A COMMON METRICS AND SET OF INDICATORS FOR ASSESSING BUILDINGS AND URBAN FABRIC SUSTAINABILITY PERFORMANCE

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Summary

Many developments have an impact at a larger scale than the single building. A global sustainability assessment method must take into account the urban dimension and not only the single building itself.

The CSTB (The French Centre for Building Science) has developed an original approach through its cross-disciplinary Urban Morphologies Laboratory. For several years now, this collaborative effort of scientists, engineers, architects and urban planners, has been investigating in a dozen world cities the factor of urban morphology and shown that urban morphology alone has an impact on energy performance of the order 2 – i.e. the potential to halve or double a city's carbon footprint.

The paper will present a common metrics, which links the scales of buildings, urban blocks and neighborhoods for an assessment of energy efficiency of the whole urban fabric including buildings and spaces between buildings such as street canyons. This metrics is based on a set of common comprehensive shape factors: for example the volumetric compactness and solar admittance, which are important for energy efficiency in Central Europe can be evaluated at the 2 scales of building and urban fabric.

The derivation of this metrics into a set of performance indicators is currently developed in the framework of the iiSBE Urban Working group chaired by the author. These indicators will be presented in 12 chapters, which are essential to build sustainable buildings and cities (density, volumetric compactness, connectivity, energy efficiency, bioclimatic potential, etc.) and associated with development strategies.

Keywords: urban morphology, urban metrics, assessment tools, urban sustainability, neighborhood assessment

To measure the performance of a city, its ability to deliver goods and services while offering a pleasant and healthy environment to the citizens and to produce as less carbon emissions as possible, assessment methods have been conceived using different indicators. Indicators are useful tools since they are objective measurements on the contrary to ideals proposed by architects, urban planners or politicians. They enable us to compare cities, to follow evolutions and to observe the results of politics or constructions, and to the consequences of some decisions or plans. A good indicator can be defined by five criteria:

- It must be handful and accessible, which means its analysis must be simple and the data needed to calculate it must be not too hard to access and not too expensive to get.
- It must be relevant, that is to say answering the right question.
- Its results and their explanations must be simple. It must not make the problem even more complex.
- It must be comparable to other indicators and allow comparisons between objects thanks to its results.
- It must improve the global reflection.

Here we present a series of planning more than monitoring indicators, geometrical and related to Urban Morphology. We tried to select a short list, but considering numerous themes and problems of the sustainable city. We classified our indicators following the topics of the human size of the city, its ability to create wealth, the connection and accessibility of the city, its diversity, its density, bioclimatic urbanism, the place of nature and finally the resiliency of the city.

I. A city at human size

1 Making the city more diverse

1.1 Social diversity

LBL= $\frac{\sum low\ income\ housing}{\sum total\ housing}$ (%) Example : the french law SRU advises 20%.

1.2 Complexity

Complexity measures the potential of information circulation between the citizens

H = $-\sum_{i=1}^{n} Pi\ .\log_2 Pi$

H measures the quantity of information in a message. The unit is the bit of information per person. The formula is derived from the Shannon formula and the theory of information. Pi is the probability of happening of the variable i and indicates the number of members presenting a favorable issue for this variable among the members of the community. The aim is to know the number of information bearers which have a possibility of contact, they shoud be numerous, diverse and well distributed in the city. What we call "information bearers" are in reality legal persons classified by category: economic activity, corporations, institutes, share capital …

The information content calculated with a logarithm indicated either the useful quantity which would be available if the system was organized forming a useful message, or the useful quantity of confusion if it were not organized.

Example : in a selection of 200m x 200m, H could be >6 bits of information per person in area with offices, shops, or public transport stations, and > 4 bits for more residential zones (recommendations by Barcelona Urbanism agency).

2 Make the urban space alive and attractive

2.1 Number of private and public seats per km2

A large number of seats encourage people to be, live and meet in the streets. Doing so make the street a social space and not only a transit oriented space. It increases sociability and the feeling of well being for the citizens.

Example : In Melbourne, a development plan enabled the city to increase the number of seats outside cafés and bars from 0,84 per km2 to 2,34 per km2. The number of public seats is 1,47 per km2. In Copenhagen, the number of public seats is 1,17 per km2 et the number of seats outside cafés and bars is 4,17.

II. A city creating wealth

1 Wealth produced in K€ or K$ per kg of carbon produced (carbon intensity)

$$I_{carbone} = \frac{Em_{Carbone}}{PIB}$$ (tCeq/1000USD de PIB)

Example : Japan has the national economy the more sober for a developed and industrialized country with 80kgCeq/1000USD[1]

2 Ratio Jobs/housing:

$$DE = \frac{\sum Jobs}{\sum flats}$$

Example: 157 jobs per hectare in the center of Paris; ratio: 0,78. 27 jobs per hectare in the first circle around Paris; ratio: 0,44. 14 jobs per hectare in the second circle around Paris; ratio: 0,77. *(source APUR)*

III. A connected and accessible city

1 Maximizing connections

1.1 Streets Density

$$\sum \frac{total\ length\ of\ all\ the\ streets\ in\ a\ zone}{surperficy\ of\ the\ zone(m2)}$$

A big number would allow smaller streets, but more numerous ways to go from one point from another and certainly more diversified ways (for pedestrian also and not only for cars).

[1] Source Rapport parlementaire: http://www.assemblee-nationale.fr/13/europe/rap-info/i1260.asp

1.2 Number of links:

Links are ways between two nodes. A big number of links include a big number of nodes and more possibility of different ways from one point to another. Nevertheless, the number must not be too big, so that the city do not become a maze.

1.3 Average distance between intersections:

Examples *(results from the Urban Morphology Lab):*

Center of Toledo, ancient town: 40m

Part of Torino extension: 80 m

Brasilia Lucio Costa Plan: 400 m

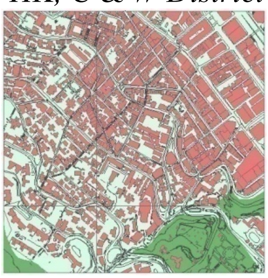
1.4 Cyclomatic number:

It gives an idea of the number of different ways to go from one point to another everywhere in the area studied. A big cyclomatic number would mean a large variety of different ways and so a big connectivity.

$$\mu = L - N + C$$

L= number of links (segment between two nodes)
N= number of nodes
C= 1 (generally)
Examples:
(results from the Urban Morphology Lab)

HK, C & W District



Guangzhou, CBD

Paris

	HK	Guangzhou	Paris
Cyclomatic number	51	6	88
Average distance between intersections	157	518	153
Density of intersections	6.38	1.93	6.5

IV. A diverse city

1 Balancing ground use

1.1 Ground Coverage:

$$GC = \frac{\text{Area on the ground occupied by buildings}}{\text{total area}} \%$$

Examples: 2/3 in the totality of Paris;80% in a neighborhood of 800x800 in the center of Paris; 10% in a selection of 800x800 in the CBD of Guangzhou.*(results from the Urban Morphology Lab)*

1.2 % of green spaces and gardens

$$CEV = \frac{\text{ground area occupied by green spaces}}{\text{total ground area}} \%$$

Examples: 16% in Paris (source APUR)

1.3 Roads ratio

$$TS_{roads} = \frac{\text{roads superficy}}{\text{Total superficy}} \%$$

Only roads outside are counted, not underground. It measures the part of roads in the area selected.

Examples: In European capitals, this ration is around 15%.

1.4 % of roads reserved to public transport

$$TS_{commun} = \frac{\text{superficy reserved to public transports}}{\text{Superficy of roads}} \%$$

Example: From one third to a half is a mean we find in the city well provided with public transports.

2 Diversifying the plots

2.1 Number of buildings per hectare

The more this number is high, the more the urban tissue is diverse and resilient.

Example:In majority, there is between 20 and 80 buildings per hectare in Paris.

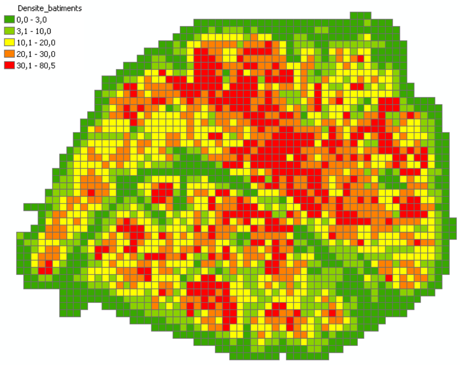


Fig. 1 Map of Paris presenting the number of buildings per hectare.

2.2 % of places dedicated to firms and businesses

$$\text{LPJ} = \frac{\sum \text{places dedicated to firms } (m^2)}{\text{total of places available in area } (m^2)} \quad (\%)$$

<u>Example:</u> In a selected area of 100 x 100m, diversity exists when this ratio is between30% and 60%.

2.3 Percentage of activities based on knowledge:

$$\text{A@} = \frac{\text{Nbre d' activités@}}{\text{total de personnes juridiques}} (\%)$$

This type of activity must be encouraged because it creates creativity and urban dynamism. They are new activities based on new technologies of information and communication, research, publishing, culture, multimedia, computer science… These activities create and control information and are therefore strategic.

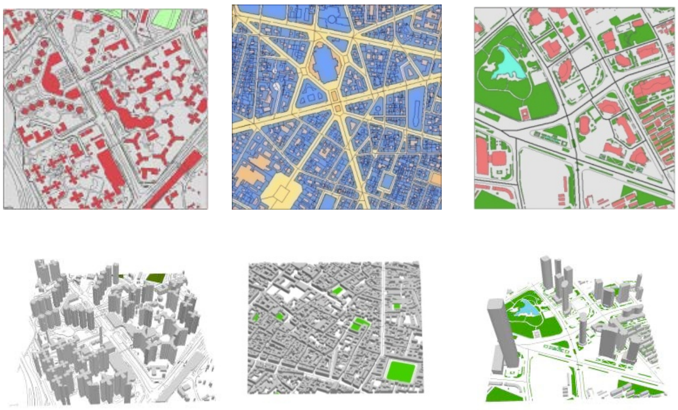
V. A dense city

1 Built density

Built density enables to create neighborhood in which the use of pollutant modes of transport is no more needed. It helps create neighborly relations, and provide the inhabitants with what they need to live, work and have leisure in a small perimeter.

$$\text{BD} = \frac{\sum \text{floor superficy of every storeys of buildings } (m^2)}{\text{ground level superficy } (m^2)}$$

<u>Examples: </u>*Results from the Urban Morphology Lab*



Hong Kong Paris Shanghai

In the area selected above: 3,1 in the center of Hong Kong, 4,5 for the center of Paris, 3, 7 in Shanghai

VI. Bioclimatic Urbanism

1 Limiting heat loss

1.1 Form factor

$$C = \frac{Surface}{(Volume)^\wedge(2/3)}$$

The ratio S/V measures the volumetric compactness of a building and indicates its capacity to keep heat inside, reducing loss by the envelope. The power 2/3 enables to compare all types of buildings, since with the ratio S/V, big buildings are always more compact because of their size. The ratio S/(V^(2/3)) enables to compare the ability of different forms to keep heat independently of the size effect. The more the ratio is small, the more the building is efficient and keeps the heat inside.

Example: Haussmann's buildings in Paris have a C of 8, which is correct. The towers of Le Corbusier have a C of 19, the problem is that light and air do not enter the major part of the building anymore,a and artificial means consuming energy are needed.

2 Using natural elements to provide light, thermal comfort, and ventilation

2.1 Urban Canyon

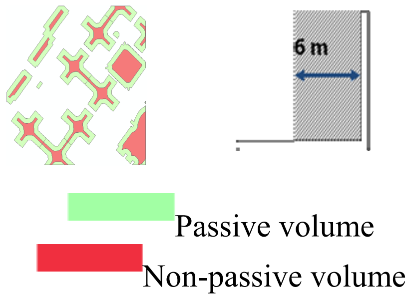
$$H/W = \frac{\text{mean height of buildings in a street (m)}}{\text{width of the street (m)}}$$

It is an indicator of penetration of wind and of shading of the street.

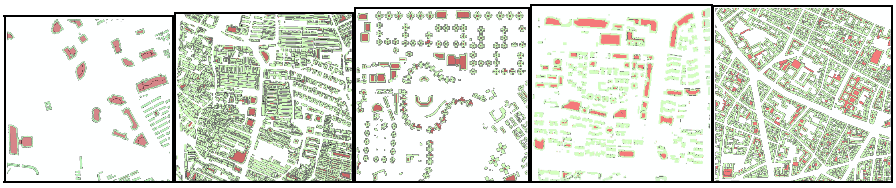
It_depends on the climate and of the objective: a big H/W corresponds to a narrow street and will be efficient in hot climate to give shade to the streets; on the contrary, a small H/W corresponds to a wide street and will allow the wind to penetrate the streets which is good for pollutants dispersion.

2.2 Passive volume

Ratio passive volume= $\frac{\Sigma_{buildings}\, passive\ volume}{\Sigma_{buildings}\, built\ volume}$



Shanghai Guangzhou Hong Kong Shanghai Paris



43% 66% 80% 80% 80%

(results from the Urban Morphology Lab)

VII. Reducing the ecological and energetic footprint of the city

1 Guideline: increasing productivity

1.1 Productivity of the urban metabolism

$$T_{prod.met} = \frac{M_{waste}}{M_{mat\ import}} \quad (\%)$$

M_{waste}= volume of waste
$M_{mat\ import}$= volume of imported material
Lowering this rate of some percent each year can be a target for cities.

1.2 Productivity of resources

$$P_{ress.} = \frac{V_{matièresconsommées}}{PIB}$$

This indicator measures the total quantity of material used by the national economy to satisfy the population’s needs and compares it to the GDP to know the quantity of material needed to create a unit of wealth. It shows the link in a city between resource consumption and wealth production.

Example: Resource productivity in France increased of 50% in 30 years. Between 2000 and 2004, resource productivity increased of 3,5% per year in France and 2,3% in the European Union (15 countries)

2 Guideline: Limiting non reusable waste

2.1 Rate of waste reused

$$T_{valo.} = \frac{M_{reused}}{M_{.total\ waste}} \quad (\%)$$

M_{reused} = volume of waste reused
$M_{.total\ waste}$ = total volume of waste

Example:it can be >80%. If there is a reusing of material producing energy at the same time, this ratio can even be superior to 100%.

2.2 Rate of material coming from recycling

$$T_{Matrenouv.} = \frac{M_{bio.} + M_{recycl\acute{e}}}{M_{mat.tot}} \quad (\%)$$

Example: It could be fixed by use or category : for example 90% of coating of roads, 25% of concrete, 100% of canalizations in cast iron (LEED objectives).

3 Guideline: optimizing water use

3.1 Water productivity:

$$T_{prod.eau} = \frac{V_{water\ needed}}{V_{final\ water}} \quad (\%)$$

Rate of water real needs compared with observed consumption.
Take into account the loss in canalizations.

Example: For example for domestic uses: estimation of 80 L/day/inhabitant
The goal could be >100% thanks to loops, local recycling and rainwater collect
In Paris: T=54%: 130 L/day/person is consumed and 20% of the water is lost in canalizations.

4 Guideline: encouraging the production of clean energy and reducing losses

4.1 Rate of electricity coming from renewable sources (final energy):

$$T_{ENR} = \frac{E_{renewable\ electricity}}{E_{total\ electricity}} \quad (\%)\ \text{kWh/year}$$

<u>Example:</u> In France, 7% of the energetic needs and 13% of the electricity consumption came from renewable sources in 2007. The French objectives in the short term are respectively of 10% and 21%.

4.2 Quantity of residual energy collected

Ratio between residual energy collected and total energy consumed by the city

$$T_{Edec} = \frac{\sum E_{rés}}{Ep_{conso.tot}} \ (\%)$$

4.3 Quantity of energy produced locally

Ratio between energy produced locally and energy consumed

$$T_{Epassiv.} = \frac{\sum E_{p\,loc}}{Ep_{conso.tot}} \ (\%)$$

5 Guideline: favoring local supply

5.1 Potential of renewable supply

$$P_{global.site} = \min\left(P_{resources}\right) \quad \text{(eq. inhabitant)}$$

Each site has a potential of renewable resources. Its stock and the rate of renewal can be evaluated. We take into account water resources, possibility of producing energy without pollution, ability to provide food and material, in a perimeter of 60km around the city. The global potential corresponds to the smallest resource capacity.

VIII. Nature in the city

1 Guideline: give access to nature to city dwellers

1.1 Maximum distance between a green space and every point of the city

<u>Objectives found in literature:</u>

- Access to a green space of more than 1000m2 at less than 200m (reachable by foot every day)
- Access to a green space of more 5000 m2 at less than 750m (reachable from time to time by foot)
- Access to a green space of more than an hectare and to a green corridor at less than 2 km (reachable by bike)
- Access to a green space of more than 10 hectares at less than 4 km (reachable by public transport)

2 Guideline: Let nature penetrate into the city.

2.1 Number of trees by hectare

Objectives found in literature:

- 200 trees by km of road for primary network (outside the urban blocks) with a double alignment.
- 400 trees minimum by km of road for the network inside the urban blocks with a double or more alignment.

2.2 Green coverage in altitude (% of total area)

$$CV = \frac{\text{green coverage area } (m^2)}{\text{total studied area } (m^2)} \ (\%)$$

Example: 30% for an area of 400 x 400 m2

3 Guideline: ensuring biodiversity

3.1 Quality and quantity of biodiversity

In the city and its influenced zone (60km around the city)
Quantity:

$$Quantité = \frac{[\sum number\ of\ species]_{now}}{[\sum number\ of\ species]_{in\ 1970}}$$

It can also be used with other date , the aim is to have a picture of the evolution: is there more or less species now than before. This indicator should be watched regularly.

Quality:

$$Qual_{moy} = moy_{espèces}\left(\frac{[N_{individuals}]_{present}}{[N_{individuals}]_{zero}}\right);$$

$$Qual_{\sigma} = \sigma_{species}\left(\frac{[N_{individuals}]_{present}}{[N_{individuals}]_{zero}}\right)$$

The standard deviation can also be calculated to identify if one species is proliferationg at the expense of others

Objectives found in literature:
Quantity must be one or > 2/3
Quality must be > 50% and the standard deviation must be >15%

IX. A resilient city

1 Guideline: minimizing energy consumption while maximizing social interactions

The sustainable city consumes less energy while enabling a development of human activities.

1.1 Efficiency of the urban system[2]

This indicator measures the quantity of primary energy necessary for the city to get a level of complexity, in the sense of circulation of information and maximization of interactions between people. The reduction of this ratio means a better efficiency in the use of resources to produce organized information.

$E_f = E/H$ (see indicator before)

E is the consumption of primary energy in the urban system.
H represents the complexity of the system, defined in I.1.

<u>Example</u> : A small result will normally represent an efficient system being complex while consuming few energy. But this reduction of this indicator must be obtained by increasing H and reducing E, and not by reducing both.

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