mean different things to different people depending on where their interests lie. Some people speak of 'sustainable growth' or 'sustainable development.' For the discussion in this paper, a sustainable situation is one that can be *continued into the indefinite future* – for as far along the time horizon as one can imagine. The most obvious example of such a sustainable situation is the profusion of

biological life, proceeding in ever-greater complexity and diversity for some 3,900 *million* years now. What could be more sustainable? If we want to continue the human experiment into the indefinite future, what could be a better standard to emulate than the Earth's living biological legacy?

There is something about the patterns, processes, and structures – the very nature of biological systems – that promotes self-perpetuation and long-term viability. The purpose of this paper is to explore those qualities of biological systems that contribute to this sustainability. Once these are recognized, the next step will be to propose that human systems, if they are at all to be sustainable, *must be modeled upon natural biological systems.* (What could be more obvious?) A coinciding conclusion will be that the current so-called "global system" cannot ever be sustainable, as it is, because it is an abject deviation from organic evolution and is fundamentally antagonistic to the underlying biological and ecological patterns, processes, and structures that support it.

Once these propositions are established, the final step will be to explore the theoretical synthesis of biological and human systems at the scale of 'human settlement design' – in effect hypothesizing a 'biology of human settlements.' For the purposes of metaphorical musing, an idealized sustainable human settlement will be modeled upon one of the most elegantly simple yet usefully replicable biological systems in Nature – the living eukaryotic cell. Sustainable settlement design will then have a chance to become a human enterprise of mimicking and emulating cellular biological systems at a meta-scale. In this way, the 'human experiment' will then have the opportunity to be continued into the indefinite future.[1]

The intellectual discipline that most closely accommodates the synthesis of biology and human settlements is proposed here as "Ecovillage Design." The ecovillage is a recent innovative solution to the call for sustainability. The ecovillage can be defined as a:

* Human scale
* Full-featured settlement
* In which human activities are harmlessly integrated into the natural world
* In a way that is supportive of healthy human development
* And can be continued into the indefinite future[2]

[1] "The emerging biology could actually provide the basis for reorganizing society more holistically and for solving our critical world problems using information accumulated by our planet over five billion years of evolutionary experience" (Harman and Sahtouris, 1998, p.8).
[2] This definition can be found in Gilman, 1991, p.7

There are currently many ecovillages-in-process, scattered about the globe, but not one, as yet, fully-functioning ecovillage that can match this criteria. This paper, then, will be at length a theoretical inquiry into the qualities that can be designed into an ecovillage so that it can reproduce the sustainable achievements of cellular biological systems.

BIOLOGICAL EVOLUTION

Humankind (the species *Homo sapiens sapiens* at the moment)[3] maintains its entire existence within a breathing, pulsating, vibrantly alive biosphere. Humanity is an integral cellular component fully immersed in the vast cellular network that is the living biosphere; in fact, it is one of the more recent outgrowths in the long, progressively complexifying and diversifying, 3,900 million year advance of biological evolution (Margulis & Sagan, 1995, p.56). Humankind, comprised of multicellular organisms called human beings, in every conceivable way owes its emergence to the past successes of countless prior cellular organisms, and depends on its continued existence by the successful ongoing maintenance of a multitude of conterminously existing, interdependent cellular organisms – the Web of Life in all its glory.

All life is cellular. The first living organic beings to self-organize from out of the primordial chemical soup were tiny microbial *bacterial* cells called prokaryotes. These first life-forms inherited the three necessary characteristics of Life: 1) They possessed a *pattern* of autopoiesis, or self-making; they created themselves; 2) They initiated a *process* of cognition, in that they perceived conditions in their environment and responded to those conditions in order to maintain their autopoiesis; and 3) They were *dissipative structures*, or living systems maintaining themselves in highly energized, ordered states far from chemical equilibrium (Capra, 1996, p.160). This fundamental organic living triad of pattern, process, and structure – as first embodied in the prokaryotic (i.e. pre-nucleated) cell – has persisted on Earth for billions of years. Not only did these bacterial cells proliferate and fill the waters of the early Earth, but the descendants of those same successful pioneers continue to diversify, adapt, and specialize to this day – filling, opportunizing, and making use of every available environmental niche. Many of these life-forms have remained virtually unchanged throughout the aeons.

The prokaryotic cellular pattern has proven itself extremely viable. Prokaryote cells do not need sex to reproduce and therefore know no 'programmed' or timed

[3] This is to acknowledge that there are historically many species in the genus *Homo*, and to propose that there may be more to come; *Homo sapiens sapiens* may not be the endpoint of evolution! Perhaps, even now, the genus *Homo* is diverging into separate forms that will one day be classified as distinct species, just as *Homo neanderthalensis* and *Homo sapiens* coexisted for awhile before Neanderthal was proven less viable, despite having a larger cephalic index (Brace, 1967).

death; they freely trade genetic DNA material and can mutate themselves within hours, responding almost instantaneously to changing environmental conditions (Margulis & Sagan, 1995, pp. 127-30, in a section entitled "Sex and Death"). In effect, they constitute a global super-organism whose metabolic processes maintain the Earth as a fit place for Life (Lovelock, 1987). Potential terrestrial disasters (such as nuclear holocaust, global warming or cooling, comet or asteroid impact, general environmental degradation, etc.) could easily exterminate many or most of the recently appeared, multicellular life-forms, but the highly adaptable prokaryotes will surely endure to the end.[4]

For thousands of millions of years, Life worked with the fundamental prokaryotic cellular pattern, testing and experimenting with new structures, relationships, shapes, and metabolisms until ultimately all the cellular technologies used today had been tried, adjusted, refined, and incorporated. One branch of these cells, the cyanobacteria, learned how to use the energy from sunlight to break the hydrogen bond in water to make carbohydrate food for themselves, autotrophically; this was a major metabolic breakthrough that led to the emergence and ramification of the plant kingdom. The byproduct of this photosynthetic chemical process was free oxygen. As the cyanobacteria became ubiquitous on sea and land, oxygen began to accumulate in the atmosphere precipitating a global crisis for all the pre-existing life-forms, for oxygen was a deadly poison to these anaerobic creatures. In response to this crisis, some single cells penetrated and took refuge in the bodies of larger host cytoplasm; other cells ingested, but did not digest, the smaller cells that had learned how to photosynthesize (proto-chloroplast) or to use the oxygen as an energy source (proto-mitochondrion), creating novel, if uncertain, necessary partnerships. As these relationships evolved and stabilized over time a more complex form of single cell organic being arose – the eukaryotic cell. The eukaryotes were endo-symbiotic; that is, they incorporated previously evolved prokaryotic structures, organic unities in their own right, into a larger, more inclusive, inherently cooperative cellular whole.[5]

The eukaryotic pattern consists of a nucleus, housing the precious genetically encoded DNA macromolecules, surrounded in cytoplasm by numerous organelles: mitochondria, chloroplasts, ribosomes, lysosomes, centrioles, Golgi apparatus, endoplasmic reticulum, etc, all contained within a protective membrane cellular wall. "Like organs within bodies, organelles are functioning structures within eukaryotic cells" (Margulis & Sagan, 1995, p.97). Many of the organelles themselves are enclosed within

[4] "By constantly and rapidly adapting to environmental conditions, the organisms of the microcosm support the entire biota, their global exchange network ultimately effecting every living plant and animal…The result is a planet made fertile and inhabitable for larger forms of life by a communicating and cooperating worldwide superorganism of bacteria" (Margulis 1986, pp.18-19).

[5] The above story is synthesized from Margulis (1970), Margulis (1981), Margulis and Sagan (1986), Margulis and Schwartz (1988), and Margulis and Sagan (1995).

their own intracellular protective membrane producing their own DNA, ample evidence to conclude that these cellular components are descended from once independent organic beings.[6] Each of these organelles performs a specialized function within the larger body of the cell: the mitochondria carry out aerobic respiration and therefore energy production; the ribosomes are the sites of protein synthesis; the Golgi apparatus store and transport products such as enzymes and hormones; in plants, the chloroplasts produce food by synthesizing carbon dioxide and water, etc. Each eukaryotic cell is an extremely complex and amazingly internally coordinated arrangement of seemingly disparate independent structures cooperatively working together to accomplish the self-maintenance, self-regulation, and self-regeneration of the larger, collective cellular whole. This same exact description could be applied to the workings of a sustainable human settlement – these are the appropriate metaphors to begin working with.

The eukaryotic cellular pattern, too, has proven to be an extremely viable, sustainable structural arrangement, persisting now for over 1,900 million years. It has an evolutionary advantage over the prokaryotic cellular pattern by its enormous capacity for complexification, ramification, and its ability to form extracellular partnerships and collectivities. By 1,500 million years ago, unicellular eukaryotes were creating cooperative unions with one another, merging into multicellular bacterial forms called protoctists. The ability for individual cells to come together to form cooperative unions may have been a random or chance event the first time it happened; but thereafter it was motivated by desire and opportunism. Individual cells floating in a medium have limited evolutionary potential; multicellular, cooperative, systemic arrangements embody expanded evolutionary capabilities – emergent properties arise that are not possible at the individual scale.[7] The primary, teleological imperative of Life to perpetuate itself – to maintain its autopoietic, self-making capability for as long as it can – is enhanced at the multicellular level by increased cognitive (sensing, perceiving, and responding) capabilities and by the specialization of tasks of individual components. The

[6] Lewis Thomas elaborates: "The membrane lining the inner compartments of mitochondria are unlike other animal cell membranes, and resemble more closely the membranes of bacteria. The DNA of mitochondria is qualitatively different from the DNA of animal cell nuclei and strikingly similar to bacterial DNA…The RNA of mitochondria matches the organelles' DNA, but not that of the nucleus…the mitochondria do not arise *de novo* in cells; they are always there, replicating on their own independently of the replication of the cell…The chloroplasts in all plants are, similarly, independent and self-replicating lodgers, with their own DNA and RNA and ribosomes. In structure and pigment content they are the images of prokaryotic blue-green algae…[T]hese two organelles are, in a fundamental sense, the most important living things on Earth" (1974, pp.82, 84).

[7] "Systems almost always have the peculiarity that the characteristics of the whole cannot (not even in theory) be deduced from the most complete knowledge of the components, taken separately or in other partial combinations. This appearance of new characteristics in wholes has been designated *emergence."* (Ernst Mayr, as quoted in Augros and Stenciu, p.37).

same is true of *meta*-multicellular aggregates of human beings that organize themselves into cooperative communities.[8]

This new, multicellular pattern was so full of opportunity and potential that it rapidly expanded into ever more complex and diverse life-forms, exponentially blossoming in a profusion of organic creativity, giving rise to the so-called "kingdoms" of animal, plant, and fungi. Yet, all these more recent organic beings, continuing up to the present day, no matter how complex, are still completely constituted from a collection of individual eukaryotic cells. This fundamental pattern persists and endures and remains the foundation for all further advanced life-forms. All Life is cellular!

Multicellular organisms further self-organize into *meta*cellular patterns – higher octave communities composed of many multicellulars. These metacellular patterns – whether bee hives, societies, villages, ecosystems, herds, etc. – are fractal patterns; that is, the fundamental, primordially-patterned organic unit of the 'cell' is repeated over and over again at ever-increasing levels of complexity. Complex structures are always composed of previously created structures in ever-higher orders of integration. For example, a temperate rainforest contains many different communities of animals and plants. Each of these communities is a symbiotically attuned aggregation of individual organisms. Each organism is made of many different organs. Each organ, in turn, is made of tissues, and each of these tissues is composed of many individual eukaryotic cells – the fundamental "building block" in all cases. And, all of the more complex structures in this holarchical arrangement[9] are created from more simple structures that have proven themselves viable at an earlier stage of evolutionary development. At each of these fractal levels of integration and synthesis, the respective cellular systems *cooperatively,* unadversarily associate, ensuring the integrity of overarching suprasystems and underlying subsystems simply by maintaining their own health and integrity at each respective scale – and by finding a useful, mutually-supportive 'niche' within which to fit into the whole.

This last concept cannot be overstressed and may be considered a divergence from orthodox biological evolutionary thinking as first formulated and enshrined by Charles Darwin. In his *On the Origin of Species,* he states:

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[8] "It has been proposed that symbiotic linkages between prokaryotic cells were the origin of the eukaryotes and that fusion between different sorts of eukaryotes…led to the construction of the *communities* that eventually turned out to be metazoan creatures. (Thomas, 1974, p.8) The italics have been added to emphasize the relevance of the term 'community' to all levels of biological aggregates.

[9] To be distinguished from 'hierarchical.' 'Holarchical' implies interdependency and a mutually interactive network as compared to the top-down, mutually exclusive, potentially 'power-over' arrangement of a hierarchy. The holarchical pattern could be extended outward to include bioregions, Gaia, the solar system, the galaxy, etc., and can be turned inward to include organelles, molecules, atoms, and fundamental particles. Each of these unities in the holarchy is termed a 'holon', and each holon both autopoietically maintains its own existence and contributes to the life of the holons within and without it.

> There must be in every case a struggle for existence, either one individual with another of the same species, or with the individuals of distinct species, or *with the physical conditions of life* (Darwin, 1859, p. 47, added emphasis).

This somewhat desperate outlook, this proposed existential tension, contradicts much of the more recent findings and observations in biology – and especially in its sub-discipline ecology. Science, at any given moment, can be considered a reflection of the worldview or paradigm of the society in which it is being practiced, and perfunctorily will use metaphors to support and describe that worldview. Descartes, for example, rather simplistically spoke of "a clockwork universe" during a time when the most sophisticated mechanical contraptions were clocks, supporting an emerging paradigm that was separating itself from Nature and adopting a view of the universe conceived as created by a grand engineer, *deus ex machina*. LaPlace's ultra-determinism was modeled upon an image of the collision of imaginary billiard balls commencing at the birth of the universe and reaching their ultimate physical extension with predictable precision. Today, the frontiers of science are attempting to describe Nature in terms of "chaos" and "complexity," as our complicated world-system becomes ever more incomprehensible, erratic, and seemingly poised for transformation.[10]

One must imagine in Darwin's day a world situation that would encourage him to postulate a theory of evolution based on 'win-lose' competition, the "survival of the fittest," "the struggle for existence," and "The Preservation of Favoured Races in the Struggle for Life."[11] Indeed, the social conditions of his Victorian era warranted such ideology: Europe was releasing its population pressure in an institutionalized and often brutal colonialism that needed a rationalization for its genocide of indigenous people; capitalism was on the rise, moralizing a classist 'win-lose' society of haves and have-nots, and looking for scientific justification for this pretense; Europe had been in an almost continual state of war for 500 years. Under these conditions, an image of Nature "red in tooth and claw"[12] seemed entirely justifiable. A "Social Darwinism" emerged sanctioning the actions of those 'most fit' – that is, those born with privilege – to exploit and/or exterminate lesser beings and disadvantaged people. Darwin writes:

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[10] "Complexity Theory, in particular, appears to bring a radically new possibility to evolutionary theory. It is widely recognized that the Darwinian hypothesis of the origin of new species – random mutations followed by natural selection – does not adequately fit the observed data. The gradual change and continuity that this implies is simply not found in the fossil record. New types of organisms appear on the evolutionary scene, persist for varying periods of time, and then become extinct. There is no widely accepted explanation for the relatively sudden emergence of novelty…the appearance of order out of chaos in complexity theory seems to give a promising lead toward accounting for this phenomenon." (Harman and Sahtouris, 1998, p.xiv)

[11] This last phrase is the shocking subtitle of his *On the Origins of Species.*

[12] Tennyson's now famous phrase.

> [W]e have seen in the chapter on the Struggle for Existence that it is the most closely allied forms…which, from having nearly the same structure, constitution and habits, generally come into the severest competition with each other; consequently each new variety or species, during the progress of its formation, will generally press hardest on its nearest kindred, *and tend to exterminate them*. (1859, p. 84, emphasis added)

Sibling rivalry? The demise of the family? Patricide? Urban crowding? Darwin's theory, while presenting an important hypothesis for biological evolution – natural selection – was tacitly conceptualized and worded to accommodate and reinforce the predominant socio-economic political ideology of his society, in his time, as all scientific theories ultimately do.

A growing number of writers and thinkers in this day and age are forwarding contrary images of biological evolution, accommodating the emerging ecological worldview of *our* times. For example:

> Whenever we find rather similar animals living together in the world, we do not think of competition by tooth and claw, we ask ourselves instead, how competition is avoided. When we find many animals apparently sharing a food supply, we don't talk of struggles for survival; we watch to see by what trick the animals manage to be peaceful in their coexistence…A fit animal is not one that fights well, but one that avoids fighting altogether (Paul Colinvaux as quoted in Augros and Stanciu, 1987, pp. 99, 102).

Such an attitude, as expressed, articulates a 'win-win' situation that is a much more accurate portrayal of the realities of Nature, and may be considered the philosophical basis of a moral declaration for sustainability. Of course, the capitalist sector, who have everything to gain by perpetuating the 'win-lose' scenario, are not going to be able to accommodate this; but then, that system is not sustainable and is not an accurate reflection of the realities of Nature.

More specifically, regarding the vegetable kingdom: "There is no violent struggle between plants, no warlike mutual killing, but a harmonious development on a share-and-share basis. The cooperative principle is stronger than the competitive one" (Fritz Went as quoted in Augros and Stanciu, 1987, p.93). Or finally, how about a contribution from that avid perennial biology watcher, Lewis Thomas: "Most of the associations between living things that we know about are essentially cooperative ones, symbiotic in one degree or another…we do not have solitary beings. Every creature is, in some sense, connected to and dependent on the rest" (1974, p.6). We may more accurately claim "*interdependent* on the rest" because, in a community of organisms, "every

species…directly or indirectly, supplies essential materials or services to one or more of its associates" (Lee Dice as quoted in Augros and Stanciu, 1987, p.116). Or, then again, "There is a tendency for living things to join up, establish linkages, live inside each other, get along whenever possible. This is the way of the world" (Thomas, 1974, p.147).

These mental images of Life in general more accurately reflect the essential nature of communion, cooperation, and mutual co-existence that can be found within the interacting components of complex biological systems, beginning in all cases with the scale of the interdependent community called the eukaryotic cell. What would happen if the nucleus in a cell sought to exert its influence and attempt a hierarchical power-play over the Golgi apparatus? Absurd, right? So then how can any of the more complex meta-configurations of the eukaryotic pattern, for instance individual holons of the species *Homo sapiens,* attempt to justify their domination and subordination of completely interdependent elements of systems of which they are a part under the rationalization of "survival of the fittest?" Darwin's theory, the evidence reveals, is much more an historical, social justification than it is objective, scientific, biological truth.[13] Sustainable, long-term evolutionary conditions are cooperative, mutually-reinforcing, holarchical, and are designed so that the health of each contributes to the health of all.

These necessary requirements become increasingly visible as consciousness grows to be ever more inclusive. Under advanced conditions, competition becomes self-referential, a striving to be the best that one can be in comparison to a personal history or an idealized spiritual example. No one need be defeated; self-actualization is the goal.

[13] The metaphor of natural selection derives from the dominant socio-economic ideology of the Victorian era, now rejected by nearly all of humanity. The mechanistic conception of life which it inspires is equally outmoded and inappropriate. Why should we cling to this metaphor when it can serve no other purpose than to reinforce the prejudices which gave it birth?" (Mae-Wan Ho, 1988, as quoted in Harman and Sahtouris, p.53)

HUMAN EVOLUTION

Homo sapiens has, in many ways, attempted to bypass or circumvent organic, biological organization. Owing to the growth of a neocortex, an organ offset somewhat from the centralized, axial nervous system, *Homo sapiens* has developed the capacity for abstract, rational thought and self-reflection. Being able to assume the perceived position of standing outside oneself and, supposedly, objectively looking back upon oneself has led to the perceived position of the rational observer, supposedly, standing outside of Nature objectively looking back upon Her. This mistaken point of view, as amply affirmed by quantum physics, has led modern human beings to believe that they are somehow separate from or standing above Nature. These feelings of separation and superiority – an over-emphasis on rational, logical, abstract thought localized in the neocortex – has given 'civilized' people the self-proclaimed license to control, dominate, and exploit other life-forms. This attitude can only result in the formation of contrived, unnatural, stressful cultural patterns that deviate from organic patterns – the epitome of which is western global civilization.

But it is existentially impossible for *Homo sapiens* to stand above Nature, to be separate or superior; they are merely one of the more recent outgrowths of the 3,900 million year advance of biological evolution (Margulis & Schwartz, 1998). It is said that if the entire history of life on Earth was as tall as the World Trade Center, then the human cultural experience would be no thicker than the layer of paint on the ceiling of the top floor. An individual *Homo sapiens* could be considered nothing more than a complex, cooperative community of eukaryotic cells. Since the eukaryotic cell will persist long after *Homo sapiens'* demise, one could even go so far as to say that the cellular organic unity called *Homo sapiens* is just an advanced tool for the eukaryotic cellular collectivity to enhance *its* evolutionary potential through increased cognitive (sensing) capabilities. Why, then, does *Homo sapiens* seem to be stumbling so?

What is the purpose of the neocortex, the organ that distinguishes *Homo sapiens* from all other species? What could be gained by the ability of the 3,900 million year old cellular collectivity to position itself in outer space and assume a perspective that could look back upon itself? Would this not suggest that the cellular collectivity, Earthlife itself, has achieved self-consciousness or self-awareness through the organ of *Homo sapiens*? *Homo sapiens* does not stand outside of Nature; *Homo sapiens* **is** Nature becoming self-aware of her own marvelous organic beauty and complexity. And, *Homo*

sapiens is not the endpoint of evolution, the complete finished reflection of the Divine; *Homo sapiens* is a transitional phase (as most species turn out to be transitional) with the potential to evolve into even more complex forms, just as many other organic beings evolutionarily branched out to reach the complex multicellular form of *Homo sapiens.* The neocortex, then, could also be considered a transitional organ, offering an initial glimpse of self-awareness, but bound to be just another base structure from which the evolution of further cognitive organs can manifest.

Further growth will need to take place in the posterior of the brain, closer to the spinal cord, in intuitive regions called the Occipital lobe, to offset the recent bulge of the frontal lobe neocortex. This new growth will help to balance and ground the abstracting, separating tendencies of the neocortex with the organic intuition of the entire pre-existing, global evolutionary intelligence centered amid the basal reticular structures. The result will be self-consciousness aligned with organismic wisdom and purpose. It seems likely that the abstract thought-forms of the neocortex are a short-term evolutionary experiment into a dialectic exchange with projected, alternate, possible futures, but are not sustainable in the long run. This is because these thought-forms exist entirely in a linguistic domain that has a tenuous, uncertain, and at times distant relationship with organic evolution. To accept these thought-forms as strictly reality, as *Homo sapiens* so readily does – to mistake the model for the real thing – is to construct a world that is lacking a biological foothold. This abstracted world, if proven inimical to the real world, will not have a long-term future and could have the potential of evaporating into its own ethereality.

This is the nature of *organic* evolution: Nature continues to complexify, diversify, multiply and expand for as long as it can, simply because it can, until the co-evolving environment provides the "power of limits."[14] Should one particular emerging structure prove viable, able to maintain itself over the long run, new structures will evolve upon the ground of that previous structure; but the fundamental principles remain the same: all new emerging structures ultimately trace their ancestry all the way back to that first primordial prokaryotic cell that self-organized from out of the chemical soup. This lineage never waivers or is compromised: In organic evolution, new structures never appear out of nowhere, they are always deeply connected with their roots. The way to ensure long-term sustainability in human systems is to design and create structures, patterns, and processes – even novelties – that are deeply connected with their organic roots, and this understanding has profound design implications.

[14] It is conceivable that Life is a universal process having achieved evolutionary finalities elsewhere. These forms that have come before, no matter where they occurred in the universe, would have created fundamental "morphogenetic fields" that would form the structural templates for re-occurring, re-initializing planetary life evolutionary processes. Morphogenesis is still one of the greatest puzzles in biology (see Sheldrake, 1981 and 1992).

CULTURAL EVOLUTION

Homo sapiens has proven to be a remarkably adaptive, creative, and prolific community of eukaryotic cells. "[T]he human species has been and still is evolving at an exceptionally rapid pace, and in an entirely new direction from that which any species population has previously taken" (Stebbins, 1970, p.177). *Homo sapiens sapiens,* modern civilized "man," has achieved dominance over his environment and over his fellow creatures, yet, "[t]he way in which this dominance has been achieved is…so different from organic evolution…that it must be given a different name and defined in a different way. We can call it *cultural evolution*" (ibid, p.178). There has been no selective pressure for humanity to evolve anatomically for 40,000 years and the *rate* of brain growth began to level off some 500,000 years ago. With cultural evolution, humanity modifies the environment to suit its needs, rather than hereditary modifications of the body co-evolving with a changing environment. The products of cultural evolution can be termed "exosomatic," or outside the body. What are the implications of a distinctly cultural evolution discontinuous with organic evolution? If these two start out discontinuous, what happens as they increasingly diverge over time? Is it possible to consciously work toward *con*vergence?

Largely because of intense population pressure, *Homo sapiens sapiens* has contrived a prodigiously complex world system called 'civilization.' Civilization is essentially the culture of cities – city and especially urban life. The first cities arose in crowded conditions where traditional, close-to-the-land, organic cultural systems were displaced. Civilization, in no small way, was a direct product of the rationalizing, conceptualizing, future-projecting qualities of the neocortex attempting to formulate workable solutions to the new, crowded, artificial environments of cities. These solutions were social constructs in the form of laws, philosophies, doctrines, governments, ethics, institutionalized religions, etc. Since the neocortex gave *Homo sapiens sapiens* the perceived sense of standing outside of Nature, it is totally congruous that the constructs of this neocortex also reflect the qualities of being separated from Nature. Civilization, and its co-generative city culture, then, is an abstract human construction *intentionally* disconnected from its biological roots; how could it ever be sustainable?

To support this assertion, consider the following: Nature is a synergistic and highly evolved meta-system where the needs of 'each' correspond to the needs of 'all;'

each part provides a function for and contributes to the optimal health of the whole simply by maintaining its own optimal health. "The parts of a healthy holon contribute to each other's welfare in a balance of interests, a balance of conservatism and change. Every cell looks out for itself as well as for its tissue, organ, and entity" (Harman & Sahtouris, p.154). The first law of ecology is: "everything is connected." Civilization, on the other hand, is a system where the *needs* of the whole – optimal long-term viability for all – are compromised for and subordinated to the *wants* of a few, where privileged parts can maximize their own short-term self-interest, feeding off the health of the whole at the expense of the long-term interests of the whole. Is this not the nature of global capitalism, the seeming culminating end-point of civilization?

Or, to put it another way, Nature is a primordial, time-tested interaction of relationships arranged to serve the collective good – the continuing complexification and diversification of Life. Civilization is a human-made, abstract, recent invention that has not withstood the tests of time and at its core undermines and is hostile to the collective good – the broad-based perpetuation of Life. Civilization, in the form of predatory, centralized, arbitrary power structures, colonizes and exploits natural living systems for its own personal gain and short-term profit, then leaves behind an eroded wasteland, in every case.[15] Civilized global capitalism homogenizes diverse, place-based cultures into a bland, amorphous, dispossessed statistical aggregate. Any way you describe it, civilization and its culminating finality in the global capitalist system is a contradiction to the patterns, processes, and structures of Nature. In every location that it has been imposed the result has been ecological degradation and impoverishment. Is this not the essence of the "sustainability" discussion? For, any construct that is disconnected from and hostile to its biological roots will not be sustainable – that is, it will not be able to be continued into the indefinite future.

Consider the structural arrangement of the 'city' – the crown achievement and localized configuration of the abstract cultural pattern called 'civilization.' In comparison to organic living systems, the city is a rigid, mechanical, engineered construction that requires huge inputs of external energy to maintain its hyper-entropic, frenetic thermodynamic waste. The city is a machine whose purpose is to rapidly transform the material component of the Earth into so many artifacts and products for consumption; to achieve its purpose, it is necessary that the people living in these cities become efficient sub-units in the machine. The city is concentrated in a central power core that radially extends outward with no perceivable boundaries – resembling a cancer, there is no inherent limit to its growth. Expanding cities will consume outlying settlements, always pulling power back to the centralized, concentrated urban core. Cities are often

[15] Dale and Carter, 1955, provide an historical account of the repeated demise of civilizations after they deplete their topsoil.

laid out in an abstract, square grid pattern of buildings, streets, and blocks with no perceivable relationship to the buried, underlying natural hydrology and ecology. The central core will grow vertically, rising above the ground in phallic towers, figuratively separating the people at the top of the socioeconomic hierarchy with those on the streets below.

The city (and civilization) is an abstract human construction, both structurally and socially, with no comparable morphology or pattern of organization to be found in Nature; you could say it is a patriarchal edifice whose purpose is to control, tame, and subdue Nature, to hide and replace Nature with a completely human-built environment so that maximum efficiency, productivity, and obedience is promoted in the populace. But what does it mean for the people living in these artificial, mechanical, droning structures? What are the effects of this sort of advanced, western techno-cultural evolution on the inhabitants' biological evolution?

Consider, for example, modern civilized human beings living high in an apartment tower in Tokyo or New York. When they look out their window all they see is buildings and streets, perhaps some atmospheric patterns behind the smog, maybe a few trees far below, maybe they could even spot other human beings looking out of windows of the buildings across the way – but generally not much life. When these apartment dwellers get hungry, they will walk down the hall to the elevator, then take the elevator down to the garage. They get in their cars and drive to the market. For the single minute it takes to walk into the store their head is exposed to the sky, perhaps for the first time all day. They get their goods, get back in the car, back to the parking garage, then up to their little 'loft.' Safely back inside, they turn on the TV, sit down with their industrially processed food and beer, and prepare to receive information from a transnational corporate newscast. Perhaps they will be metabolizing prescription pharmaceuticals they ingested, along with the artificial chemicals from their meal, as they sit and vibrate to the bombardment of intrusive electromagnetic signals coming at them from all around.

Sure this scene is ugly, but is it so far-fetched? My purpose is not to berate city-dwellers – I admire their resiliency and fortitude. My purpose is to explore the question raised earlier: What are the implications for the *biological* evolution of an organism being raised in a completely artificial, unnaturally squared, sterilized, crowded, caged, stressful, sensory deprived, Nature deficient, hierarchically power-structured environment? Evolution can be defined as, "an orderly sequence of changes in the relationships between the population and its environment" (Stebbins, p.177). "No organism makes sense in abstraction from its natural living conditions; the environment is part of its definition" (Augros & Stenciu, p.320). Evolution does not occur in a vacuum – it is always the *co*-evolutionary process of an organism structurally coupled to its

environment, each influencing and reciprocating one another. The organism shapes the environment as the environment shapes the organism. The life-cycle of an organism could be considered the historical accumulation of its ontogenetic relationship with a particular environment. The implications for the phylogenetic evolutionary trajectory of generations upon generations of human beings structurally coupled to an artificial environment of their own making is not good; they are moving in a direction discontinuous with and divergent from organic biological evolution. Is it any wonder, then, that this evolutionary trajectory would eventually arrive at a crisis of sustainability, a serious re-evaluation of whether this course can be continued at all? Is not the long-term viability of *Homo sapiens sapiens* being called into question? Would it not be advantageous for Nature, or the cellular collectivity, to now be experimenting with new forms of human being?

BIOLOGICAL STRUCTURES AND METAPHORS

"[S]cience deals with models and metaphors representing certain aspects of experienced reality…science does not work by deduction "but *mainly by metaphor*" …the choice of the appropriate metaphors is thus the main work" (Harman and Sahtouris, pp.26-28, added emphasis). Originating with Classical Greece and then intensifying some four-hundred years ago, the philosophers of science envisioned the universe in mechanistic terms. They saw a giant machine that could best be understood by reducing the whole into its subsequent parts and then analyzing each part in ever-finer detail. They searched for immutable laws that governed the operation of the machine that could be expressed everywhere and anywhere. They excluded consciousness or purpose as innate causative agents of reality and only accepted perceptions that could be quantified and measured. They eventually came to see a lifeless, purposeless, random universe that was running down, its final destiny to collapse in the heat loss of advanced entropic decay. This is the paradigm and mindset that guided and informed the rise of materialistic industrial civilization and has brought us to the crises we face today. "As things stand, our main metaphors for life and the universe at large come from our invented mechanics. We discuss the machinery of nature and extend the metaphor beyond science to our socioeconomic systems, which we hope to run as well-oiled machines" (ibid, p.10). Since all machines are prone to entropy and eventual breakdown, our global socioeconomic system is destined categorically for collapse and replacement.

Any discussion about a *sustainable* future must begin with replacing the overworn, outdated, mechanistic metaphors with living, breathing, organismic metaphors. We must learn again to experience, as the ancients did, the universe as conscious and alive and deeply purposeful, all of its parts tingling and vibrating with the animating essence of Life. The rocks, the plants, the stars, the wind, the Earth, the human beings and the settlements they live in – all are living holons in the vast, timeless, living holarchy that is the universe. Fortunately, this emerging worldview is receiving ever wider and deeper, and ever more sincere authorship, largely under the

designations of "holistic," or "systems," or "ecological" thinking. It seems that a fundamental paradigm shift is underway.[16]

For those of us involved in the field of "ekistics" – the scientific, multi-disciplinary approach to human settlements – this means envisioning the sustainable human settlement as an organism, a biological structure, an organic living system embedded within larger living systems and comprised of smaller living systems. We must begin to model its patterns, processes, and structures upon organic, biological, and ecological realities and to learn to use the metaphors that support this transformation. An excellent place to start will be to imagine the design of sustainable, village-scale settlements modeled upon the characteristics of the eukaryotic cell, the fundamental "building block" of Life.

In preparation for this endeavor, Janine Benyus, in her excellent precedent-gathering book *Biomimicry: Innovation Inspired by Nature,* gives us some general criteria to work with (1997, p.7):

- Nature runs on sunlight
- Nature uses only the energy it needs
- Nature fits form to function
- Nature recycles everything
- Nature rewards cooperation
- Nature banks on diversity
- Nature demands local expertise
- Nature curbs excesses from within
- Nature taps the power of limits

[16] "Arguments between mechanists and holists have raged for decades. What is at stake are fundamental models or paradigms of reality. In the context of growing fears of environmental crisis, it has become obvious that our attitudes affect the way we live and even affect our prospect for survival as a species. The debate over mechanistic and animistic models of reality is now not just a scientific or philosophical issue but also a political one" (Sheldrake, 1992, p.152).

THE ECOVILLAGE as a LIVING CELL

The living eukaryotic cell orders itself into four types of multicellular patterns: protoctist, fungi, plant, and animal. The two forms most relevant for this exercise are the plant and the animal; thus, the 'village-cell' will be a synthesis of the two. It makes sense, as human animals, to re-create metacellular forms modeled upon the characteristics of the animal cell; but the plant cell also has some interesting and useful features worth borrowing. The following, then, is a partial list of structural characteristics of the living eukaryotic cell that can be incorporated metaphorically into the design of sustainable human settlements, most appropriately and effectively at the scale of the 'ecological village.'

Membrane: A defining characteristic of all living systems is their enclosure within a limited domain. There is a unifying boundary that encircles their autopoietic, self-maintaining processes within a self-defining area of activity; this boundary creates a field of experience. If there is no boundary there is no living system; without a boundary, the vital, concentrated internal order of the system is scattered and diffused into the surrounding environment. The first living systems to self-organize from out of the amorphous chemical soup 3,900 million years ago, those first prokaryotic cells, did so by first constructing a lipid wall that could form a distinct boundary between their ever more ordered and refined internal processes and the seeming chaos raging outside their boundaries.[17]

In a living cell this boundary is called a *plasma membrane.* "Every cell…has a plasma membrane forming its outside border and setting it off from its fluid environment. More than just a boundary, the plasma membrane enables the cell to take up needed molecules from the surroundings, provides sites where important chemical reactions occur, and disposes of wastes. In doing so, it helps maintain a life-sustaining collection of molecules inside the cell quite different from that of the outside environment."[18] Also, "The difference…between a dead bacterium and a live one is

[17] "It takes a membrane to make sense out of disorder in biology. You have to be able to catch energy and hold it, storing precisely the needed amount and releasing it in measured shares. A cell does this, and so do the organelles inside…To stay alive you have to be able to hold out against equilibrium, bank against entropy, and you can only transact this business with membranes in our kind of world." (Thomas, p.170)
[18] Campbell, Mitchell, and Reece, 1997, p.51

membrane potential. In living cells, the concentration of chemicals or charges inside the enclosing membrane is different from the concentration outside…A process like photosynthesis actually creates unequal gradients…This polarizes the membrane, making the inside of the sac different from the outside…Living cells can use that energy potential…On a cellular level, life lives in the tension between unequal concentrations, unequal charges."[19] The difference between the living and the non-living, then, is the difference in potential achieved by concentrating and storing negentropic order within a highly defined field of experience.

The plasma membrane is the cellular wall, the barrier that provides protection from rapid fluctuations in the physical and chemical conditions of the external environment. The cell, as a living system, must remain open to the flow of materials because it is in the transmutation of these materials that it maintains its form amid constant change. The cellular wall is the barrier that provides protection from the intrusion of unwanted or nonessential materials, nutrients, or entities, and marks the interface where the exchange of wanted or necessary materials is transacted. The membrane is the point of discrimination, where the cell decides what it will let into its internal environment and what it would choose to keep out. An unhealthy cell will have a permeable membrane and will lose its ability to choose what enters its domain. In short, the membrane provides a self-contained, inner sphere of activity that is remarkably different in quality from its encompassing environs. In a plant, the plasma membrane is rigid cellulose, often in a geometrical polygonal shape; an animal cell usually has a flexible membrane, polytudinal, which adjusts and fits itself to its location, much as an ecovillage ecologically integrates itself into its surrounding topography.

All of these membranous metaphors could be extended to describe the characteristics of the quintessential sustainable human settlement – the ecological village. All ecovillages need a well-defined boundary, a membrane demarcating their highly ordered and refined internal processes with the surrounding environment. This membrane will be the village cellular 'wall,' the enclosure that defines it as an autopoietic unity. Each village will adopt a structural form depending on its function, and the village 'wall,' or symbolic enclosure, will help to maintain its morphology. [20] Each village will have an optimal size determined by its function within the bioregion (the larger tissue) and the carrying capacity of its encompassing ecosystem. The cellular wall will prevent the village from growing beyond its ecological limits, implying that internal human population must remain in equilibrium. Should the village-cell find itself in ecological conditions where desired growth would not exceed carrying capacity, then the village-cell must undergo mitosis, divide, and organically create a new village-cell

[19] Benyus, p.66
[20] The relationship between form and function is an aspect of biology ripe with metaphors.

structurally centered outside its boundaries. To allow a village to grow outward without limits, without a well-defined, ecologically conscious boundary, is to enter the murky realm of unsustainability.

Nucleus: The eukaryotic cell is distinguished from its prokaryotic predecessor by the possession of a nucleus, a well-defined center, so we can assume the function of the inclusion of this organelle has something to contribute to the ability of eukaryotic cells to conjoin into complex, multicellular patterns. "The nucleus contains the genetic material, deoxyribonucleic acid, that determines the specificity of cellular behavior and controls its metabolic activities…[T]he nucleus is not merely functioning as the archive of the cell and repository of the genome [hereditary pattern information]; it is also translating information encoded in the DNA of the chromosomes into specific sequences of amino acids in *messenger RNA,* which then passes out of the nucleus to transmit to the appropriate sites the instructions that direct the specific synthetic activities of the cytoplasm" (Fawcett, 1966, p.2, original emphasis).

The nucleus is often called the "control center" of the cell, but this is misleading because each nucleus is "completely dependent on the surrounding cytoplasm, which, in turn, is ultimately dependent for continued functioning and survival on the nucleus" (Brown and Bertke, 1974, p.304). This sort of explanation more accurately portrays the mutually-supportive interdependency that exists between components, or holons, of any viable biological community. "Control center" is a mechanistic metaphor arising in a materialistic, militaristic culture. A more holistic approach would be to say that the function of the nucleus within the cell is to coordinate, regulate, and manage the multitude of self-maintaining, self-regulating, self-regenerating activities that ensures the cell's ongoing autopoiesis. This is truly one of the great marvels and mysteries of Life, for each cell completely manages its own affairs, internally, without the need for external authority. And to think, even more inclusive levels of the holarchy – the multicellular patterns of organs, bodies, and ecological communities – are also all completely self-organizing without the need of an external authority.

Structurally, "Nuclei are generally spherical or oblate spheroids" (ibid, p.307), though some may be polymorphic, or irregular with a lot of edge; these last types occur in conditions of high metabolic activity. Most eukaryotic cells contain only one nucleus but some are binucleate or even multinucleate. The nucleus is enclosed within an *intra*cellular, double membrane called an envelope, into which are perforated numerous pores or passageways used as communication channels with the cytoplasm. Inside the membrane is the information packed DNA, and scattered nucleoli rich in RNA.

The metaphors here are obvious: The ecovillage needs a well-defined center to coordinate, regulate, and manage its internal processes as well as to communicate and integrate activities with neighboring village-cells, with the encompassing ecosystem, bioregion, continent, planet, and cosmos. It must be important for the nucleus of the ecovillage to have its own distinct membrane, spatially distinguishing it from the body of the village, with a limited number of passageways or communication channels. The nucleus will contain numerous substructures: libraries and archives, schools, communication technologies including computer and satellite equipment, government offices including decision-making bodies, the village hall for politicking and philosophizing, and the temple or church. The village nucleus contains the descriptive, encoded, cypherable, ancestral, particular information that culturally-characterizes the unique function of this particular village within the larger body.

Chloroplast: "[I]t is not possible to overemphasize the importance of chloroplasts…chloroplasts carry out photosynthesis, absorbing solar energy and converting it to chemical energy in sugar molecules. Most of the living world runs on the energy provided by photosynthesis [!]. In viewing a chloroplast's internal structure…we see a solar power system much more successful than anything yet produced by human ingenuity" (Campbell, Mitchell, Reece, p.63).

Structurally, the chloroplast is self-enclosed in its own 'discoid or ellipsoid' membrane and is internally partitioned into three compartments. Such fine spatial organization evolves within a biological structure that engages in complex, multi-step processes. There is a center region in the chloroplast in which are located numerous disks, called *thylakoids*, occurring in highly ordered stacks called *grana.* "The grana are the chloroplast's solar power packs – the sites where chlorophyll actually traps solar energy" (ibid). Frequent connections called *frets* are made between adjacent grana, and the entire three-dimensional arrangement is a highly interconnected network array of solar receivers, channels, and relays.

The "Ecovillage Millennium" (Jackson and Svensson, 2000) will also become the Solar Age. Each ecovillage, or sustainable human settlement, will strive for energy self-reliance, converting entirely and inevitably to renewable energy sources. Within each village-cell will be chloroplast sites where light from the Sun is collected, transformed into electricity, and stored for future use. (Yes, this is worthwhile even in overcast climates). Solar engineers have a lot to learn from the structure and chemistry of the chloroplast. It should be possible to create an entirely clean, wholly accessible energy technology that runs entirely off the Sun. Oh, if the exalted human technology could

only come close to the prowess of Nature's ingenuity. Benyus (1997) devotes a whole chapter to leading research in this area.

Endomembranous Network: There is an internal (endo-) network of membranes in the eukaryotic cell that compartmentalizes the cell, providing districts and quarters for specific organelles and their functions. This partitioning allows space for distinctly different chemical conditions to occur simultaneously throughout the cell as required by each organelle and its specific metabolic function.[21] This network of membranes vastly expands the metabolic potential of the cell by greatly increasing its total surface area, as, "many enzymatic proteins essential for metabolic processes are components of organelle membranes" (Campbell, Mitchell, Reece, p.57). "[S]uch a system of interconnecting cisternae [folded membranous cavities] provides channels throughout the cell which could be used for the transport of material" (Toner and Carr, p.28).

Three organelles intimately involved with the endomembrane are the ribosomes, the endoplasmic reticulum (ER), and the Golgi apparatus. Together they act as the 'industrial' sub-units of the cell, 'manufacturing' proteins, enzymes, amino acids, and other chemicals and molecules as needed by the cell, or in many cases to be transported outside the cell. "With mind-boggling precision, each cell manufactures nearly 200,000 different chemicals, hundreds at a time" (Benyus, p.187). "A cell is like a big industry, which manufactures different products at different sites, ships them around to assembly plants, where they are combined into half-finished or finished products, to be eventually, with or without storage in intermediate facilities, either used up in the household of that particular cell or else extruded for export to other cells or waste disposal" (Weiss as quoted in Augros and Stanciu, p.30).

The ribosomes may be scattered independently, in groups, or attached to the cisternae of the ER. They are usually densely packed with RNA. "The RNA of the ribosome is the site of protein synthesis in the cytoplasm. This fundamental activity is finally controlled by the genetic code of the DNA. The ribosomes themselves may be synthesized in the nucleolus, but they receive their instructions for the manufacture of specific protein molecules from messenger RNA in which the genetic code is transcribed" (Toner and Carr, p.24). Doesn't this kind of wording sound remarkably like an economic process? It is known that what makes proteins, amino acids, and enzymes useful for specific functions are their three-dimensional shape, the way they fit together. Is this not analogous to the 3-D artifacts a settlement produces for its own self-maintenance? At risk of sounding over-mechanistic, the ribosomes are shops or

[21] It will be useful at this point to define *metabolism* because a sustainable human settlement, a village-cell, could be considered to have a metabolic process: Metabolism is "The complex of physical and chemical processes occurring within a living cell or organism that are necessary for the maintenance of life. In metabolism some substances are broken down [consumed] to yield energy for vital processes while other substances, necessary for life, are synthesized [manufactured]. (American Heritage Dictionary)

small factories, the RNA is the shop tools, or die, or casting and molding sites, and the DNA, stored in the central libraries or archives, is the accumulated knowledge of generations that is transcribed into the patterns, shapes, and arrangements of the RNA. Or is it the other way around, so that our shops and factories are in reality meta-ribosomes? I guess it all depends on what they produce. In any case, using the eukaryotic cell as a guide, it will be beneficial to have these production centers spread throughout the settlement rather than all concentrated into a singular 'industrial zone.'

The endoplasmic reticulum comes in two types: 'granular' and 'smooth.' "Perhaps it would be…correct to regard the membranes of the endoplasmic reticulum, whether granular or smooth, as having a single common function, the formation of a favourable 'metabolic environment' which becomes adapted in different ways to serve different biochemical functions in specialized cells" (ibid, p.28). There is less ER in cells that produce mostly for their own consumption; there is more ER in cells that produce molecules used outside the system. "In cells which 'export' the proteins they make, the membrane system seems essential for the segregation and transport of the finished product through the cytoplasm to the Golgi apparatus in preparation for further processing and discharge" (ibid, p.27). It is difficult to draw direct spatial analogues here. It seems obvious, however, that the more complex the cellular economy, the more proliferation of inner variation and differentiation within the cell; simpler economies have a less segregated landscape. In the village-cell, then, complex differentiation of space – through the skilled placement of geometrically arranged buildings, winding streets, walls, hedgerows and other plantings, water courses, and height variation – will encourage biochemical diversity and, potentially, economic complexity.

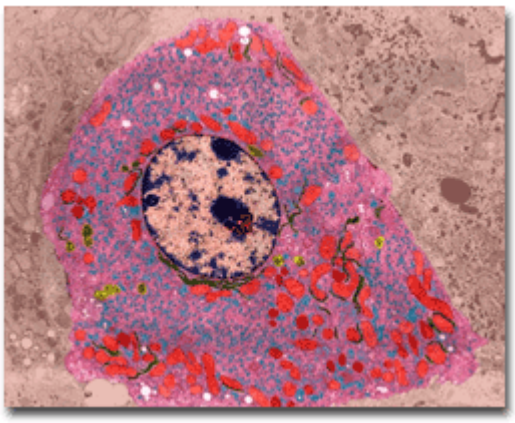
The Golgi apparatus are prominent in cells with a secretory function. "The *Golgi apparatus* performs several functions in close relationship with the ER. Serving as a molecular warehouse and finishing factory, a Golgi apparatus receives and modifies substances manufactured by the ER. One side of a Golgi stack serves as a receiving dock for transport vesicles produced by the ER…The 'shipping' side of the Golgi stack serves as a depot from which finished secretory products, also packaged in transport vesicles, move to the plasma membrane for export from the cell" (Campbell, Mitchell, Reece, p.60). These writers are well-versed in the use of metaphor so there is not much more I can add, except to repeat that all these biological functions existed thousands of millions of years before the first human 'shipping depot.' To ensure that the metaphors flow in the right direction, it is more correct to say that a 'shipping depot' resembles a Golgi apparatus than to say that a Golgi apparatus resembles a 'shipping depot.' Both refer to an essential structural assembly in a nucleated cellular unity that produces materials for use outside its system.

Mitochondria: The mitochondria are virtual 'power stations,' generating energy through an oxidation process whereby carbohydrates are converted "to the chemical energy of a cellular fuel molecule called ATP (adenosine triphosphate)" (ibid, p.63). The ATP molecule contains two high-energy phosphate bonds that can be released as needed. "In cells which produce large quantities of energy…[t]he high 'metabolic rate' of the cell is reflected in the number, size, and complexity of the mitochondria" (Toner and Carr, p.34). The mitochondria tend to be spatially concentrated where the energy is needed in the cell, although some may move about freely from one position to another within the cytoplasm. Others change shape and volume in movements that can be described as rhythmical (Brown and Bertke, p.198). "Phase contrast microscopy of living cells shows that mitochondria grow in length, branch, divide, and coalesce. These changes, occurring in periods less than one minute, indicate that mitochondria are probably almost as dynamic in structural configuration as the plasma membrane" (Wolfe, p.103). This last paragraph emphasizes the importance of designing for flexibility, change, and shifting priorities when planning a sustainable settlement situation.

Structurally, the mitochondria are seen as larvae or bean shaped bodies two to four times as long as they are wide, with a distinctively fine inner structure. There is both an inner and an outer membrane; the inner membrane is highly folded into cristae which greatly increase its surface area and separates the interior of the organelle into numerous distinct compartments. This intricate folding enhances the mitochondrion's ability to conduct the complex chemical energy conversion that is its function. This energy conversion is none other than *cellular respiration,* a sophisticated technology that was perfected almost two billion years ago. "Oxidation describes any reaction in which electrons…are removed from a substrate…Depending on the arrangement of the atoms and bonds in the oxidized molecule, more or less energy is associated with the removed electrons; the energy is used to do chemical work in the cell…The energy of the electron can be expressed as relative *potential* or voltage" (Wolfe, p.105).

This fascinating correlation between voltage and chemical oxidation (the cascading of an H+ ion) perhaps has not been fully examined by electrical engineers. The mitochondria serve such a vastly important role in the maintenance of life that the technologies they use to do their work surely must be relevant, to be successfully recreated at human scale. The technologies of the industrial era, while so often praised, are extremely wasteful, often relying on combustion or controlled explosions. Nature has been perfecting non-lethal, non-polluting technologies for billions of years now. It will be extremely worthwhile to finance and amass the full human effort into discovering the secrets of these technologies in a new science of "Biomimicry." This new knowledge could very well mean the difference between a sustainable and an unsustainable future.

This exploration into the use of biological metaphor to describe structural features to consider in the design of sustainable human settlements, most notably at 'village' scale, could be fruitfully extended much further. I feel at the moment, however, that I've expended my three credits' worth of inspiration. I want to return to this study someday (maybe soon) and take it to the next level of refinement. I see many avenues of ideas still to traverse: Exploring more deeply the relationship between form and function in biological structures could yield an entire new chapter; synthesizing those findings with an "organic architecture" could yield a book! Looking closely at the morphology and metabolism of the nerve cell, in particular the neuron, is something I wanted to include in this study but ran out of time for. I want to become knowledgeable of the structure of the human brain and nervous system so I can begin to translate this information into the image of *Homo sapiens* as the mental component of an 'awakening-to-self-awareness' Gaian super-organism. To be conscious of this, *Homo sapiens* (or its successor) will want to create ecological villages morphologically similar to the neuron, and will want to create a village network pattern mimicking neuronal cellular assemblies. This would, in effect, be creating a metaphoric global brain. And then there is the whole idea of human settlements, not as cells in tissue, but rather as organs in a bioregional body…that notion could incite a lot of thought and writing. The intention in all these cases, just as the intention in this paper just written, is to keep the metaphors flowing in the right direction – *human systems must be modeled upon biological systems in order to be sustainable.* Then humanity (but not likely *Homo sapiens)* will have the chance to be around long enough to witness the climax of biological evolution.



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