Cooling the Public Realm:

Climate-Resilient Urban Design

Shaping Resilient Cities for the 21st Century by Adapting Urban Design to Climate Change

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Submitted by:

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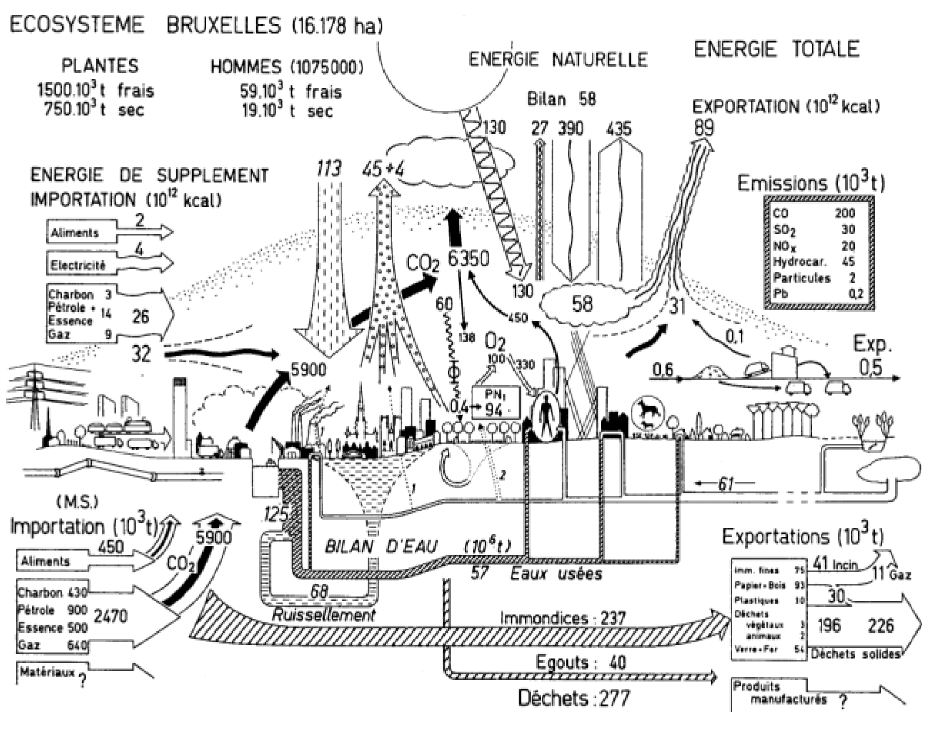
The traditional urban design process is not sufficient for 21st century cities. Global climate change has made it obsolete. A new paradigm is required to develop resilient cities that can adapt and thrive in changing global conditions, meet the requirements of carbon-reduction and other environmental measures, and sustain urban populations in more compact settings by providing amenities that people need and want.

The scope and speed of changes taking place now and predicted for the future requires urbanists to define a compelling vision and coordinate an integrated design process to shape resilient cities that are sustainable in the 21st century and beyond.

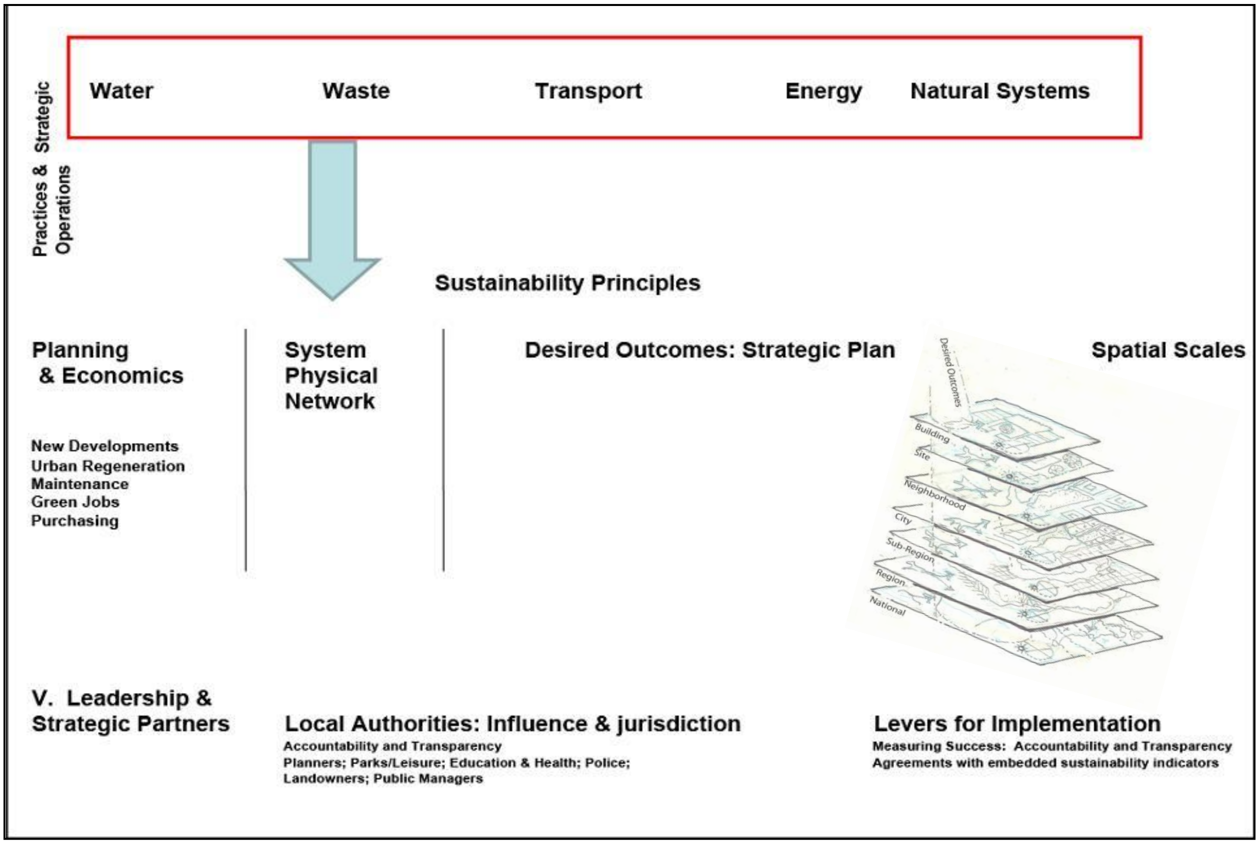
With their roles as team integrators unchanged, urbanists need to expand their scope to implement desired ecological outcomes across spatial scales that comprise urban systems and physical networks. From energy and transportation to water and green infrastructure, urbanists need to use these systems to shrink our ecological footprint, shape resilient urban form and adapt our cities to climate change **(Fig. 2, 3, 4)**.

As the climate heats up, a central challenge for urbanists will be to create compact "cool" communities whose natural amenities offer alternatives to urban sprawl and its consequences. However, climate-resilient urban design—drawing from urban climatology and sustainable design-- is not well understood although considerable technical knowledge exists within these fields. There are a number of barriers to implementing climate-resilient design on a large scale, including lack of institutional capacity. Despite its enormous potential for city adaptation to climate change, climate-resilient urban design has not yet emerged as a major consideration in standard urban design practice.



1. Cover: Climate-Resilient Urban Design for Proposed Waterfront District, Thanh Hoa City by 2020, Vietnam, Raven-LBG (2008).

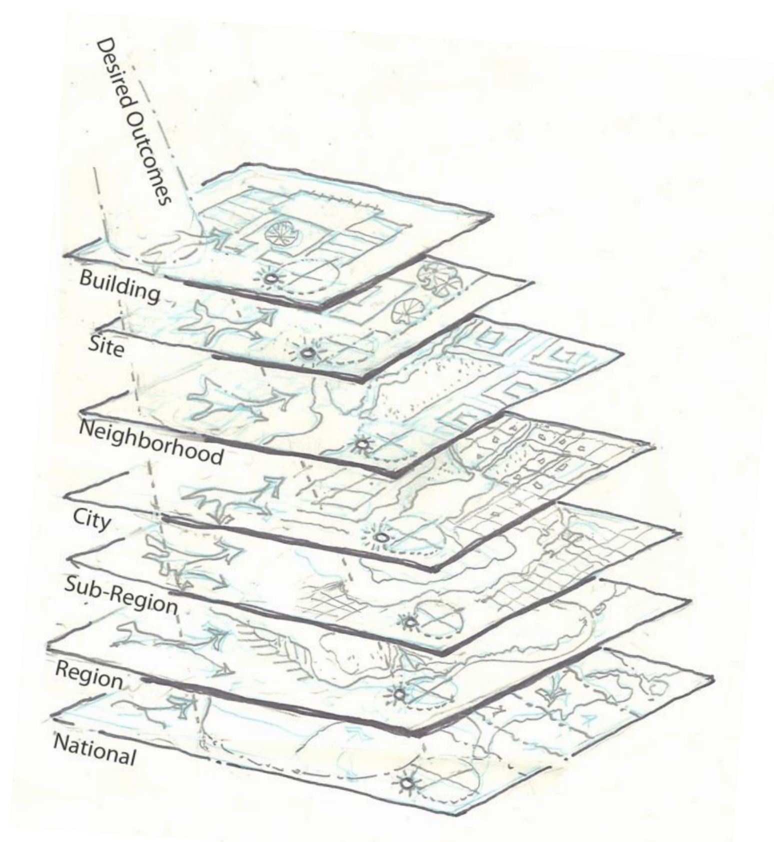
2. Left: Inputs and outputs-- a systemic approach to an urban context across sectors and scales, Duvigneaud, P. et Denayer-de *Smet*, S. (eds.) (1975) L' *Ecosystème* Urbain.



3. An integrated sustainable planning process, Adapted from CABE, http://www.sustainablecities.org.uk (2009).

Climate-resilient urban design across all phases:

- *A handful of systems play a central role in the life of urban districts including Energy, Transportation, Waste, Water, and Green Infrastructure/Natural Systems.*
- *These systems are part of a physical network.*
- *Physical networks are within the jurisdiction and responsibility of key stakeholders.*
- *Once sustainability principles have been defined by stakeholders, an integrated planning process should be undertaken.*
- *"Desired Outcomes" result from filtering original sustainability principles through the integrated planning process unique to a context and spatial scale (Fig. 4, right).*
- *Transparency and Accountability: Political, social and economic forces shape the implementation of the "desired outcomes".*
- *Practices and Strategic Operations: Implementing sustainability strategies at a project level.*



4. Implementing key climate-resilient urban design desired outcomes across varied spatial scales, Raven (2008).

Sustainable Designation Systems are currently in development in the United States at the neighborhood and district scales, with the aim of developing sustainable communities throughout the country. This paper suggests a "morphological", climate-resilient urban design goal and measures for the Sustainable Designation Systems. The term "morphological" as described here means the simplified three-dimensional form of the built environment and the spaces it creates. This climate-resilient urban design goal should be adapted to Sustainability Designation Systems with pilot testing evaluation criteria for measuring benefits.

The prototype Sustainable Designation Systems STAR Community Index (STAR), US Green Building Council's (USGBC) LEED for Neighborhood Development (LEED ND), and the international Clinton Climate Initiative's Climate Positive Development Program (Climate+) provide opportunities for developing a climate-resilient urban design goal, backed by prescriptive measures and performance standards for broad implementation **(Fig. 5)**. The STAR Community Index target audience is municipal government, and "sustainability" is broadly-defined to include equity, economy and environment. Its policy-driven mandate ranges from urban design to local economy to social justice (STAR, 2009). The primary target audience of LEED ND is the building industry, from property developers to architects. Its project-driven mandate ranges from storm water capture to traffic-calming and urban density incentives (LEED ND, 2009). The primary targets of the Climate Positive Development program are public-private partnerships required for large international developments. Its project-driven mandate hinges on reducing the amount of on-site CO2 emissions to below zero (Climate Positive, 2009). These designation systems all aspire to become "gold standards" for their target audience and provide robust metrics with which to measure success.

5. STAR Logo for STAR Community Index, ICLEI (Local Governments for Sustainability) (2008). Logos: USGBC LEED ND and Clinton Climate Initiative's Climate Positive Program.

These designation systems are currently in the development phase, and it remains to be seen if the final versions of these Sustainable Designation Systems will overcome considerable challenges to directly address climate-resilient urban design strategies for climate adaptation and test pilot projects for future resiliency. A central hurdle involves the discontinuity of urban policy measures between local and regional form that challenges the public understanding of urban form holistically. The unclear link between regional decisions on neighborhoods or individual parcels and vice versa is just one example of this challenge. The lack of tools to assess conditions in the urban environment at city block or neighborhood scale is another. Agency departments within government administrations are often insufficiently coordinated to capitalize on cross-disciplinary synergies. Silos of expertise are difficult to harness over the long-term due to different departmental missions, and these ad hoc, disconnected approaches often fail to exploit synergies between professional practitioners. With the ambition, time, finances and scope of effort required of these designation systems, ensuring long-term public support and policymaker buy-in, including timely financing, will require a transparent planning process and clear accountability **(Fig. 3, 4)**.

Given its ambitious scope, varied scales and geographic diversity, the STAR Community Index may be the most challenging of the Sustainable Designation Systems to measure success **(Fig. 6)**. Yet, this is what STAR proposes to do. *Measuring Sustainability* (STAR, 2009) describes how USGBC's LEED designation systems provide a precedent for measuring progress and define how indicators of performance "can play a role in the STAR Community index that Post-Occupancy Evaluation plays in LEED: confirming actual performance vis-à-vis the designed or intended condition" (STAR, 2009, p.3). The STAR Community Index is a sustainability framework conceptualized as a "Designation" type of rating system. Designation Systems primarily rely on prescriptive measures and performance standards to set achievement levels of the attainment of "points" or "credits" within the system (STAR, 2009, p.1).

6. Cities are uniquely complex due to scale, climate, socio-economic conditions, overlapping urban systems and regional form. The development of sustainable cities by urban planning practitioners tends to focus on broad policy objectives, as illustrated by the Egan Wheel, Eganwheel.www.microcoaches.co.uk, *(2009).*

Traditional "place-making" urban design qualities should be expanded to include "sustainability supporting" qualities, that include resilience, comfort, resource efficiency, and biotic support **(Fig. 7)**. In the "Resilience: Adaptive" column, urban design would explicitly address climate change vulnerability at the settlement district level. Applying these types of climate-resilient urban design characteristics to Sustainability Designation Systems helps to identify and strengthen prescriptive measures and performance standards. These will address threats posed by climate change on the public realm—by focusing on public realm vulnerabilities and adaptive opportunities through climate-resilient goals, measures and performance indicators.

Traditional Urban Design "Choice-Supporting" Paradigm Compared to "Sustainable" Urban Design	
Traditional Urban Design	*Sustainable Urban Design*
Permeability – connectivity	Resilience – Adaptive
Vitality – Interactions	Comfort - Environment Permeability
Variety – Options	Resource Efficiency - Demand, Synergy, Re-Use
Legibility – Understandable	Biotic Support - Environmental Diversity
	Health - Pathological Prevention

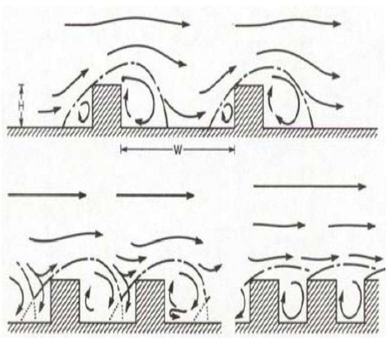
7. Broadening traditional place-making urban design qualities with "sustainability supporting" qualities, Odoleye et al., (2008).

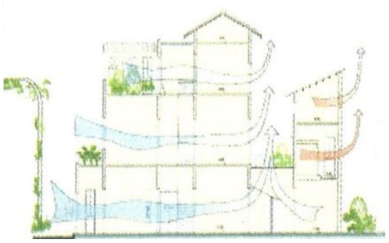
To illustrate the impact of such measures and standards, this "climate-resilient public realm" goal area would strengthen community adaptability to climate change and mitigate urban heat island effect through systemic, interconnected and protective micro-climates within the public realm to achieve reduced energy loads, cleaner air and enhanced civic life. Prescriptive measures and performance standards for a "climate-resilient public realm" goal area would address systemic impacts on the public realm, including urban ventilation, green infrastructure, and solar design. Albedo, "sky-view factor" and anthropogenic (user) emissions remain key elements within these categories.

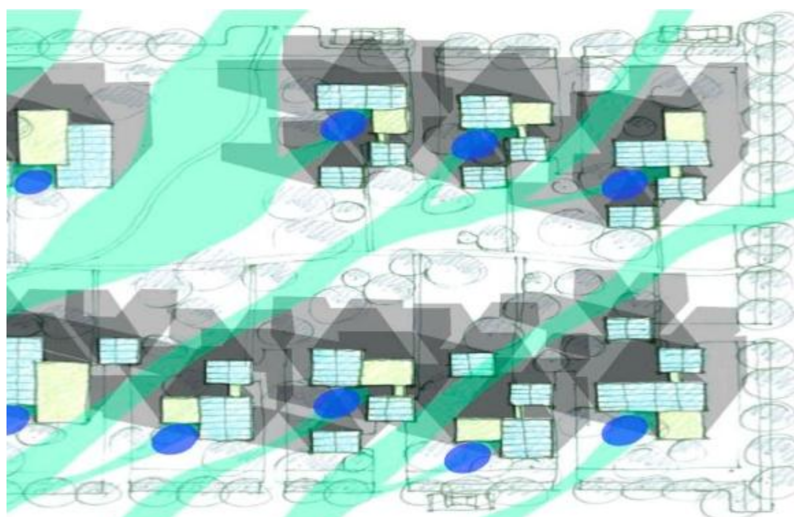
Urban Ventilation and Green Infrastructure: Prevailing Breezes, Air Quality and UHI

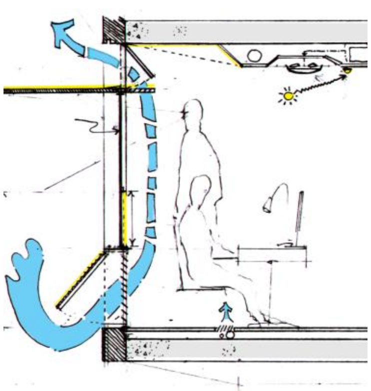
Wind affects temperature, rates of evaporative cooling and plant transpiration and is thus an important factor in implementing district-wide passive cooling strategies at a micro-climatic level **(Fig. 8-12).** Urban morphology is responsible for varying the surface roughness **(Fig. 8)** and 'porosity' of the city impacting airflow's effectiveness in passive cooling and reducing energy loads in the built environment **(Fig. 9, 10)**. Advection across parks, green roofs and water bodies can accentuate the cooling effect of the wind, and alignment of street canyons can be used for external cooling but also can be effective for passive cooling in buildings **(Fig. 8-17).** For example, Masdar's streets are mainly used for circulation, fresh air distribution, and microclimate protection. Its two green park bands that stretch throughout the city are oriented toward the sea breeze and the cool night winds **(Fig. 15)** (Schuler, 2009).

The *Thanh Hoa City by 2020* plan in northern Vietnam uses similar strategies in a tropical climate, where linear parks along canals align with prevailing summer winds to create fresh air corridors through the city grid **(Fig. 9, 13, 14)**. The viability of passive ventilation strategies hinges on considerations across other urban sectors, from transportation to anthropogenic heat sources from day-to-day activities of city inhabitants **(Fig. 17)**. In Masdar, streets continue serving city-wide circulation, but phasing out internal combustion engines from city streets in favor of electric vehicles removes important air quality and noise challenges (Schuler, 2009).









8. Top left: Wind flow associated with different urban geometry and surface "roughness", Oke (1987).
9. Top, right: Waterfront district configured for maximum urban porosity, to capture summer breezes, Raven-LBG (2008).
10. Bottom, right: Site plan configured for maximum urban porosity, to capture summer breezes, l'Université de Laval (2006).
11. Bottom, left: Ensuring opportunities for cross-ventilation and solar access, including laying out dual-aspect living and working quarters, Raven (2008)
12. Middle, left: Configuring vegetation and buildings to direct desirable summer air flows; cross-ventilation through dual-aspect buildings, l'Université de Laval (2006).

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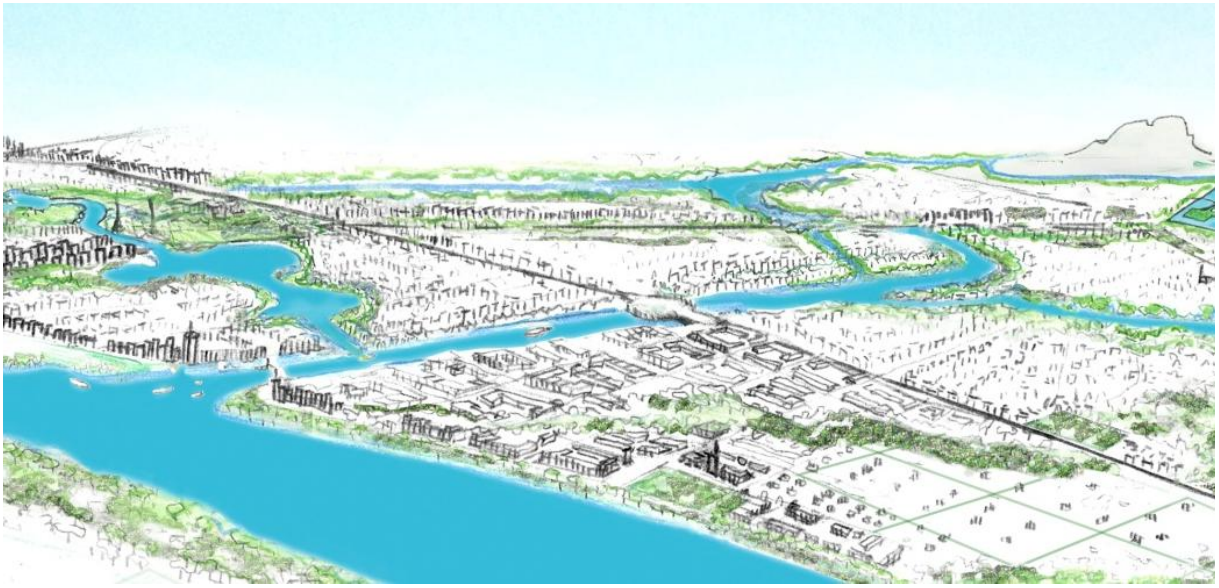
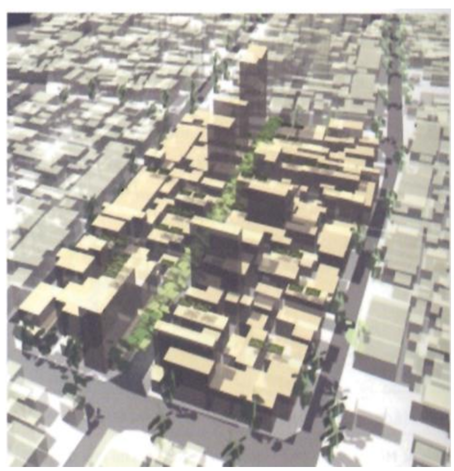


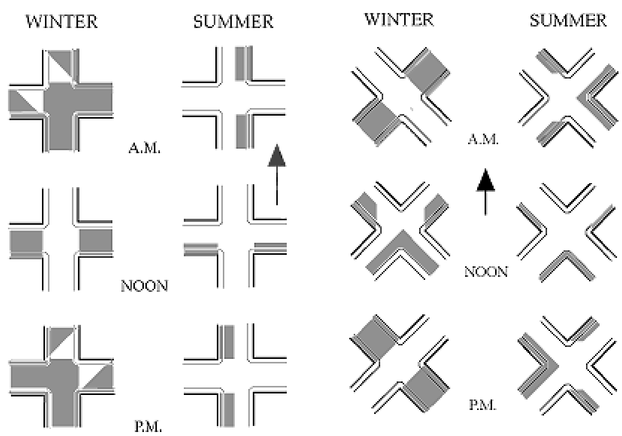


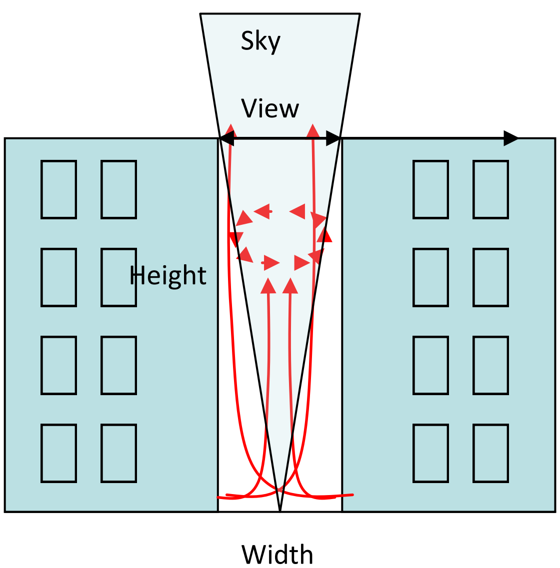
13. Top and 14. Above left: Green and blue fingers - Linear parks and urban forests: Contiguous green corridors, canals and open space networks; conceiving stormwater retention as urban design amenities; enhanced connectivity and transportation, Thanh Hoa City by 2020, Raven-LBG (2008).
15. Above right: City model detail- "Green fingers" through dense, energy-efficient, pedestrian-friendly neighborhoods of cool streets, urban squares lower building cooling loads, Masdar carbon-neutral development, Abu Dhabi, Fosters + Partners.
16. Right, middle: Retrofitting an urban network of many small green spaces or "urban forests" through Hanoi, l'Université de Laval (2006).
17. Left, bottom: The viability of passive ventilation strategies is increased through adjoining low-impact transportation systems, illustrated in Vauban, Germany, http://graphics8.nytimes.com/images/blogs/greeninc/ vauban. jpeg, (2009).

Solar Design: Passive Strategies to Increase Comfort and Reduce Energy Loads

The urban canyon, which is a simplified rectangular vertical profile of infinite length, has been widely adopted in urban climatology as the basic structural unit for describing a typical urban open space (Ali-Toudert et al., 2005, p.2). For street canyon geometry, one of the most useful measures of the urban terrain is the "sky view factor" (SVF) **(Figs. 18, 19)**. It expresses the relationship between a surface and sky, introducing the concept of opening or closing the space.

In addition to vertical profile, the orientation of the urban canyon has a decisive impact on the human thermal sensation at street level. Patterns of urban settlement based on climate, topography and geology highlight the important relationship between passive climate-resilient strategies derived from urban form and a comfortable public realm. During summer months, when the sun is highest, east-west and north-south streets will receive little shadow at mid-day, potentially exposing the public realm to excess heat and brightness. The diagonal grid leaves every street with some direct sunlight during winter months, and some shadow during most of the summer day. However, it is also important to weigh preferred street configuration in light of optimal building configuration, where the most exposed sides of the buildings are close to due north and south **(Fig. 20)**.





18. Left, top: Fish eye image used for measuring sky view factor (SVF), http://www.gvc2.gu.se/ngeo /urban /Activities/svf.htm (2009).

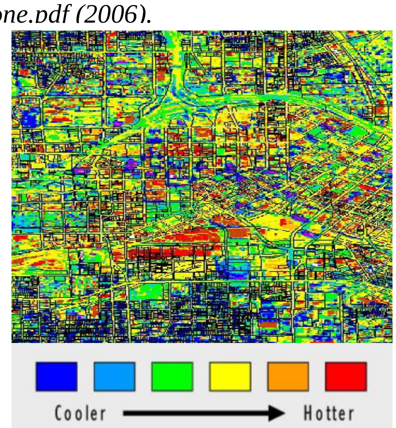
19. Left, bottom: Cross-section through a symmetrical urban canyon. "Height" is the building height and urban canopy height, "Width" is the separation between buildings, "Sky View Factor" is defined as the proportion of the viewing hemisphere occupied by the sky. Red arrows illustrate heat trapped within urban canyon or reflected to the sky, depending on urban geometry and surface materials.

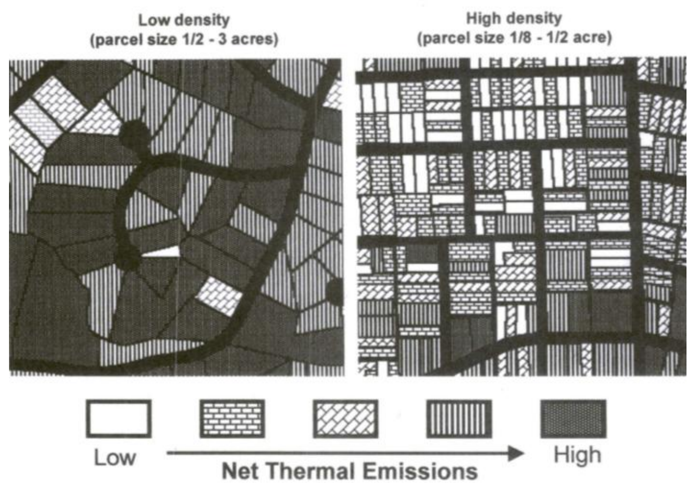
20. Top: "Jeffersonian" grid (left) that runs along north-south cardinal points; "Spanish" grid (right) with 45-degree diagonal orientation off cardinal points, Walter et.al. (1992).

There is currently no single “silver bullet” climate-resilient urban design tool that has been developed across spatial scales and sectors. Researchers have determined that more than a single tool will be necessary. This Iterative, Spatial, Scalable, Synthetic, Multi-issue, Accessible, and Economical “suite” of tools, would share a common engine of methodological concepts and standards (Miller et al., 2008, p.23). This suite of tools will be required to provide practical guidelines across systems and spatial scales for urban design practitioners, and generate scenarios based on alternative urban forms.

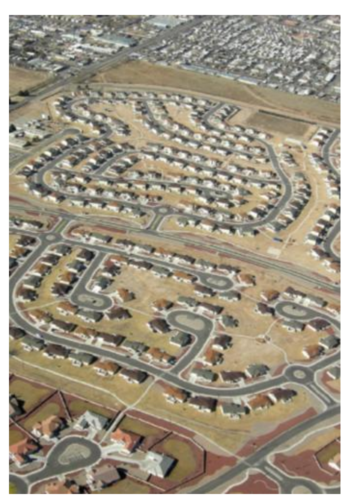
At a regional scale, the quantity of radiant heat energy emitted by low-density, largely single-family districts can be determined with the aid of remotely sensed thermal data collected by the National Aeronautical and Space Administration (NASA) **(Fig. 21)** (Stone et al., p.3). Comparing low-density with higher density “compact” districts in Atlanta, this research has argued for a nuanced analysis of the relationship between land use density, urban morphology and the urban heat island effect. The research argues that “thermal efficiency” (based on thermal emissions) per single-family plot of land actually increased in higher-density, more compact districts **(Figs. 3-9, 3-10, 3-11, 3-12)**. This finding directly challenges common assumptions that higher residential densities are less thermally efficient than lower residential densities. Through the prism of impervious surfaces to tree canopy layer, this method can illuminate the benefits of district-wide urban form better adapted to climate change.

21. Below, left: At a regional/district scale, parcel-based surface warming showing thermal emissions efficiency based on morphological indicators, http://www.gcp-urcm.org/files/A20060904/ theme4/stone.pdf (2006).

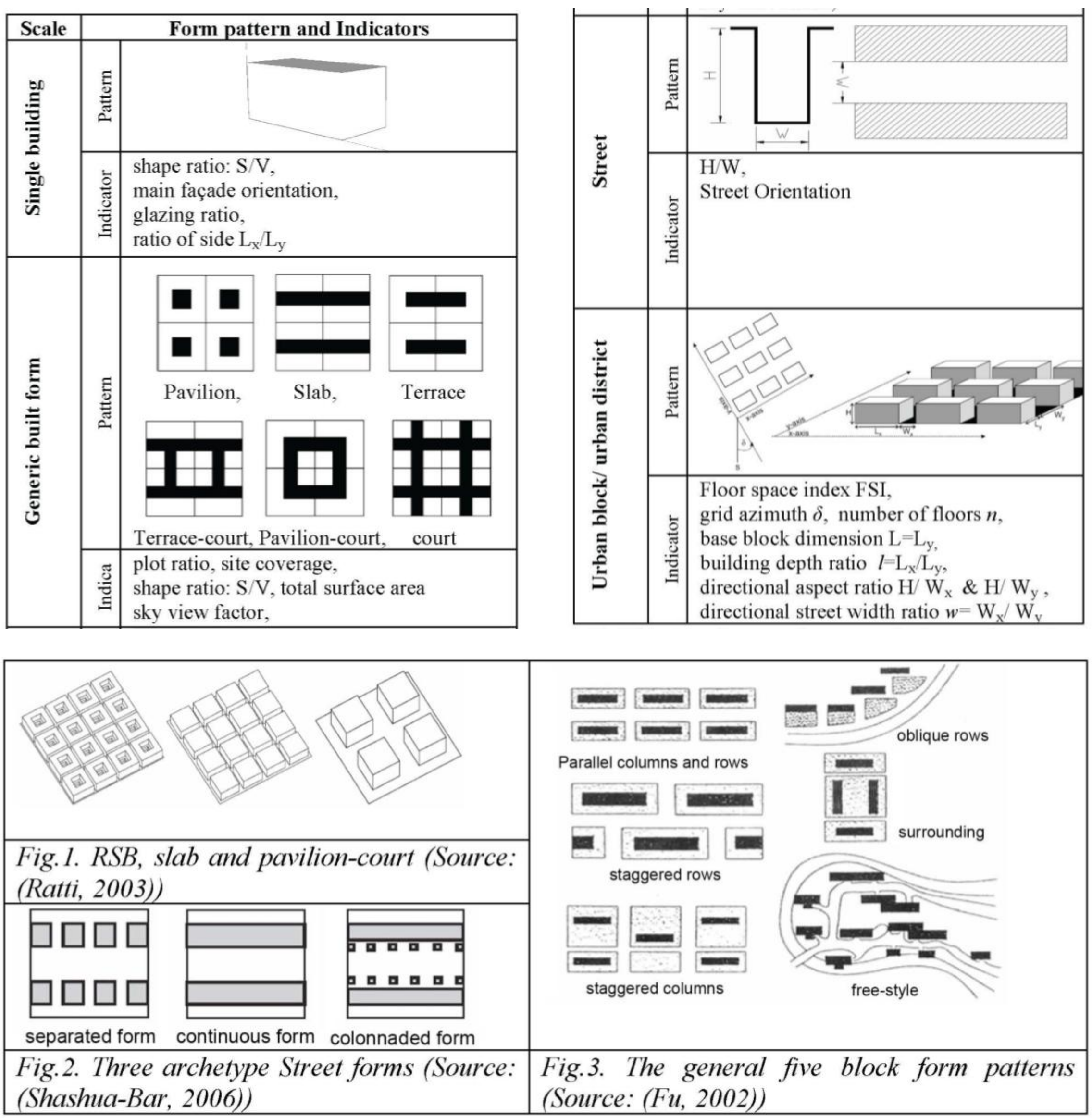




22. Top-center, and right: Urban form related to thermal efficiency, “Urban Form and Thermal Efficiency: How the Design of Cities Influences the Urban Heat Island Effect” Stone, et.al. (2001).
23. Left bottom: New suburban sprawl: Low-density development, low-efficiency thermal emissions per parcel, http://www.re-nest.com/uimages/re-nest/5-11-2009suburb.jpg (2009).
24. Right bottom: Higher density residential development, mature tree canopy layer, higher-efficiency thermal emissions per parcel, http://www.davidwallphoto.com (2009).



Since planning and urban design in metropolitan areas is often undertaken at two spatial scales, site-specific scale and larger scale municipal or regional plans, it is important to develop clear performance linkage between site and regional resilience. Researchers have attempted to develop tools to test built configurations and learn about the physical phenomenon that take place in an urban space, to create archetypal generic built form derived from simplified urban fabric, comprised of parcels, blocks, districts, and streets. A simple representation of urban texture is a figure-ground map. In the study by Ratti et al. at the Martin Center in University of Cambridge (Ratti et al., 2003), the six archetypal generic built forms from an urban block arrangement derived from a simplified urban fabric were linked to solar exposure (Ratti, 2003). As illustrated below in Figure 25, a framework composed of basic urban form patterns and morphological indicators should be developed representing different spatial scales.

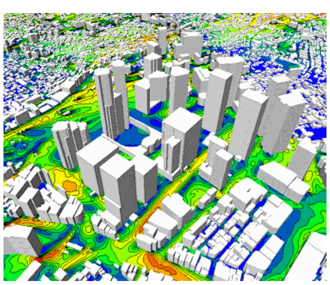


25. An elementary framework composed of basic urban form patterns and morphological indicators should be developed representing different spatial scales, Bouyer (2009).

For the "climate resilient public realm" goal in Sustainable Designation Systems, these archetypal, generic urban form patterns would be characterized to form the basis for applying morphological indicators. Those, in turn would be the basis for prescriptive measures and performance standards. For example, it is possible to characterize a limited number of generic North American neighborhood configurations and the related district configurations into which they assemble. Once characterized, the inherent or potential capacity for climate from this small palette of neighborhood types and limited set of inputs could be assessed, thereby avoiding the necessity of assigning attributes on a much smaller parcel by parcel scale. Once assembled, these patterns could then be used to generate regional scenarios. With this method, it would be possible to develop a tool that would simplify data input, analyze scenarios quickly and cheaply, and potentially function in real-time in collaborative, public processes. (Miller et al., 2008, p.24).

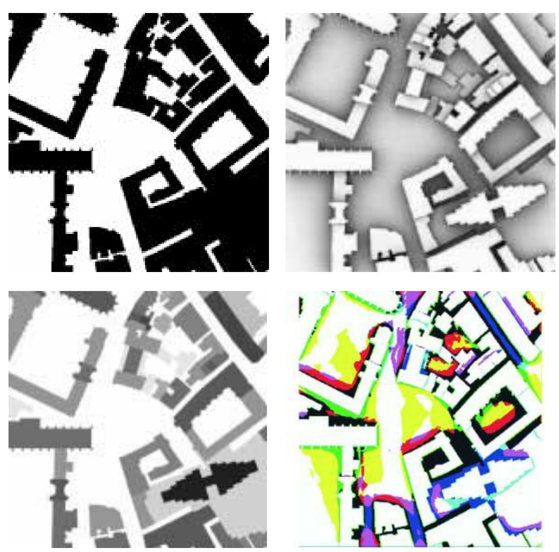
If height information is included at a more detailed level, a Digital Elevation Model (DEM) could be developed, which is an image where each pixel of the figure-ground map has a grey-level proportional to the urban surface **(Fig. 26)** (Ratti et al., 2003). By correlating urban form and various aspects of environmental performance with respect to the solar and wind environments and energy consumption, an evaluation of the environmental impact of alternative urban forms can be accomplished without the need for elaborate models. Sky view factor (SVF), the proportion of sky visible in a 180 degree field of view, or the aspect ratio, the height of the street canyon divided by its width, are both readily quantifiable measures of urban terrain **(on p.8, Fig. 18, 19)** (Smith et al., 2008, p. 2). By applying image processing techniques to three-dimensional urban textures, a suite of tools can draw connections at a simplified level between urban form and microclimate characteristics (Steemers et al., 2004, p.17).

More sophisticated software is increasingly available for simulating sunshine, lighting and thermal radiation to determine micro-climate impacts of three-dimensional urban form. These tools evaluate sunshine/shadow; solar energy, solar reflections, luminous transmission and thermal radiation as factors that shape the comfort profile of the public realm **(Fig. 27)**. After having grouped the radiative characteristics of materials, a 3D model can be made of the study district. The 3D model represents the external surfaces of the urban site: roofs, façades, courtyards and street, from which radiative characteristics to surfaces are derived (Bouyer et al., 2009, p.6).



27. Computational fluid dynamics (CFD) in Urban Design: Pedestrian Wind Environment around Buildings http://www.aij.or.jp / cfdguide/ image.gif (2009).

26. Right, illustrating selection from suite of tools, determining comfort or "desirability" factor in the public realm, based upon individual microclimatic variables (2004). Clockwise: Figure-ground map; Sky-view factor (SVF) map; Open space diversity profile; Digital elevation model (DEM), Steemers, et al. (2004)

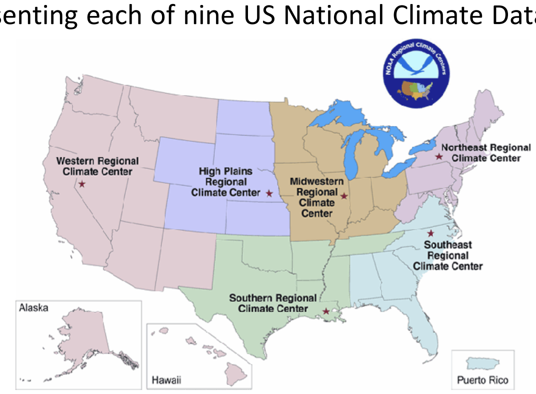


The Pilot Test methodology for the Sustainable Designation Systems should measure the success of these climate-resilient urban design strategies across different spatial scales, geographies and climate. The development of Sustainable Designation Systems, such as STAR, LEED ND, and the Climate Positive Development Program, should involve a sequence of phases, each with feedback loops to test the system's logic and validity. None of these Sustainable Designation Systems are fully operational. Therefore, this paper did not actually "model and test" the micro-climate indicators of an actual climate-resilient urban design pilot goal. Rather, a prototype framework and methodology is suggested for the Pilot Phase so as to evaluate the results.

The quantitative climate-resilient assessment of a Sustainable Designation System pilot case-study would be based on climate-resilient urban design performance standards described earlier. This would include the use of two sets of archetypal standard urban patterns for study, targeted to a varied group of city types, climates and geographies. This could range from a high-density urban core to an inner-ring suburb to an edge city, from sub-tropical to desert. One set for each location would be a "baseline" conventional urban design pattern. The second set would represent "best practice" urban form suitable to local conditions. Built in the same locations as the archetypal models, actual Sustainable Designation System-accredited Pilot Community projects would be evaluated in real time against these two sets of benchmarks.

The three sets, baseline model, best practices model and actual Pilot Community project would be tested based on climate-resilient urban design indicators discussed earlier in this work. The "suite of tools" would evaluate albedo, sky view factor, solar design and urban ventilation. Anthropogenic heat sources from city inhabitants should also be factored in. For lower-density, uniform morphologies, radiant heat energy could be modeled to simulate the thermal efficiency study of residential districts conducted by Stone. For more localized urban spaces, the micro-climate analysis would begin to suggest unique diversity and desirability profiles.

To account for climate change, these indicators should assume at least two plausible future climate conditions: increasing temperature (20 and 90 years time period) and increasing intensity of heat wave events, based on weather data (Pyke et al., 2007, p.13). A "modest change" scenario would be equivalent to extrapolating the observed trend for 20 years (a typical time horizon for planning). A "longer-term change" scenario would be equivalent to extrapolating the observed trend 90 years into the future (i.e., end of the 21st century, a benchmark often used in climate change analyses). These changes should be applied to a ten-year historical daily climate record (1996-2005) from each of the nine representative cities (Pyke et al., 2007, p.14). For the United States, nine Pilot Communities could be selected based on geographic variation, representing each of nine US National Climate Data Center (NCDC) regions **(Fig. 28)**.



28. For project verification in the USA, nine Pilot Communities should be selected based on geographic variation, representing each of nine US National Climate Data Center (NCDC) regions, http://lwf.ncdc.noaa.gov/oa/climate/regionalclimatecenters.html (2009).

The climate adaptive performance of the Pilot Communities should compare morphological urban design indicators against conventional "baseline" condition and "best practice" models. The important question in evaluating the results would be: do the pilot tests accurately predict performance? It would be important to create effective feedback loops so that this information continues to shape the Designation Systems.

In addition to striving for technical accuracy in climate-resilient strategies, a prototype testing protocol similar to the one suggested here could provide transparency and accountability to the decision-making process. As these Sustainable Designation Systems continue through the prototype phases, developing transparent testing protocols backed by clear accountability will be the next stage of the work.

TClimate mandates from federal, state and provincial governments are now impacting the practice of urban design as cities face mandates to bring their transportation, zoning, building codes and economic development policies into alignment with required greenhouse gas reduction goals. In response, urbanists are being called upon to help shape a resilient built environment to reach the low-carbon mandates and reduce vulnerabilities and impacts from that part of climate change that is already unavoidable. This development has signaled a shift in focus in urban design policies from greenhouse gas emission mitigation strategies to risk analysis, adaptation and resilience.

The half-century “design life” for the built environment means that current urbanists and policymakers must create resilient cities within paradigms appropriate for future climates. With changing conditions, solutions requiring fewer resources rather than more are likely to be robust, which is why reducing energy demand through climate-resilient strategies is such an important first step. Such a forward-thinking approach to “climate-proofing” can reap significant benefits in the long term, including economic savings and risk reduction through reduced energy consumption and improves a community’s ability to persist and thrive through potentially catastrophic climate change..

Forward-thinking cities should exploit climate-resilient urban design measures in order to “future-proof” the built environment in expectation of continuing climate change. They help reduce the risk of relying on bolted-on, applied technologies that may require expensive maintenance or become obsolete in a short time. These free, passive urban design strategies “lock in” long-term resilience and sustainability, thereby protecting the community from unwise decisions that might undermine its adaptability to respond to future change. Climate-resilient urban design strategies are among the ultimate guarantors of post-habitation sustainable strategies, a key metric in assessing life-cycle costs, payback and the livability of urban areas.

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