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Review

Ecologizing Our Cities: A Particular, Process-Function View of Southern California, from within Complexity

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Abstract: Cities, as the quintessential socio-technological artifacts of human civilization, are seen to set us apart from nature. But an ecosystem view from nested scale-hierarchical process-function ecology shows us that cities are best seen as the emergent and nodal end points of interactive flows of matter, energy and information. From within such a view, a clear need emerges to ecologize our cities by better integrating them back with nature. Arguing from such an ecosystem approach to depicting reality, this paper proposes that tracing the processes and functions which constitute the morphology of the city leads us to articulate an urban ecology that incorporates heat island mitigations, urban forestry, and ecological landscape management (taken both as the introduction of native vegetation and the insertion of increased proportions of pervious paving), all considered within the framework of an integrative ecosystem approach to land use planning. More importantly, such an approach to urban ecology is useful because, as a mode of intervention, it rests on—indeed, requires—an acknowledgement in ecological planning of the often amorphous and usually only indirectly sensible atmospheric, biogeochemical and hydrological processes and functions.

Keywords: ecosystem approach; urban ecology; eco-cities; process-function ecology; heat island mitigation; urban forestry; green infrastructure; ecological landscape management

1. Introduction

It is clear that we are squarely in the Age of the Anthropocene—an epoch in which humans are the dominant geophysical force shaping planetary processes. As Steffen *et al.* [1] state, “Human activities have become so pervasive and profound that they rival the great forces of nature and are pushing the Earth into planetary terra incognita. The Earth is rapidly moving into a less biologically diverse, less forested, much warmer, and probably wetter and stormier state".

If this is true, then surely cities need to be at the center of this concern. Over half of humanity is already urban, and it is projected that by 2050, 80% of humanity will be living in cities. What this means is that if we care about reducing our impact upon the planet, we need to lighten the weight of our cities and make their ecological footprint smaller, on a per capita basis.

Grimm *et al*. [2] and Pickett *et al*. [3] collectively make the point that it is useful to distinguish between ecology *in* cities and ecology *of* cities. The first refers to the study of fragments of nature within the urban context. The second refers to the study of the urban context itself as an ecological system. While this is an important distinction, pointing as it does to two quite diverse ways in which the idea of urban ecology can be taken, the concern here is more with ways in which cities themselves can be ecologized—that is to say, rather than trying to increase fragments of nature within urban areas, we need to be concerned with the pervasive replacement of built, grey infrastructure by natural, green infrastructure.

One significant way of doing this is by allowing nature to do what nature does well, and by not going against the flow of natural processes and functions. In this particular light, it makes sense to transform existing cities into Eco-cities, retrofitting the built environment and make sure that all new urban development itself abides by the principles of Eco-city design.

Although there is not yet an accepted international standard specifying the development of Eco-cities, certain principles and practices can be distilled from the literature [4–7]. Key amongst these is the principle of working with nature, rather than trying to dominate and control it.

Register [4] (p. 182), in establishing the eco-cities meme, suggests that, "(t)o begin, we might try the Ecological Golden Rule: do unto others—including plants, animals, and the Earth herself—as you would have others do unto you. Dividing the golden rule into two, we might embrace the social ecological commandments taught to every pre-kindergarten child: be nice to others and clean up after yourself. Refining this a bit further, we could say that there are three major environmental prescriptions into which most others fit: Conserve, recycle, and preserve biodiversity".

Taking this deeper, we might look at the Hannover Principles devised by William McDonough [5] for EXPO 2000, the World Fair at Hannover, Germany. Along with the chapter by Head and Lam [6], titled "How Cities Can Enter the Ecological Age", in which they conclude that our cities might ecologize themselves most effectively by: (a) reducing their carbon footprint; (b) reducing their ecological footprint; (c) improving their Human Development Index scores; and (d) increasing biodiversity. As well as de Jong *et al*. [7], in which they parse out the diverse set of labels given to eco-cities with a frequency analysis.

As it turns out, there is a distinction worth making between the ecological footprint of cities, which is large, and the per capita ecological footprint of urban dwellers, which is small compared to that of non-urban dwellers. The ecological footprint of a city, typically, is orders of magnitude larger than the area of the city itself. But the ecological footprint of a typical urban dweller is a fraction of the footprint of rural or suburban dwellers. What this means is that there is something to be said for living in cities, but still, cities need help with reducing their total ecological footprint.

With this as background, and with a foremost concern for reducing our urban footprints—ecological, carbon and socio-cultural—the questions we are presented with are these: How do cities most press themselves upon nature? What is it that cities do, which most generate a load upon the planet?

Table 1. Resolving the pressures cities put on nature.

If the problem with cities is that…	Then the solution is for cities to…
They contain huge amounts of impervious surfaces (roofs, roads, driveways, pavement)	Entrain storm-water into the ground, using porous pavement and vegetation and trees and cisterns and roof gardens
They import huge quantities of energy (fossil fuel, electricity)	Increase energy efficiency and conservation Use distributed energy generation and renewable energy
They import huge quantities of nutrients (food)	Grow more food in cities
They import huge quantities of raw materials	Use less stuff (Sustainable Production and Consumption, SCP)
They export huge amounts of waste matter	Divert more solid waste from landfills (increase recycling, composting, and reuse of materials)
They are islands of heat (2–4 degrees C hotter than the countryside)	Heat Island Mitigation (cool roofs, green roofs, trees)
They consume nature (farmland, open space, parks, wetlands)	Create more nature within cities (urban farms, open space, parks, bioswales, wetlands)

It may be worthwhile to consider that, in one sense, there are three urban sectors that put the most load on nature: Buildings, Transportation, and Electricity [8] (p. 2). Here the emission of Greenhouse Gases (GHGs) is taken to be a proxy for "load on nature". In one sense, the carbon footprint of human activity is a useful way of characterizing natural pressures and stresses. But, clearly, this is only one piece of the global puzzle [9,10].

In the case of these three sectors—Buildings, Transportation, and Electricity—there are a few well-known ways of mitigating this load—green building and energy standards; mixed land-use development; transit-oriented development; distributed generation of electricity; and the societal promotion of renewable energy options.

Of course, the key to ecologizing cities is to let nature do what nature does well, and to do everything else in ways that put the least pressure on natural processes and functions. This last is central to the successful ecologization of our cities—that is to say, we must first learn to see our cities as physical entities emergent from the flows of matter, energy and information. Then we understand that the way to managing our cities is less by morphological manipulation and more by managing the flows of its constitutive processes and functions. Pruning and culling is necessary and useful, in its place. But Bonsai gives us a head-start to low-impact control over morphological growth. In that light, the sorts of solutions that rise to the surface then become the subject of our attention.

2. Setting a Glocal Context

There is a clear degree of urgency in this call for the ecologization of cities across the world. Over the next two decades, mid-sized cities everywhere are expected to see a marked surge in population, and the mega-cities of the world are likely to become even more unwieldy. Much of this growth is going to occur across the Asia-Pacific region, and most of it will be driven by rural-to-urban migration, rather than by internal population growth [11]. But we can be sure that cities everywhere are going to come under even more pressure to refresh, enhance and expand their infrastructure.

The question is, what form will this infrastructure expansion take? Crudely, there is a binary choice between conventional "grey" infrastructure and innovative "green", "blue" and ephemeral (digital) infrastructure. We can either try to build our way out of the problem of increasing urbanization, or we can, more intelligently, proceed to ecologize our way into a solution. Given the extent to which the cities of the world are already loading the planet, and given the massive ecological footprint of humanity, at large, it should be clear that further increasing our footprint is, quite simply, not an option. Then one root articulation of the situation is: how can we accommodate a growing urban population even as we shrink our global urban footprint.

We need, indeed, a way of *using* nature to facilitate the entirely foreseeable surge in urbanization, since, clearly, abusing nature is not giving us the sorts of outcomes we actually want. We need to grow our cities capacity to support a high quality of human life even as we quite dramatically shrink our urban footprint. And we need to do this very rapidly, and without hesitation. Here, fortunately, the two countervailing forces of Globalization and Localization can be made to work in our favor.

2.1. The Homogenizing Forces of Globalization

Even as vast populations across the world are urbanizing, just so are these populations—and their cities—westernizing. New Delhi begins to approach Taipei, which in its turn reaches out toward Tokyo. But, at the same time, though much more painfully, there is a south-to-north flow as well, with Curitiba landing memetic tentacles in Los Angeles, and thence to—could it be?—Singapore, as the idea of bus-rapid-transit (BRT) becomes increasingly contagious. Congestion pricing crystalizes first in Singapore, moving from there to Europe and the USA.

Anything we can do to nurture the free flow of "smart" ideas across the globalizing landscapes of the planet might well work in our favor. Without in any way seeking to suggest that organic foods are going to "save the day" for us, the fact of the matter is, "green" ideas are emerging far more rapidly in the surging countries of the south than they ever did in the entrenched cities of the north.

The cultural speed with which ideas spread is cause for hope. But at the same time the flow of modernization ideals from north to south is disturbing, undercutting as it does, local values and customs. Ideas *can* spread very rapidly. The question is, which ideas are deemed spreadable and which ideas do, indeed, diffuse.

2.2. The Hetrogenizing Forces of Localization

Ideas, like plants, tend to hybridize as they are transplanted out of their native context. And so they seek out novel contexts within which to flourish. Take, for example, the case of biogas digester technology. If we take the 1970s and the early 1980s to represent the first wave of appropriate technology—driven in no small part by E.F. Schumacher's 1973 opus [12], *Small is Beautiful: Economics As If People Mattered*—and if we take that first wave to have broken and dissipated itself, spent against the forces of an inexorably Westernizing world, then surely this decade is a time when the very same ideas of an appropriate technology can be revitalized.

In that first wave, and as one example, the Government of India expended significant resources in the development of technologies such as biogas plants and solar cookers. These technologies died at birth, by and large. Today, however, with localization more effectively beginning to balance out globalization, solar water heaters are endemic in at least some cities of the south. Similarly, new generations of biogas digesters are showing themselves to be entirely adaptable to the high-stakes game of contemporary urbanization.

2.3. The Integrative Forces of Glocalization

One of the reasons that this second wave of appropriate technology might stand a chance to help us innovate our way out of a dire predicament, is because the artifact of such technologies, though largely unchanged, is riding on the coat-tails of entirely different processes and functions. As we realize the strict limits of large, centralized, infrastructure solutions—power plants, sewage treatment plants, storm-water processing facilities, and other urban utilities—we become more aware of the power of decentralized, distributed solutions. Small-scale solar photovoltaic systems may offer tightly localized solutions to the highly global problem of energy poverty. Modular biogas digesters begin to solve the organic and sewage waste problems of an urbanization process that simply cannot keep pace with current growth rates.

In this spirit of innovation under "Glocalization", it may be entirely possible to shrink our burgeoning urban footprint even as we scramble to accommodate a surging urban population, provided we actually deploy "smart", amorphous, green and decentralized technologies that are chosen, strategically, for their ability to fill functional niches, in highly localized conditions but at a globalized scale.

3. Mitigation Measures

3.1. Managing Ecological Processes and Functions as a Way of Reintegrating Cities with Nature

Dark, heat-absorbing, impervious surfaces—roofs, roads, and parking lots—are one iconic hallmark of urbanization. Such surfaces, often unmitigated, have a range of significant and cumulative adverse effects on the ecological and biogeochemical processes and functions that underwrite our cities, and so shape our inhabited world. Conventional building practices result in increased ambient temperatures due to the proliferation of heat-absorbing surfaces, increased urban storm-water runoff, reduced groundwater recharge, disruptions of local landscape ecologies, fragmentation of natural habitats, increased air pollution, increased water pollution, increased biological and mechanical heat stress, and exacerbate as well the separation of humans from nature.

This diverse range of changes to processes and functions can partly be captured by the concepts of urban heat islands, urban forestry, and xeriscape. We can dramatically change how our cities work, and how they sit in nature, by paying conscious attention to these ecological phenomena in land use planning. Although these various effects, as well as the measures that can effectively mitigate them have been known for some time, the ways in which we choose to plan and build have just barely begun to take these factors into account—perhaps because we continue to treat the urban world as mechanical, rather than embracing its essentially organic basis.

Such dark, under-shaded surfaces absorb in-coming solar radiation and then re-radiate this heat into the lower atmosphere, raising localized temperatures, often by 2.5 to 5.0 degrees Celsius. This increase in ambient temperatures usually results in greater expenditures of energy for cooling the structures we inhabit, particularly in the mid- to low-latitudes and in the summer afternoons, when energy demand is often at its highest.

Mitigation measures—the use of lighter colored and heat reflecting surfaces for roofs and paving, as well as the increased planting of ecologically suitable species of trees and vegetation—are capable of reducing ambient temperatures by 2.0 to 4.0 degrees Celsius. This reduction is achieved partly by physically altering the heat-absorbing properties of surfaces, partly by increasing localized cooling due to evaporative transpiration from plant and soil systems, and partly by morphologically inserting shade into the urban landscape, thus reducing energy consumption in the summer and in the afternoons when energy demand is highest.

It should be mentioned here that there is a converse "winter penalty" that is incurred, in some cases, by the wide-spread application of these heat island mitigation measures, in that the cost of heating buildings in the winter would be increased somewhat. But Rosenfeld *et al*. [13] (p. 54) find that this is a small penalty, and the cumulative summer-time benefits of reducing air conditioning costs by far outweigh the winter penalty. Elsewhere, Rosenfeld *et al*. [14] (p. 57) note that this net energy saving applies as far north as New York City, explaining that, in all mid-latitude locations, winter sun is lower in the sky, and thus the ratio of sunlight striking the roof to the walls is also smaller. In addition, winter days are shorter, and so they suggest that the summer benefits of lighter colored roofs may substantially outweigh their winter penalty.

Taken together, these mitigation measures have a number of other quite substantial benefits as well. Tropospheric ozone formation is a temperature sensitive photochemical reaction, in which precursor gases—volatile organic compounds (VOCs) and oxides of nitrogen (NO_x)—react in the presence of sunlight to form smog. This reaction is temperature-sensitive. Thus, reductions in urban ambient temperatures carry the potential of reducing smog-formation, without physically reducing the volume of precursor gases exhausted into the lower atmosphere.

The extensive planting of ecologically suitable species of trees and shrubbery, besides increasing morphological shading and enhancing the locally cooling processes of evaporative transpiration in soil-plant systems, also greatly increase the surfaces available to capture ambient particulate matter (dust) generated by traffic and by urban activity, thus potentially benefiting respiratory health. In addition, the vegetation of the urban landscape increases the proportion of pervious to impervious surfaces, which, in turn, reduces storm-water run-off even as it increases ground-water recharge. A variety of habitat-enhancing ecological and community effects can also be ascribed to the increased native vegetation resulting from such measures. Not incidentally, these reductions in temperature also reduce the often considerable thermal stress on roofing and paving materials, measurably increasing their effective life span and reducing maintenance costs [15] (p. 1).

We have known about these processes and phenomena for some time, but the shape of how we plan and build has only just begun to take these factors into account in transformative ways. No doubt this lag in adoptive action is shaped most by disciplinary fragmentation in research, and by the professional segmentation of environmental planning into functional and siloed typologies such as land use planning, air quality planning, water quality planning, storm-water management, urban forestry, and so on. But it may as well be the case that conventional descriptions of the world are traditionally biased toward the morphological—in that, it is easier to mobilize action against pollution processes that are directly sensible to us, based on sight and smell, and harder to do so against pollution processes that can only be indirectly measured, using instruments and models, such as climate change.

3.2. Albedo Modification, Vegetation and Urban Forestry as Heat Island Mitigation

Impervious surfaces are a hallmark of urbanization. Vitousek [16] argues that land use and land cover change, taken together, are one of the three most significant global change processes that ecologists must take into account. From within an ecological perspective, roofs, roads and paving are perhaps the single most critical factor that set cities apart from the countryside [17–23]. The consequences of such a concentration of impervious surfaces, usually in the form of dark asphalt and roofing materials, extend to influencing the local climate and the local hydrology in varying degrees, depending upon the particulars of locational and ecological context. Taha [24] (p. 99) notes that "northern hemisphere urban areas annually have an average of 12% less solar radiation, 8% more clouds, 14% more rainfall, 10% more snowfall, and 15% more thunderstorms than their rural counterparts".

However, urban heat islands, like most ecological phenomena, are not a singularity. In general, urban areas are 2.5 to 5.0 degrees Celsius warmer than their surrounding countryside. Depending upon latitude, the surrounding ecology, and meso-scale climate, a heat island effect may show itself most either in the summer or in the winter, during the day or at night, and cause increases in heating, smog formation or rainfall. In the higher latitudes, urban heat islands may most markedly increase temperatures in the winter, thus reducing building heating costs. In lower latitudes, the effect may be most pronounced in the summer months, resulting in higher air-conditioning costs and increased smog formation. In coastal arid climates such as Los Angeles, the heat island effect may be most relevant in the afternoons, causing increased smog formation and energy consumption. Along the more humid Atlantic seaboard, heat islands may generate increased rainfall and thunderstorms [25–28]. While in desert locations, and with depressed topographies such as Phoenix, the effect may most show itself most at night, keeping the urban core hotter for hours after the sun has set [29,30] and thus increasing energy consumption long into the otherwise-cooler nights.

In Southern California, in the case of the urbanization in the region surrounding Los Angeles, the Mediterranean climate is influenced by its coastal location, juxtaposed with an inland desert ecology, and capped by a tropospheric inversion layer that tends to trap smog-forming precursor gases—namely, volatile organic compounds and oxides of nitrogen. In such a case, and broadly speaking, the urban heat island effect is most markedly manifest at about 2 p.m. in the afternoon, when increased ambient temperatures most severely affect peak demands for electricity, and when the temperature-sensitive photochemical smog-forming reactions most manifest their pollution effects.

Here, three sorts of strategies are available to mitigate the heat island effect. We can physically increase the albedo, or heat reflecting properties, of sunward oriented surfaces such as roofs, roads and paving, by using lighter colored or otherwise more heat-reflecting materials. We can increase the proportion of vegetation and shrubbery to hard landscapes, and promote the adoption of roof-top gardens or green roofs, thus increasing opportunities for the plant-soil based processes of evapo-transpirative cooling to find play. And we can use urban forestry programs to extensively plant strategically sited and ecologically suitable tree species throughout the urbanized area, increasing both evapo-transpiration and physical shading.

Rosenfeld *et al*. [13] describe a "cool communities" strategy for the inland urbanized Los Angeles area, in which they assess the energy conservation and tropospheric ozone (smog) air pollution reduction benefits of a two-pronged strategy that focuses on increasing the albedo of roofing and paving materials by an average of 0.30, and on the strategic planting of 11 million trees in the more densely inhabited parts of the region. Their analysis shows a 12% reduction in the number of days per year on which tropospheric ozone exceeds the National Ambient Air Quality Standards (NAAQS), and a 10% reduction in air-conditioning loads during peak early afternoon demand. They found that, at peak temperatures, around 2 p.m., an approximately 2.5 to 3.0 degrees Celsius reduction in ambient temperatures would be effected by their "cool communities" strategy.

Their research concludes that the proposed albedo modification component and the tree planting component of their "cool communities" strategy generate roughly equal amounts of ambient cooling in the lower atmosphere of the Los Angeles urbanized area. That is to say, if about one-third of the rooftops within the region, and if the paved surfaces concentrated within 25% of the inland urbanized area, were treated so as to increase the albedo of treated roofs by about 0.35 and the albedo of modified paving by about 0.25, this would generate an average increase in the albedo of sunward oriented surfaces in the order of about 0.30. And if, in addition, about 11 million ecologically suitable species of trees were to be planted strategically across the region, then about half the cooling in ambient temperatures would be attributable to each of these two strategies. "The cooling for 'albedo only' turns out to be equal to that of 'trees only,' and is additive" [13] (p. 53).

Estimating smog reduction benefits on the basis of the reduction in the number of days in the year that smog concentrations exceed the California ambient air quality standard of 90 parts per billion by volume (ppbv), their simulation shows that the combined benefits of the tree planting and albedo modification strategies result in a 12% reduction in the number of days in a year on which the air quality standards for tropospheric ozone are exceeded. "In apportioning how much of the benefits we calculated could be attributed to the three separate strategies (trees, roofs, and pavements), we found 50% of the temperature decrease (and thus 50% of the smog reduction) arises from tree planting. The remaining 50% was proportionally attributed to albedo changes resulting from light-colored roofs (0.35) and pavements (0.25), which translates to 29% of the benefits from light-colored roofs and 21% from light-colored pavements" [13] (p. 53–54).

Smog, or tropospheric ozone, is not a directly emitted pollutant, but rather is the product of a complex reaction involving two sets of precursor gases—oxides of Nitrogen (NO_x) and volatile organic compounds (VOC)—in the presence of sunlight. The photochemical reaction may be either NO_x-constrained or VOC-constrained, depending on the relative proportion of the gases present in the troposphere. In the case of Southern California, Rosenfeld *et al*. take the reaction to be NO_x-constrained. In assessing the smog-reduction benefits of their proposed heat island mitigation measures of shade tree planting and a change to lighter colored paving and roof surfaces, they consider two components in the reduction of NO_x gases—the direct reductions in NO_x emissions by power plants, due to reductions in peak-time electric power consumption, and the effective or "equivalent" reductions in NO_x, due to reductions in ambient temperatures.

In the base case for Southern California, they assume that 1225 t of NO_x and 1350 t of VOCs are present and available to the photochemical smog-formation reaction by the early afternoon peak reaction time. They find that the reductions in electricity consumption result in a small reduction in NO_x emissions by power plants, in the order of 6.35 t, or a direct reduction of 0.5% in NO_x. However, as they point out, "(r)educing smog by citywide cooling can be considered equivalent to reducing the formation of smog precursors at constant temperatures". Relying on research by Taha [31,32], Rosenfeld *et al*. conclude that the two strategies of shade trees and lighter colored or higher albedo surfaces, together result in a 10% reduction in smog. They conclude that this 10% reduction in smog is equivalent to a 25% reduction in precursor gases, with the tropospheric system behaving as though there had been a 317 t reduction in NO_x emissions within the air basin.

Albedo modification strategies, cool roofs and cool paving interventions that cumulatively increase regional albedo from 0.25 to 0.40, have been modeled to effectively reduce localized ambient temperatures by as much as 4.0 degrees Celsius in Southern California's mid-latitude climate [24] (p. 101). Taha concludes, "temperature decreases of this magnitude could reduce the electricity load from air conditioning by 10% and smog (ozone concentrations) by up to 20% during hot summer days". Elsewhere, Taha [32] (p. 1668) has found that the average albedo for sunward oriented land surfaces in Southern California is 0.14, and has concluded that the theoretical "maximum increase in albedo will probably never exceed 0.30", and that this should be established as the extreme upper bound for modeling purposes, while an albedo increase of 0.15 for sunward oriented surfaces is a reasonable moderate increase.

The results of Taha's simulation of such changes in albedo, for a clear and warm day in August, at 3 p.m., indicate that the urban core might see a decrease in temperature of about 1.5 to 2.0 degrees Celsius in the case of moderate (0.15) increase in albedo, and up to 4.0 degrees Celsius in the case of an extreme (0.30) increase in albedo, with outlying areas showing a more modest decrease of about 1.0 and 2.0 degrees Celsius [32] (p. 1670). The estimated effect of such a temperature reduction on tropospheric ozone formation was considered to account for "(1) a decrease in some photochemical reaction rates; (2) a decrease in temperature-dependent biogenic hydrocarbon emissions; (3) a decrease in evaporative losses of organic compounds from mobile and stationary sources; and (4) a decreased need for cooling energy, generating capacity, and, thus, emissions from power plants" [32] (p. 1667).

3.3. Changing the Albedo of Roofing and Paving Materials

Vernacular architecture, in a cross-cultural context, is defined as the traditional, native, locally prevalent mode of building, using locally available materials and construction techniques, and based on a traditional and historically tested knowledge-base. Many "traditional", and hence by implication "primitive", modes of knowing may actually be more effective than modern-day beliefs and practices. Take, for instance, the traditional architectures of places that fall within desert climates. In most cases, structures in such places are regularly white-washed, including rooftops. For instance, "building owners in hot cities like Haifa and Tel Aviv are required to whitewash their roofs each spring, after the rains stop" [14] (p. 55). Modern day building practices are driven far more by the contemporary economics of air conditioning, which routinely fail to internalize many of the costs of not using such traditional building techniques.

An ecological approach to building would require attention to such knowledge processes. One key insight from process-function ecology is that direct human sensory perception is at best a limited means of "getting at" the processes and functions that actually shape our world. Conventional empiricism, being based on a reliance on our senses of sight, smell, hearing, taste and touch, has only limited value in an ecosystem approach. Processes and functions outside the scope of our senses drive many of the phenomena that matter most to us.

Albedo is one such phenomenon. In general, and very incompletely, the gradient from light to dark colors does approximate the gradient from high to low albedo—that is to say, from highly heat reflecting properties to highly heat absorbing properties. But a substantial part of the heating that occurs due to incoming solar radiation is in the near-infrared range of the spectrum, and so hidden from our direct sensory abilities. This explains why, for instance, "dark" terracotta roofing tiles may be measurably cooler than "white" asphalt-fiberglass shingles [14] (p. 57), and why old "white" shingles may be more heat reflective (by up to 10 degrees Celsius) than modern "white" shingles, which use one-sixth the thickness of white pigment than they did in 1960 [14] (p. 55).

What this means, of course, is that we are not strictly constrained to the aesthetic of "white", in our urban landscapes. The use of, for instance, titanium dioxide (TiO_2) as an additive to paints used to coat roof surfaces, allows us to apply a range of pastel shades which still have the high albedo properties in which we are most interested. Recent developments in building materials, particularly some very interesting contemporary research about the dirt-repelling properties of TiO_2-coated materials, for instance, raises interesting prospects for longer-lasting albedo-increasing effects in a variety of building materials [33,34]. Another facet of such an albedo-modification approach would focus on roads and pavements, where direct experiments show substantial heat reduction benefits as well.

3.4. Tree Planting and Vegetation Change as Integrative Regional Environmental Interventions

Landscape level land use change is one of the most significant ways in which we shape, and by which we can reshape, our lived environments. The displacement of native vegetative cover, first by small-scale agriculture, then by the more extensive irrigated agricultural systems that mark our recent industrializing history, resulted in a host of ecological changes upon the land.

Just as one example, Southern California saw a significant decreasing trend in ambient temperatures as large-scale agriculture and orchard cultivation took hold at the turn of the previous century, with yearly high temperatures dropping almost as low as 35 degrees Celsius by about 1930. Then, urbanization became the ecologically dominant force in land cover and land use change, and the yearly high temperatures began a fairly steady increase, which has continued into the present [14] (p. 56).

The insertion of ecologically appropriate species of trees and vegetative cover into the urban fabric can be at least as powerful a transformation of the ecosystem processes and functions that support the city, as was their displacement by impervious surfaces. In the particular context of urban heat island mitigation, the most obvious way in which trees help is by physically interjecting shade into our built landscape, thus reducing the heat loads on the walls and immediate surroundings of our urban environment. Shade alone may provide a significant reduction in heat flux, reducing the amount of heat transferred through walls and roofs into the interior spaces by as much as 16 to 27 degrees Celsius, and thus directly reducing the amount of cooling work needed to be done by our air-conditioning systems.

3.4.1. Soil-Vegetation Evaporation and Transpiration as Cooling Processes

However, there is a subtler, though at least as effective, process of cooling that is a by-product of tree and plant growth. Vegetation draws up water from the soil below, through its root structures, and some of this water is released in the form of moisture by the foliage (transpiration) and by the soil itself (evaporation), so cooling the lower atmosphere. The soil-vegetation complex acts to enhance this natural process of evaporative transpiration, or evapo-transpiration. This process can be a major influence in micro-climate cooling, as walking under a broad, leafy tree on any hot, dry summer afternoon will directly demonstrate. Evapo-transpiration processes can generate estimated reductions in local ambient temperatures of 5.0 to 7.5 degrees Celsius, on a typical summer afternoon [35–37]. This cooling effect is more pronounced in dry, semi-arid climates such as Southern California.

3.4.2. Green Roofs for Heat Insulation and Storm-Water Retention

A different, but equally effective and promising strategy is the widespread introduction of what are coming to be called "green roofs", or roof-top gardens. As Oberndorfer *et al*. [38] (p. 823) point out, green roofs provide multiple ecosystem services in urban ecosystems, "including improved storm-water management, better regulation of building temperatures, reduced urban heat island effects, and increased urban wildlife habitat".

Both through extensive experimentation and through materials innovation, green roofs are now poised to significantly help restore nature and natural processes back into the built urban environment. Broadly speaking, there are two sorts of green roofs—extensive and intensive. Extensive green roofs are usually thin layers of vegetative growing media, typically six inches or less, spread over large expanses of roofing, with some suitably durable and hardy species of ground cover, such as one of the many varieties of sedum. "The challenge in designing extensive green roofs is to replicate many of the benefits of green open space, while keeping them light in weight and affordable. Thus, the new generation of green roofs relies on a marriage of the sciences of horticulture, waterproofing, and engineering" [39].

Green roofs have evolved, in recent years, from being thought of as an additional burden to be placed on roof structures to being seen now as an additional protective covering that helps shield the waterproofing membranes of conventional flat or very low slope roofs from heat stress. Experimental tests seem to indicate that well-designed and properly constructed extensive green roofs may help extend the life of the waterproofing membrane and of the roof structure itself, even as they insulate the enclosed spaces from the worst ravages of the summer sun [15].

As a heat island mitigation strategy, green roofs are different from albedo modification and urban forestry in that their primary functional action is to physically insulate the roof membrane. Certainly the albedo of such green roofs is likely to be higher than that of conventional (particularly normal asphalt) shingles. But, when compared to the albedo of most materials normally used for their heat-reflective properties (titanium-dioxide treated white shingles or some of the more contemporary membrane materials), the benefits are likely to be nominal. There is certainly an evapo-transpirative effect, but since it plays out in the rather narrow zone immediately above the ground cover, its heat-reducing actions, either locally or regionally, are again likely to be nominal at best.

However, extensive green roofs do have one additional advantage, in that they can be designed to deliver, at little increase in cost and performance, virtually any desired level of storm-water retention. A 50% reduction in runoff is almost the default setting, and additional gains are easily made. Designers across the world have worked very extensively with green roofs, and case studies are available across a very wide range of siting conditions and using different technologies, making comparative analysis possible. Most researchers who have worked with green roof technologies seem to be clear that these technologies, with some little care and attention in execution, are consistently reliable and do, indeed, deliver the range of benefits that theoretical calculations suggest.

3.4.3. Green Façades and Living Wall Systems for Heat Island Mitigation and Air Pollution Control

Extending the discussion of green roofs to the remaining skin of the building envelope, it is worth noting recent developments in our understanding of green facades and living wall systems [40,41]. Essentially, vertical panes of vegetation are used to envelope either exterior or interior walls of buildings. These provide multiple benefits—reducing energy consumption by improving the thermal performance of the building, mitigating the heat island effect, mitigating noise pollution, improving indoor air quality, improving health and well-being, and more generally, enhancing urban biodiversity [40] (p. 2).

There are a number of ways in which green façade and living wall systems can be implemented. Pre-planted panels can be attached structurally to the wall, with an integrated irrigation system. Alternatively, felt pockets with growing medium can be attached against a waterproof membrane, with nutrient-laced fluids being used to keep the system moist at all times. A third alternative involves the use of planter boxes and a system of trellis-work. Such systems can be used on both eternal walls and interior vertical surfaces. In the latter case, it is not uncommon to link the living wall with the air conditioning and circulation system of the building, to capture the air purification and humidification benefits of the vegetated system.

While the aesthetic, air quality and noise pollution mitigation benefits of such systems are quite clear, it is not at all obvious that—at a systems level—green façades and living wall systems are economically viable. But research has started to emerge that seeks to establish the comparative life cycle analysis and the cost-benefit analysis of such vertical vegetation systems [41,42].

3.4.4. Urban Forestry and Landscape Ecology in Air Pollution Mitigation

Heat island mitigation measures that include strategic and intensive tree planting can cumulatively reduce local ambient temperatures by between 2.0 to 4.0 degrees Celsius. As discussed earlier, this reduction in local temperatures can potentially reduce the formation of tropospheric ozone (smog) by up to 20%.

An additional and not insignificant benefit to urban ecology derives in the case of Southern California, from the implementation of tree planting ordinances for downtown surface parking lots and car dealerships. This is particularly salient in the case of Los Angeles County, where little effort is currently made to implement or enforce any such minimum tree cover measure, and acres of cars can be seen sitting baking in the sun all day. A 50% tree cover ordinance would go a long way to mitigating the range of adverse environmental impacts from these typically treeless expanses of impervious surfaces [43–47]. Not only are there measurable benefits to be realized from the reductions in evaporative emissions from such parked vehicles, but substantial storm-water and ground water benefits would accrue as well, both in terms of storm-water mitigation and in terms of ground water recharge. This is especially true if tree-planting ordinances are combined with land-cover management techniques such as the use of porous pavement and pervious concrete, implemented in appropriate ways [19,48–50].

These reductions in local ambient temperature have the additional benefit of decreasing the need for air conditioning during peak demand periods—that is to say, in the summer and in the mid-afternoon. This decrease reduces the region's need for cooling energy, particularly in the residential context, as Rosenfeld *et al*. [13] and Taha [32] point out, in turn reducing the demand for electricity generating capacity, and so indirectly reducing emissions from power plants. Of course, power plants supplying electricity to a particular region, such as Southern California, may or may not be located in that region. And nuclear power plants are also an exception to this case. But, in most instances, some air pollution benefits can be expected to accrue from this reduced demand for air conditioning energy. Beside toxic ozone-precursor emission reductions, a substantial abatement of greenhouse gas emissions can also be attributed to such heat island and urban forestry sorts of interventions.

An additional and related air pollution control benefit accruing directly from increased use of ecologically appropriate species of trees and vegetation is the capture and sequestration of carbon dioxide (CO_2), a significant greenhouse gas, through the natural process of photosynthesis. Rosenfeld *et al*. [13] (p. 57) suggest that urban trees may provide three times the CO_2 reduction benefits than the same trees planted in forests or in non-urban areas. This reduction occurs because, in urban environments and besides the direct sequestration of carbon into the biomass through photosynthesis (which might be in the order of about 5 kilograms of carbon), these urban trees may also reduce energy consumption for air conditioning if they are appropriately sited so as to provide direct shading to buildings, by as much as 15 kilograms each year. Nowak and Crane [51] (p. 387) estimate that urban trees, through a combination of direct carbon sequestration and carbon dioxide emission avoidance, may provide four times the GHG reduction benefits of the same tree planted in a forest stand. As such, projects that seek to implement tree planting as a net carbon sequestration strategy should consider prioritizing the planting of trees in urban environments, particularly in cases where these trees might directly and indirectly shade air conditioned buildings, as their return on investment will be much higher than if they were to fund similar projects in forest or rural areas.

Besides direct local shading and local cooling through evapo-transpiration, another local air quality benefit accrues from the ability of leafy trees to trap fine and ultra-fine particulate matter onto their leaf surfaces. The dense planting of otherwise low-biogenic emission tree species [52–54] downwind of dust pollution sources such as traffic corridors with high volumes of, for instance, truck traffic, would substantially reduce human and ecological exposures to toxic exhaust gases in strategically identified "hot spots", generating potentially substantial environmental health benefits.

3.5. Impervious Surface Management and Landscape Ecology for Storm-Water Retention and Groundwater Recharge

The extent to which our cities are marked by the spread of impervious surfaces is a powerful indicator of our ecological footprint, and of the weight of our tread upon the land. A variety of strategies are available to us to mitigate the ecological impacts of roofs, roads and paving. We can insert trees and vegetation into our urban landscapes far more copiously than is our current practice, taking care to choose species of trees, shrubs and ground cover vegetation that are well adapted to local ecosystem conditions. We can advocate strongly for the conversion of conventional urban and suburban lawns, which intensively use irrigation and chemicals, to xeriscape sorts of plants and vegetation. We can begin to popularize the use of green roofs, which will do quite well in Southern California with thoughtful design and appropriate selection of cover species, such as the wide variety of sedum, which are able to thrive with little on-going maintenance.

A variety of porous materials are also available for parking lots and for paving, which, when combined with rainwater harvesting technologies, can substantially increase groundwater recharge even as they dramatically reduce storm-water run-off [19,48–50].

4. Implications

4.1. Letting Nature Back into Our Cities, Using Ecological Processes, Functions and Landscape Management

Conventional building practices result in increased ambient temperatures due to the proliferation of heat-absorbing surfaces, reduced groundwater recharge and increased urban storm-water runoff. Constructing tree-less parking lots, placing non-native vegetation in ornamental gardens and synthetically maintained lawns, result in a patchwork appropriation of land uses, increased air and water pollution, more biological and material heat stress, and ultimately, the deepening separation of humans from nature.

Rather than using locally appropriate building materials and climatically adapted dwelling types, we choose instead to capitalize on what seem, in the short term and in some narrowly defined way, like the clear economic benefits of mass-production mass-culture. Of course, we must then compensate for the ecological consequences of such narrowly constructed choices through the increased use of air conditioning and heating, single-occupancy automotive transportation, and the ever-greater importation of water and electricity. And so it is, that by denying ecology, we come to live more heavily upon the land.

Fortunately, it need not be so. We can let nature back into our cities, using intelligence and trees and native vegetation to lighten our tread. These strategies from urban ecology can, together, provide many of the infrastructure benefits our contemporary society needs. Heat island mitigations, urban forestry, and impervious surface management can drastically reduce air and water pollution, significantly increase our natural water supply, substantially strengthen the connectivity of the rich and diverse habitats within which we dwell, and at the same time considerably mitigate that massive transfer of below-ground carbon into the atmosphere due to our civilization's reliance on fossil fuels.

Heat island mitigation measures use lighter colored and heat reflecting building and paving materials for sunward oriented surfaces, to reduce peak afternoon loads on our electricity supply infrastructure, and to substantially extend the life of the building materials themselves, by reducing heat stress. Urban forestry uses ecologically appropriate species of trees and shrubs strategically planted to shade our buildings, to cool the air through the entirely natural processes of evaporative transpiration, to capture dust particles upon their copious leaf surfaces, to capture and store rainwater, and penetrate the soils to increase groundwater recharge. Impervious surface management would use innovative and by now well-tested materials technologies to make our downtown parking lots more porous, while deploying drought-resistant xeriscape plants which naturally need less water to grow across our lawns and gardens. Together, and cumulatively, these green infrastructure measures would reduce our ecological footprint, and at the same time increase the effective carrying capacity of land.

The key elements to such an ecosystem approach to ecological planning require: that we give due consideration to the sometimes intangible processes and functions that drive occurrence in reality; that we conceptualize complex systems as being organized into nested levels; that we give attention to the power of multiple spatial, temporal and organizational scales to reveal different relevant aspects of reality; and that we properly select multiple depictive boundaries that simultaneously respect the ecological elements of structure, pattern and process [55,56].

4.2. Pulling It All Together: Humans as Components of Ecosystems

Integrating our cities and urban regions back into nature is an objective we should take seriously, both because it reduces adverse environmental impacts, thus reducing pollution treatment and remediation costs, and because such a strategy, if based on research-based knowledge derived from contemporary ecosystem ecology, landscape ecology, and urban ecology, would significantly reduce the ecological footprint of human habitation, thus effectively improving how we interact with planetary carrying capacity. Together, these potential benefits provide a sound and savvy science-based approach to contemporary regional sustainability planning.

Urbanizing habitat conservation planning, by percolating ecologically appropriate landscape elements back into the city, would move regions such as Southern California, with their high incidence of pressured, at-risk, threatened and endangered species, away from a reactive "crisis management" approach to a more sustainable, nurturing and proactive approach to integrating our cities back into nature.

The approach advocating for the adoption of albedo-modifying heat island mitigation measures, when combined with urban forestry, impervious surface management, and xeriscape sorts of ecologically appropriate vegetation, represents one example of innovative connections that wait to be made across conventionally disparate and insular sub-disciplines making up the planning structures of regional governance [55].

Taking a landscape ecology approach to regional land cover management in urbanizing areas would, in itself, strengthen habitat integrity, reduce pressures on nature conservation planning, reduce energy consumption, improve air quality, reduce storm-water runoff, reduce urban runoff pollution, enhance groundwater recharge, enhance community livability, allow the inculcation of a cultural connectivity with ecological processes and functions, and so, quite directly, with nature. Arguably, acting reflectively and self-consciously to take account of such usually ignored processes and functions would also strengthen the robustness of the way everyday planning and decision making happens at the community and city level.

And, at the very least, such an integrative approach to regional planning would foster synergistic support across conventional planning disciplines, with transportation planners, air quality planners, water quality and supply planners, urban foresters, land use planners, habitat conservation planners, community development planners, natural resource planners, energy planners, and so on, both providing support to, and receiving support from, one another.

A quite specific sort of ecosystem approach based on nested scale hierarchic or process-function ecosystem ecology does, in very pragmatic ways, provide us with the tools to create richly informative descriptions of otherwise complex spaces. The “dilemmas in a general theory of planning” posited by Rittel and Webber in their classic characterization of complex systems as “wicked problems”, are indeed amenable to planning [57]. But only if we are astute enough to recognize their assertion that the tools from “tame” problem planning cannot be applied, in and of themselves, to complex systems. And then we need to see that there are indeed ways in which we can engage these complex systems in meaningful conversations that generate outcomes more desirable to the greater good and across levels of organization [55].

We need to grow from a merely reactive and mechanistic problem-solving approach that attempts to singularize issues to make them easier for us to wrap our heads around, toward a planning that embraces the adoption of an adaptive management-based ecosystem approach. This approach needs also to be grounded firmly in techniques for making rich depictions that allow us to get a better handle on complexity [56]. Respect for, and especially a deep appreciation of, complexity is necessary. But we have the means for constructive engagement as well.

5. Synthesis: Hallmarks of an Ecosystem Approach to Making Rich Depictions under Complexity

Attention to context and consequence are the hallmarks of an ecosystem approach to planning, under conditions of complexity. Nested scale-hierarchic process-function ecosystem ecology offers some very useful tools for generating pragmatic descriptions in environmental planning [56]. To summarize, and as prelude to demonstrating an application of such an ecosystem approach to regional urban planning in the particular case of Southern California, three key points need to be underscored:

(1). System connectivity counts—the ecological consequences of specific actions cut across spatial, temporal and functional scales, and must be traced across levels of organization.
(2). Processes and functions may matter more than morphological entities and events—occurring actuality may trump perceived reality in coming to know ecological consequences.
(3). Multiple boundaries and scales must be chosen deliberatively, and across levels of organization, using functionally appropriate and diverse spatial, temporal and organizational scales, to richly capture ecological context.

Put differently, the core elements of an ecosystem approach to decision making under conditions of complexity consist of the self-conscious and reflective use of a multi-perspective, multi-criteria, multi-scale, multi-boundary approach to making operational descriptions, using the levels-of-organization concept to structure the planning domain under consideration, and paying particular attention to the processes and functions that may or may not be directly evident to human sensory perception [56].

Planning, as the craft of societal deliberative decision making, has already begun the work of integrating the instrumental dimensions of the sustainability imperative. Two of the keys to the sustainability puzzle are embodied in: (a) the recognition of the need for a multi-factor, multi-criteria, multi-perspective approach to describing the contextual characteristics of decision phenomena; and

(b) the need for an inter-temporal, inter-generational perspective in tracing consequence. The next step in the realization of a genuinely ecological approach—that is to say, taking on complexity fearlessly, while getting beyond the metaphoric imagery and the jargon of holism, the everything-is-connected-to-everything-else sorts of stuff—is an expansion of this view of sustainability in two directions.

First, we must broaden our ideas of system formation to accept ecological processes and functions as the real and proper "objects of concern" for regional environmental planning. This requires that we train ourselves in the sophisticated choosing of multiple functionally relevant boundaries. And also that we expand our ideas of scale beyond our current recognition of spatial and temporal dimensions, by integrating organizational and functional scales as well.

On the second front, and perhaps more urgently, we need to train ourselves in the trans-disciplinary application of knowledge, both across other disciplines and within our own. We must learn to speak in different tongues, becoming comfortable in diverse disciplinary cultures. Much of this work has already been done, as a survey of topics covered at almost any planning conference, or the interests of almost any cohort of planning students will demonstrate. We just need to get more systematic about this. And we need to reach across the divides that fragment our own discipline as well. Air quality planners should seek out habitat conservation planners, who should talk on a regular basis with water quality planners, who should be working closely with land use planners, who should be talking with the urban forestry folks, who should be working side-by-side with the community economic development planners, and so on.

Of course, none of this is really new. Calls to multi-disciplinary holism stretch back as far as recorded memory can see. What has changed is the ecological frame—evolutionary scale hierarchic ecosystem ecology—within which we can now situate a truly ecological planning practice. We have seen complexity in all its richness, and blinking doesn't make it disappear. We can move away and move back, and still see reasonable approximations of what we were looking at earlier. It is our conceptual imagination that has expanded—not displacing old ways of knowing, but incorporating them into an overarching ecosystem approach. And with the advent of new technologies in computer networking and the internet, we can begin to become savvy in decentralized and democratic information management, so as to lower the information costs of taking a truly adaptive, response-sensitive management-based approach to engaging the complex sorts of problems with which we most need to deal.

Living as we do in our four-dimensional world, the craft of planning practice requires us to broaden our scope so as to integrate across sub-disciplines. We need to extend our conception of how the world actually works so that we can give due consideration to processes and functions as the building blocks of nature. We need to extend our descriptions of phenomena both inward and outward, across levels of organization, so as to better take account of context.

And we need to reach across time-event horizons so as to better appreciate consequence. By accepting the premise—that reality is better described as exhibiting nested structures, which are shaped in their actuality by processes and functions, and requiring the use of multiple perspectives, boundaries and scales in their telling—we come to a place where we can begin the business of incorporating the constraints and principles articulated by Rittel and Webber [57]. The strategic and systematic breaching of the constructed, but now deeply entrenched, boundaries our technologies have allowed us to create between the "human" and the "natural", by integrating within and across levels of organization, and again by expanding our world-view to incorporate processes and functions as the stuff the world is actually made up of, allows us to both embrace the contextual richness illustrated by Holling and Goldberg [58] and to realize what some ecologists have already begun to see—that humans, properly, are indeed components of ecosystems [59,60]. Then we can get down to the business of getting humans back into nature, and thus of placing our cities back into their ecological context.

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Conflicts of Interest

The author declares no conflict of interest.

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