# Arbo-Structure: Ecomasterplanning the Road to Cool, Healthy Cities and Urban Islands

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**ABSTRACT**

The deliberate art of city-state design is evident in Roman, Egyptian and Mesopotamian ruins. Driven in ancient times by power and defense, urban planning evolved as a recognized profession in the 18th century, scaled to displace permeable green spaces with housing, utilities, hardscape, and transportation venues, and to manage urban waste as a prophylactic against contagious disease. By the 20th century, urban planning uniformly adopted the Haussmann model, a hierarchal plan strategy based on zoning schemes that compartmentalized or segregated different land uses (Coburn, J. 2004). Without intent, fanfare or restraint, this model launched and institutionalized the framework for urban heat islands, city geometries that squander natural resources, tax built systems and challenge social equality, often at the cost of compelling public health considerations. The human, social and environmental costs of chronic urban heat stress follow twin trajectories: a quantitative one of increasing population and demand, and a qualitative one where the most vulnerable members of an urban ecosystem risk and suffer the greatest. To temper the impacts and consequences of heat islands, an ascendant planning model has emerged that uses urban forests to recapture resources, reconnect society, and restore public health. The road to cool, however, is a destination that can only be reached through the collective skill, boldness and imagination of planners, engineers, scientists, ecologists, urban foresters, public leaders, and others who envision the 21st Century City as an ecosystem built from gray, green and blue infrastructure, and people.

## Introduction

In 1818, British pharmacist and amateur meteorologist Luke Howard recorded unusual, artificial concentrations of heat in London. A half-century later, scientist and cloud specialist Emilien Renou noted a full centigrade degree difference between the center of Paris and the then-urban edge. Anthropologist Wilhelm Schmidt noted the phenomena in post-war (WWI) Vienna, leading to formal study of heat islands through charting of global temperatures by J. M. Mitchell in the mid-20th century (Gartland, L. 2008)

### Patterns of Global Population

At present, over half the world's population lives in cities. Nearly 80% of all Europeans and Americans are urbanites, the latter disproportionately concentrated within 50 miles of a coastline. It's estimated that, by 2030, nearly 2 billion more people – or a total of 7.5 billion people - will reside in urban areas (Mcdonald, et al., 2008). Similarly, portents promise greater frequency, intensity and duration of the climatic and atmospheric conditions that give rise to exceptional heat waves (Meehl and Tebaldi, 2004).

**The Physical, Health and Social Aspects of Urban Heat Islands**

Urban Heat Islands ("UHI Cities") occur where three principles conditions coincide. First, proliferation of low-albedo surfaces such as roads, parking lots, buildings and roofs conduct and trap more heat than is capable of being dissipated overnight (Frumkin, H., 2002 The potential of these surface heat-sinks to trap ambient heat increases with the loss of trees and vegetation, which cool ambient temperatures through evapotranspiration and shading (Nowak, 2000; Heisler and Grant, 1997; Gartland, 2008; Ward, Wyman, Brown and Seth, 2008), and fragmentation of open spaces that promote air circulation (Bach, 1970; Taha, 1997). Consequently, the residents of UHI Cities require greater energy use to moderate their environments, magnifying pollution rates. In such a dynamic, UHI Cities begin each day with a solar form of daily compounded interest that can reach extremes of 150 - 185ºF (EPA, Cool Roofs).

Impermeable hardscapes, needed to house, educate, transport and sustain modern communities, have created a global class of urban centers characterized by poor air quality, minimal evaporation, increased energy consumption, degraded community health, erratic microclimates, and stormwater runoff best described by high volume, velocity and non-point source pollution (James, W. 2002). Energy consumption increases with the need to cool home, work, school, transportation and recreational areas. Higher ambient temperatures, together with increased greenhouse gases emitted by vehicles, buildings and power sources, elevate ozone levels (Sailor, D, 2007) Hot air rises above UHI Cities with enough potency to form convection fulcrums that draw in surrounding cooler air and create independent breezes, e.g., Houston, Texas and Tokyo, Japan (Gartland, L. 2008)

Beyond air quality impacts, impermeable surfaces form conveyances for the rapid accumulation and conveyance of stormwater runoff, collecting toxins and pollutants that range from garbage and debris, to septic tank overflows, lawn pesticides and fertilizers, roadway veneer of antifreeze, rust, petroleum and brake fluid deposits (Environmental Protection Agency, Stormwater), to the fastest growing pollutants – pharmaceuticals and personal care products (National Association of Clean Water, 2005). Unmanaged urbanization, and the substitution of impervious surfaces for natural ones, has made stormwater runoff our single greatest water pollutant (Beattie, et al., 2000). Thermal pollution of stormwater runoff, incubated by hot urban surfaces, further degrades water quality and aquatic life (James and Verspagen, 1996). Moreover, certain physical impacts of urban heat islands emerge distinct and greater than those attributed to global warming, suggesting that urban design, choices and behaviors are responsible (Frumkin, H. 2001).

Nearly six decades ago, the World Health Organization has defined health as a "state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity." The atmospheric composition of an UHI City, pulsed with ozone, particulate matter pollution and other greenhouse gases, is being increasingly linked to cardiac and cardiopulmonary death and hypertension (Bhatnagar and Brook, 2009; Basu and Samet, 2002; Braga et al., 2002), and cited for causal connections to premature death (Knowlton, et al., 2007; Pope and Kalkstein, 1996; Kalkstein and Greene, 1997).[1]

In addition to physical characteristics, urban heat islands follow social patterns, with predictable and considerable outcomes. Exposure to heat stress for as little as 48 hours creates physiological disruption and poses multiple human health risks (Endlicher, et al., 2008) Death related to heat waves toll highest over all other climatic events, including flood, lightning, hurricanes, tornados, and winter storms, and appear to be on the rise. (Changnon, et al., 1996). More than 700 people died in the Chicago Heat Wave of 1995 (Klinenberg, 2002), and more than 30,000 in the European Heat Wave of 2003 (World Health Organization Sept 2003). Figures in both remain somewhat elusive, since no uniform standard has been established and, frequently, so-called "excess deaths" actually attributable to extreme heat stress were recorded for other causes[2] (Davis, et al. 2003) Deaths concentrate among the elderly[3], the young, and those whose immune and physiological systems are otherwise taxed by disease, morbidity and/or treatments for other extreme illnesses. African-Americans are 19 times more likely to die from heat as non-Hispanic whites, a statistic attributed to poverty, age, general health, access to medical care, insurance, and isolation. Among minorities, English-language skills also play a role. Surprisingly, Northeastern and Midwestern cities are deemed more vulnerable, since climate variables in heat stress-producing events are not sufficiently extreme in southern cities. (Curriero, et al. 2002; McGeehin, Mirabelli 2001)

Adverse consequences are not limited only to human populations – at excessive levels, ozone has the potential to retard healthy growth in plants, crops and trees (Felzer, et al., 2007). Wildlife and even livestock are also vulnerable.[4] Globally, expanding population and urbanization are encroaching upon conservation areas and compromising biodiversity, with near-future development emerging as a threat to endemic terrestrial vertebrate species (McDonald, Kareiva, and Forman 2008).

## Urban Forests as Green Infrastructure for Successful Urban Centers

### The Role of Urban Canopy in Creating Urban Islands

The aggregate of regional heat islands and global climate change challenges traditional notions of urban planning, refocusing design not on "use" but on outcomes and impacts. While individual and social choices regarding consumption are critical to successful

[1] In their study, Knowlton et al. surmise that heat-related premature mortality in the New York will experience a mean 70% increase by 2050, and cite research predicting similar increases in the United Kingdom (250%); Lisbon, Portugal (by as much as 6 times current figures); 6-7 times greater in California, and an average 75% increase across 6 temperate cities in Australia.
[2] These include, without limitation, recording heat attack and stroke as the cause and not the consequential factor in death. Changnon et al. propose that actual death rates due to heat stress may be underreported by as much as 90%.
[3] More than 70% of all heat-related deaths in the U.S. occur among individuals over the age of 65.
[4] On July 14, 1995 in the area affected by the Chicago heat wave, more than 850 cattle, along with scores of poultry flocks, died, and milk production was reduced by 25%. *Wisconsin State Journal*, 15 July 1995.

and healthy urban centers, the fabric of high-functioning “urban islands” is a function of design and material. Traditional responses that rely on man-built systems to neutralize urban heat island effects will, over the long term, prove operational and economically non-sustainable. In this vacuum, the urban forest[5] can be planned, designed and managed as a “bio-utility” and as mitigation-infrastructure for cooler, cleaner, healthier and economically savvy communities.

**The Cooling Properties of an Urban Forest**. The urban forest has the potential to play a more prominent mitigation role as global temperatures fluctuate and heat islands develop in even more urban centers. Trees modify climate and conserve building energy by shading buildings and built surfaces (asphalt and concrete) that store radiant energy, through evapotranspiration as trees absorb solar energy and release water vapor through leaf surfaces, and by reducing wind infiltration and conductive heat loss in winter (McPherson, G. 2004). The direct benefit is temperature control, with ancillary benefits of lower energy costs and reduced ozone production as energy consumption is adjusted downward. Evapotranspiration is responsible for as much as 75% of the cooling effect of tree canopy which, on private properties, can reduce building energy consumption by as much as 30% (EPA, *Using Smart Growth Techniques as Stormwater Best Management Practices*). Subject to regional variables, researchers have determined energy cost reductions of at least 25% and as much as 50% (Nowak, 2000).

**The Urban Forest and Health Risks Related to Air Quality**. The urban forest impacts air quality both directly and indirectly, to produce a net emissions-loss based upon a formula that calculates capacity to remove and/or sequester carbon dioxide, greenhouse gases (GHG) and particulate pollution, plus the exceptional “avoidance” factor of reduced GHG in reduced energy consumption. The result is reduced by the emissions properties of the particular species, together with carbon released as trees die or are removed and any GHG released by equipment and transportation in tree maintenance and management (Nowak, 2000). Trees sequester carbon and other GHG, intercept particulate pollution at an estimated rate of 9-13%, and buffer dust from under-canopy areas by 27-42% (Ward, et al., 2008; Nowak, 2000; Beatty, ed. Garbesi et al., 1989). Other studies recorded canopy reductions of nitrogen oxides up to 45% and up to 55% for ozone (Streiling and Matzarakis, 2003). The EPA regulates ozone through each state’s obligations under the Clean Air Act Amendments of 1996. The Agency notes that ozone can trigger a variety of health problems including chest pain, coughing, throat irritation, and congestion. It can worsen chronic respiratory ailments such as bronchitis, emphysema, and asthma. Ground-level ozone also can reduce lung function and inflame

[5] The term “urban forest” is defined to include trees on private land and in public spaces that include roads and rights-of-way, beaches and parks, conservation and riparian areas, on government facilities and even coastal estuarine and mangrove forest systems.

[6] More specifically, each state is required to file with the EPA a State Implementation Plan to meet federal pollutant and emissions restrictions. A number of states, including Texas, California and Maryland, are exploring the potential of urban canopy to qualify as credits under State Implementation Plans, or SIPs, which require that proposed measures be enforceable, quantifiable, and permanent. Although urban canopy defies absolute certainty, researchers are endorsing the urban forest as an emerging measure deserving of a modified approach. *See* Nowak, D. (2005), “Strategic Tree Planting as an EPA Encouraged Pollutant Reduction Strategy: How Urban Trees Can Obtain Credit in State Implementation Plans”.

the linings of the lungs and, in the extreme, repeated exposure may permanently scar lung tissue. The public impact on air quality of a healthy urban forest arguably extends to suppression of cardiovascular mortality and morbidity (Park et al. 2005) and ozone-related excess-risk, the latter demonstrated by a 200% in Paris during the 2003 European Heat Wave (Filleul et al. 2006). The capacity of urban canopy to intercept particulate matter through dry deposition along leaf surfaces can possibly influence the heightened susceptibility of children and the aged to ultra-fine particulate matter pollution that can pass freely through the lung's membranes into the bloodstream (Johnson and Graham, 2005). In terms of air quality, alone, an urban tree captures and sequesters four times as much $CO_2$ as a conservation tree; a benefit which, in turn, is only equal to one-fourth its worth in avoided energy use (Nowak, 2000).

**Child Health Impacts, Direct and Indirect**. In addition to air quality and energy conservation benefits, a strategically placed urban forest can filter or block harmful ultraviolet radiation. UV exposure during childhood is now acknowledged as a potentially significant risk factor in adult development of skin cancers and eye diseases (Grant, Heisler and Gao 2002; Heisler and Grant, 1997). However, canopy shading suppresses onset of eye and skin disorders connected to glare and UV-exposure (Emmanuel, M.R., 2005).

A 2002 report of the American Lung Association estimated that nearly half the U.S. population, including 25 million children, live in counties with unhealthful levels of ozone; and roughly 14 million children live in counties with risk levels of particulate matter pollution. Through their susceptibility to air pollution and because of immature defense systems in both fetal and early childhood stages, children are deemed to be vulnerable to exposures that have no apparent effects in adults (Perera 2008). In addition, early pollutant exposures may manifest themselves in cognitive impairments or long-term, chronic and cumulative health challenges throughout life. Despite these risks, urban canopy has been recently identified as a causal agent in neighborhoods with *lower* rates of child asthma (Lovasi, et al., 2008).

One of the most challenging health trends in children today is obesity, and the considerable health impacts that tangent out from a sedentary childhood, including Type 2 diabetes, hypertension, and heart disease (Connecticut Commission on Children 2004). Although no study to date has specifically quantified the health benefit to children that treescapes and public realm spaces may provide, a sedentary lifestyle increases the risk of dying two-to-threefold in adult men (Frumkin, et al 2002); and adult obesity increases the overall risk of death by 250%, with a fourfold increase for heart disease, and a fivefold increase for type II diabetes. Studies show that tree canopy promotes walkable communities and lower obesity rates among adults (Lopez and Hynes, 2006). To the extent that canopy shade and urban treescapes promote social interaction and activity[7], it is probable that a link

[7] Environmental psychologist Frances Kuo, a principal of the Landscape and Human Health Laboratory at the University of Illinois at Urbana-Champaign, has authored or co-authored a series of compelling studies, including *The Fruit of Urban Nature: Vital Neighborhood Spaces* (2004), and *Growing Up in the Inner City: Green Spaces as Places to Grow*. She is also known for seminal studies on the ability of treescapes and green spaces to suppress attention deficits and hyperactivity in children. See, Faber Taylor, A. and Kuo, F.E. (2009), Children With Attention Deficits Concentrate Better After a Walk in the Park, *Journal of Attention Disorders* 12; 402-409; and Kuo, F.E. and Faber Taylor, A. (2004), A Potential Treatment for

can be drawn between enhanced child and early development health and access to parks and greenspaces.

**Economic, Social and Ecosystem Benefits of the Urban Forest**. The economy of an urban heat island is one of penalty and loss – directly, in the form of escalating demand/expense of manmade infrastructure and healthcare costs, or indirectly, through lost productivity, lost opportunity, or revenue lost because of low desirability to tourists, new businesses, and potential residents. These are less obvious but insidious impacts that, again, can be offset by land development policies that place a premium on urban canopy.

The social, environmental and economic benefits of a well-planned and managed urban forest are diverse and significant, and supplemented by even greater utility and value in urban systems of cost and risk avoidance (Nowak, et al., 2007; Wolf, K., 2004). Factoring energy increases of 2-4% or each 1ºC rise in temperature, tree canopy has the potential to reduce peak electric demand by 5-10% for a national annual savings of several billion dollars (Akbari 2001). The direct value of urban forests are, in great part, represented by their productivity as a natural stormwater apparatus[8] that operates efficiently for a fraction of the cost of manmade systems (Trusts for Public Land, 2004). Treescaped streets are safer streets, where the prudent driver controls the pattern of traffic and produces up to 40% less accidents (Dumbaugh, E., 2005; Wolf, K., 2006). Planting hardscapes, such as roads and parking lots, with evergreen species of maximum leaf surface, not only removes airborne pollutants and irritants, but extends the useful life of built infrastructure (McPherson and Munchnik, 2005). Congress, in the Cooperative Forestry Assistance Act of 1978, as amended in 1990, found that "urban trees are 15 times more effective than forest trees at reducing the buildup of carbon dioxide and aid in promoting energy conservation through mitigation of the heat island effect in urban areas".

Studies of inner city neighborhoods indicate lesser crime rates and heightened social engagement in treescaped areas (Coley et al., 1997; Kuo and Sullivan, 2001). "Daylight" views of trees and nature are credited with rapid recovery rates in post-operative patients (Ulrich, R., 1984), reduced violence in prisons (Moore, 1981), and enhanced employee performance and job satisfaction (Kaplan, R., 1990). Although these impacts may seem unconnected to an examination of urban heat islands, crime, imprisonment and workforce malaise are greater social considerations in large, urbanized cities.

In terms of urban residential, commercial and professional properties, studies indicate that treescaped residential properties are valued higher by an average of 5-9% (Anderson and Cordell, 1988), that professional centers featuring treescapes have less vacancies, turnovers and employee absenteeism and generally command rents higher by 7% (Laverne and Winston-Geiderman, 2003), and that treescaped commercial/retail districts generate roughly

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Attention-Deficit/Hyperactivity Disorder: Evidence from a National Study, *American Journal of Public Health,* 94(9); 1580-1586. All scientific articles may be accessed at http://lhhl.uiuc.edu

[8] Faced with water treatment plant construction costs of $5 billion and subsequent annual maintenance commitments of no less than $200 million, New York City opted to exploit the urban forest's capacity to control and filter stormwater runoff. Instead, a $100 million canopy tree buffer around main reservoirs has proved the prolific value of ecosystem services that can perform as built infrastructure without need for waste management, at a fraction of the cost (Frumkin 2002).

12% more revenue than their treeless counterparts (Wolf, K., 2005). Moreover, studies prove public preference for canopied, livable communities that, by default, avoid UHI characteristics and effects.

## Ecomasterplanning For Urban Islands

This discussion began with a brief history of urban planning. The metropolis is and remains a creature of human behavior, culture and psychology, from the need to compartmentalize our land use, to unsustainable patterns of personal consumption that generate waste and pollution. The contemporary failure of urbanization is fundamentally linked to a "set apart" approach, where the human population elects to control not assimilate with other infrastructures.

For centuries, man's most strategic interest was the forest. It provided our means of shelter, fire, transportation, weaponry and security, and was featured in the religious symbology of numerous civilizations[9]. The Industrial Revolution brought population increases and shifts into urban centers, where trees were imported to act principally as visual and physical amenties. New revolutions in energy, design and consumption compel us to plan, design and manage the urban forest first as a bio-utility or bio-technology (Nowak, 2006), and second as an amenity. This model turns on functionality, classifying trees for lifespan, durability in urban sites, maintenance demands, water requirements, root systems[10], leaf surface area, growth habits, and even appeal to specific wildlife. It allows for research and quantification of urban trees as capital assets, and facilitates the broader discussion that must take place among urban planners, engineers, scientists, foresters, environmental specialists, law-makers, and public health professionals, in order to arrive at a meaningful response to urban heat islands.[11]

Ecomasterplanning, a concept coined by architect and urban planner Ken Yeang, does not exalt trees, green spaces or green infrastructure over built systems, nor does it subordinate other natural systems to green. More importantly, ecomasterplanning incorporates the one element that has played little if any physical role in urban design – human capital. Yeang's

[9] The Babylonian Empire failed in part due to deforestation and resulting topsoil erosion and crop failure. At one point, timber was so scarce that homes were built without doors to conserve dwindling supplies. In the sunset of the Roman Empire, increasingly remote and costly campaigns were launched to secure timber. Scarcity of the resource ultimately left the Empire unable to fuel smelting furnaces that forged its metal currency. A shift to eventually worthless clay coinage lead to a barter society in the twilight of this great civilization. In terms of religion, tree symbology is found in Summarian, Egyptian, Greek, Celtic and Norse mythology, as well as in the Buddhist and Hebrew religions.

[10] Root systems and leaf surface and texture dictate a tree's capacity to attenuate stormwater runoff. In general, depending upon soils, climate, and other conditions, a single mature shade tree can intercept between 300 and 700 gallons of rainfall each year.

[11] These are essential principles underlying Sarasota County's Urban Forestry Master Plan, adopted May 5, 2006. See also, a study in Israel that matched tree species to unique urban morphologies based upon the trees' functionality and and efficacy in responding to the needs and consequences of surrounding infrastructure (Shashua-Bar, et al., 2009) – effectively creating a system for "tree island effects".

integrated model balances all interdependent infrastructure strands: green, blue (sustainable water and drainage systems), gray (the engineered infrastructure), and "red", or the human infrastructure. Importantly, this approach eschews the Haussmann model of zoning barriers erected to segregate land uses, for a flexible design pattern of unbroken green corridors, patches and matrices that exploit treescapes to create desirable microclimates, suppress the undesirable impacts of built infrastructure (Gill, et al, 2006; EPA), and evolve from an urban heat island to a humane metropolis. (Gill, et al., 2006; EPA).

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