RESILIENT AND EFFICIENT SYNERGY COMMUNITIES
A MORPHOLOGICAL, STRUCTURAL AND SYNERGETIC APPROACH
TO ENERGY EFFICIENCY

Serge SALAT, Architect, Director
Urban Morphology Lab
Our research has shown that an efficient urban fabric alone can reduce energy consumption and carbon emissions by a **factor of 2** - a factor too large to ignore.

This means that Urban Morphology has the potential to halve a city’s energy and carbon emissions. It is an essential lever towards more sustainable cities in the future.
Urban morphological strata

Population
Street patterns
Plot subdivisions
Topography
Land use
Built environment
Interaction forms/flows

Flows of people

Flows of transport

Exchanges
Nutrients
Waste

Interaction with
Light
Sun
Wind

Flow cycles
Key concepts

- Density
- Mixed uses
- Compactness
- Passive volume
- Solar access
- Connectedness
- Complexity
- Fractality
About urban complexity

Scale Hierarchy, Exergy Maximization & Urban Efficiency

Serge Salat
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CSTB, Paris

About urban complexity

Scale hierarchy and efficiency

Trees and Leaves

Applications: Synergy
Grids
Le Corbusier cruciform towers versus Turin historic centre

High rise towers reduce density and connectedness as well as social interactions. They increase congestion as they are giant cul-de-sacs (squares 400m x 400 m)

40km of facades on streets and 16 km of facades on courtyards in Turin center inherited from the Roman grid (710 x 770 m)
Scale hierarchy and efficiency

Insights from hard-core thermodynamics

Complex multi-scale structures have to follow Pareto distributions (Power laws) to be efficient

I. Prigogine
Minimum Entropy Production Principle

A. Bejan
Constructal law

J.J. Kay
Highly organized complex systems = Exergy maxima

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Applications: Synergy Grids
Scale hierarchy and efficiency

• Urban networks (energy, water, heat, etc.)
• Energy systems (production and consumption)
• Urban fabric: thermal exchanges with the outside

Parma in 1830

Fractal Sierpinski carpet
Scale hierarchy and efficiency

Urban networks and natural flow structures

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Applications: Synergy Grids

Pareto distributed road network

Fractal structure of a lung
Frequency/size distribution of city components (urban blocks, streets, courtyards, etc.)

Natural scaling hierarchy and urban scaling hierarchy: Pareto law

• “The small scale is connected to the large scale through a hierarchy of intermediate scales with scaling factor”

\[ p = \frac{c}{x^m} \]

• Inverse-power law:

(there are \( p \) units of size \( x \), \( m \) is the fractal dimension)
Mathematically speaking, a leaf is a semi-lattice, a much more complex and subtle structure than a tree.
Relationship between Transport and Land Use

A commonly used study of 32 cities by Newman & Kenworthy in 1989 concluded that there was a strong link between urban development densities and petroleum consumption.

Annual petroleum use per capita adjusted to US MJ (1980)
Siena and a quadra in Brasilia at the same scale
800 * 800 m

Built density (FAR):  2,98  
0,38
Six residential typologies

Best FAR: medium height buildings
(« Haussmann » typologies).
Much better than high rise buildings
(Corbusean typologies, Brasilia for instance)

Use less transport energy
Passive volume

Passive volume can benefit from natural lighting and ventilation

$\rightarrow$ Energy reduction
The unobstructed passive zone, uses two times less energy than the non-passive zone (Ratti and al.)
Shanghai, Lujiazui (CBD)  
Ratio = 43 %

Guangzhou, Tianhe  
Ratio = 66 %

Hong Kong, North Point (residential)

Shanghai, Hongkou (lilongs)

Paris, 19th century

% de volumes passifs

\[
Ratio = \frac{\sum_{\text{buildings}} \text{PassiveVolume}}{\sum_{\text{buildings}} \text{BuiltVolume}}
\]

Ratio ~ 80%
Fractals as efficient interfaces
Fractal optimisation of courtyards urban textures according to latitudes and climates.
PARIS scaling hierarchy
Street Network & Connectivity

Comparative analysis of Street Networks in our various studied cities have shown a number of conclusions thus far regarding connectivity: greater cyclomatic number (average # connections between 2 points); smaller distances between intersections; and greater density of intersections, generally indicate a more connected, accessible city fabric.

<table>
<thead>
<tr>
<th></th>
<th>HK, C &amp; W District</th>
<th>Guangzhou, CBD</th>
<th>Historical Paris</th>
<th>Kyoto</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of cycles Euler</td>
<td>51</td>
<td>6</td>
<td>88</td>
<td>83</td>
</tr>
<tr>
<td>Formula 1+L-N</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average distance btw</td>
<td>157</td>
<td>518</td>
<td>153</td>
<td>52</td>
</tr>
<tr>
<td>intersections</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intersection density</td>
<td>6.38</td>
<td>1.93</td>
<td>6.5</td>
<td>19.24</td>
</tr>
</tbody>
</table>

Based on graph theory
Pareto distributed trees are efficient. But they are not resilient.

=> *Cities should be leaves instead of trees!*
Cities facing climate change:

- Urban Efficiency
- Power Laws
- Climate change Mitigation

- Urban Resilience
- Multi-scale Feedback Loops
- Climate change Adaptation

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About urban complexity
Scale hierarchy and efficiency
Trees and Leaves
Applications: Synergy Grids
Applications: Synergy Grids

Implement feedback loops on each scale of urban networks, and between networks.

Structure and size urban networks using efficient Pareto distributions.

Switch from Edison’s classical electricity and energy tree-like network to an efficient and resilient leaf-like synergy grid.

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Applications: Synergy Grids
The concept of Smart Grids

- Electrical distribution networks;
- Energy generation sources including:
  - Traditional fossil-fuel or nuclear power generating stations;
  - Large renewable power supply sources (wind, solar, wave);
  - District or local renewable energy sources (wind, solar, biomass CHP);
  - Small intermittent power supply sources to & from individual buildings;
- Network software optimizing power demand and supply & providing diagnosis of actual or incipient problems with line or equipment;
- Power use controllers linked to individual appliances, shaving peak power demands by signaling linked equipment to turn itself off for a period of time, or to reduce its power requirements;
The concept of Smart Grids
Benefits for utilities

- Network resilience: Avoid and minimize blackouts and disruptions
- Stability of consumption
- Identify sources and characteristics of distributed power sources in the grid

Higher quality

- More efficient use w. respect to sources and peak periods
- Reduction of peak loads

Lower GHG emissions

- Fraud detection and prevention

Lower costs
The concept of Smart Grids

Benefits for operators and owners

• Real-time load and supply adjustment
• Real-time information on the source of electric power
• Performance data from the grid, that can form the basis of emissions trading
• Ability to export power
• Higher level of power quality for critical IT systems
• Smaller sized building technical facilities (savings in investment and operation cost)
• Delaying and predictive systems (cooling, heating)
• Use of energy storage capabilities in buildings
Towards Synergy Grids

Optimization of supply and demand for neighborhood-scale systems

• Buildings with a deficit or surplus of:
  – thermal energy;
  – domestic hot water;
  – grey water;
  – DC power;
  – parking spaces;

• Owners of private electric vehicles with a deficit or surplus of DC power
Towards Synergy Grids
Towards Synergy Grids

1. Space heating and cooling, thermal generation and thermal storage
2. Rainwater capture, neighborhood-scale grey-water and redistribution systems
3. Solid waste storage and recycling
4. Local transport system
Towards Synergy Grids

5. DC power as a parallel system (CHP, wind, bio-mass, other renewable sources on site)
6. Vehicle re-charging
7. Storage of DC power
8. DC power systems in commercial buildings
Structuring and Sizing Grids

For Smart and Synergy Grids to be efficient, structure and size are crucial:

« Scale Free Complexity » concept

*Urban Morphology Lab*
Structuring and Sizing Grids

« Scale Free Complexity » concept

Each level of the grid has to display the same level of complexity, no matter the scale considered.
Structuring and Sizing Grids

Insights from hard-core thermodynamics:

- Power laws
- Scale free complexity

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Energy Efficiency

Hausmannian Paris
Most of the natural networks display scale-free complexity, to optimise energy efficiency.

Structuring and Sizing Grids

Neuronal networks
Trees
Blood systems
Flows have to be recycled and reused on every scale: *low exergy approach*.

Water, energy, heat, waste, grey water are recycled on the *building scale*

Adapted from Dobbelsteent et al, 2011
Flows have to be recycled and reused on every scale: *low exergy approach*.

Water, energy, heat, waste, grey water are recycled on the *neighborhood scale*

Adapted from Dobbelsteen et al, 2011
Flows have to be recycled and reused on every scale: *low exergy approach*.

Water, energy, heat, waste, grey water are recycled on the **district scale**.

Adapted from Dobbelsteen et al, 2011
Flows have to be recycled and reused on every scale: *low exergy approach*.

Water, energy, heat, waste, grey water are recycled on the **city scale**

Adapted from Dobbelsteon et al, 2011
**GHG emission reduction potential**

**Smart Grids: up to 18%**

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Direct (%)</th>
<th>Indirect (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservation Effect of Consumer Information and Feedback Systems</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>Joint Marketing of Energy Efficiency and Demand Response Programs</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Deployment of Diagnostics in Residential and Small/Medium Commercial Buildings</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>Measurement &amp; Verification for Energy Efficiency Programs</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>Shifting Load to More Efficient Generation</td>
<td>&lt;0.1</td>
<td>-</td>
</tr>
<tr>
<td>Support Additional Electric Vehicles and Plug-In Electric Vehicles</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>Conservation Voltage Reduction and Advanced Voltage Control</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Support Penetration of Renewable Wind and Solar Generation</td>
<td>&lt;0.1</td>
<td>5</td>
</tr>
<tr>
<td><strong>Total Reduction</strong></td>
<td><strong>12</strong></td>
<td><strong>6</strong></td>
</tr>
</tbody>
</table>

Adapted from Pratt et al 2010
GHG emission reduction potential

- **Synergy Grids:** up to 44% energy consumption reduction for heating and cooling (Rotterdam Hart van Zuid Case Study)
- **REAP method:** appropriate mix of buildings, of heating/cooling requirements, of heat/cold storage
- **Knotting the flows on every scale**

Adapted from Tillie et al, 2009
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CITIES AND FORMS ON SUSTAINABLE URBANISM

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