Morphometric Integrators of a Sustainable City

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ABSTRACT: Sustainable City is an energy efficient city, but not only. It cannot be limited to a wonderful machine to save energy or greenhouse gases. Sustainable development calls for taking into account physical, cultural and social changes, and urban development. To characterize the relationship between urban form, energy and climate, our work aims at creating morphological and environmental integrators of a sustainable city, structured into systems of indicators to aid the assessment or the decision of developers. To do so, we mix top-down approaches, basic research from various academic fields, physical sciences but also human sciences, and bottom-up approaches, analysis or evaluation urban projects, at various spatial scales, by focusing especially at the neighborhood scale. At this scale, we developed a system of morphometric indicators implemented in a GIS platform, baptized "Morphologic". But these integrators based solely on morphological properties of urban areas do not reflect the outdoor climate qualities felt by users. Therefore, either by using simultaneously outdoor climate surveys, "user's path surveys" and analysis of discourse, we are able to correlate urban morphologies and outdoor climate qualities.
Keywords: Sustainable urban design, design tools

BACKGROUND

The morphology of the historic European city is based on a triptych centrality - continuity - closeness today challenged by suburban developments. In this context, our research on the sustainable city showed that:

1) ecological footprint of cities [1] is closely linked to a number of urban indicators, among them, the relevant indicators are paradoxically not the density for which a high value means flows concentration in a limited area, and is quickly accompanied by a congestion phenomenon. We may correlate the spatial footprint with the concomitance of performing approaches both of territories and urban networks. These approaches are based on the performance of urban indicators such as compactness and contiguity of urban fabric, connection of the street network, density of intersections, number of paths, multicentrality or mixed urban functions [2],

2) characterization of the relationship between urban morphology, climate and energy is heavily dependent on the geographical scale of the observation (not the phenomenon) and varies between "micro-local" at the scale of a public space, "meso-scale" at the scale of a neighborhood and the "macro-scale" at the scale of a metropolitan area. These three scales are highly interacting [3],

3) Users' evaluation of climate conditions is tightly linked with references to cultural or social practices, more than by scientific determinism. In this sense, the appropriation of a private or public space, is mainly linked with subjective criteria such as comfort, feeling of quality, adequacy to representations or expectations [Daoudi, 2009].

PROBLEM

In this context, it is urgent to create morphological and environmental integrators of sustainable city, structured into systems of indicators to aid in the assessment or decision of the planners, and useful both for diagnosis or monitoring of the existing urban fabric, and for simulation of environmental impacts of future projects (or urban renewal projects) [4]. We distinguish the "decision", for which we will compare several projects or variants between them, based on a "relative" comparison [5], and "evaluation" for which we will compare the project to goals or user's value systems [6]. These integrators must simultaneously take into account the environmental performance of projects and their outdoor climate qualities. Therefore, this research aims at developing an analysis system of city morphology based on physical characteristics which we are linking with human experience in order to use it as a planning tool in the future.

DEVELOPMENTS

At the scale of a public space, the high morphological heterogeneity is such that, to analyze the energy footprint, or the thermal comfort of pedestrians, detailed models (Computer Fluid Dynamics such as FLUENT or COMSOL software, lattice gas, radiosity models, for example), or field analysis by in situ measurement surveys, are the only means possible for a relatively precise assessment of the relationship between morphology and environment [7; 2]. Thanks to these tools, it will be quite interesting to show, for example, the effects of urban roughness on the reduction of the mean square speed of the wind, including the identification of recirculation phenomena in the wake of buildings (Figure 1 above, and Figure 2)

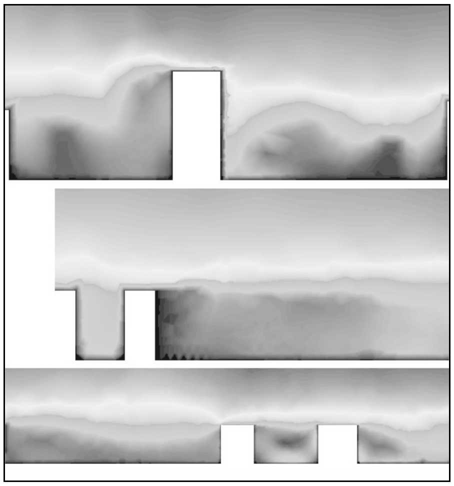

Figure 1: Air flow around building with CFD analysis

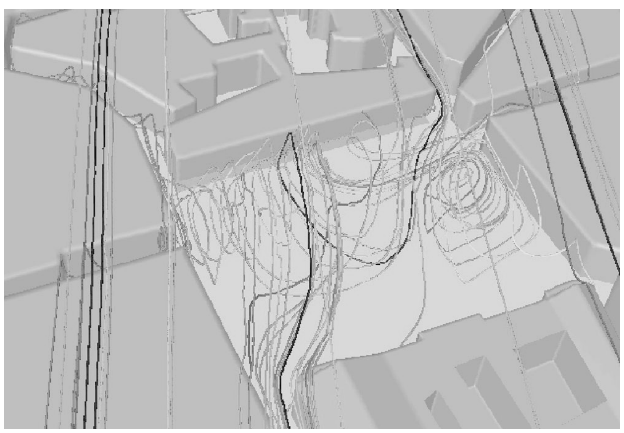

Figure 2: Air flow in the Place du Capitole, Toulouse

The CFD simulation also allows highlighting the effect of varying the aspect ratio (ratio height of buildings on street width) on the interrelation between the airflow patterns in the boundary layer and urban canopy [2]. (see Figure 2-below).

Surveys are allowing in situ measurement of outdoor climate conditions in outdoor spaces with relatively transportable systems [8] and over a short period. Their main limitation is related to their portability, the inertia of the measurement (the measurement of radiant temperature takes a few minutes before stabilization of the device), the lack of representativity of the measuring points chosen, and the instantaneous nature of the measure, especially for turbulent phenomena such as wind (see Figure 3).

Figure3 : Outdoor climate in situ surveys

The great advantage of this technique is that it may be associated with a survey of users or residents, in particular in attempts to correlate (or not) their perception with the climate (see below).

At the scale of urban areas (several miles), the continuum of street directions, and the low variability of average height of urban asperities (buildings and vegetation), make difficult the assessment of macro-local climate change. It is often limited to an average roughness derived from power laws (Prandtl law), to characterize the slowing down of the wind on the urban canopy, or the average gap between urban and rural temperature to characterize the effect of urban heat island (UHI). A typical example of the difficulty to bring up relevant urban indicators at this scale is illustrated by the low albedo variations measured on different urban or rural areas [9].

Variations in reflectivity of the fabric there is relatively low if not negligible, while the differences in surface temperature and air can be very important.

Because of the heterogeneity between the extreme outdoor climate conditions throughout a public space, and relative uniformity throughout the metropolitan area, we decided to focus our work at an intermediate scale, few blocks (typically 100 yards by 100 yards), which also has the advantage, at least in Europe, to correspond to a neighborhood area, a space of sociability, space that could be explored by foot. At this scale, it is possible to liken the urban fabric to a rigid porous structure, and propose a simple spatial model based on a set of original morphological indicators of environmental performance:

roughness, porosity, sinuosity, occlusivity, compactness, contiguity, solar admittance, and mineralization [3] (See Figure 4).

that the energy consumptions of buildings and the elevation of temperature due to these heat losses are, for

$$R_\alpha = \frac{\sqrt{\sum_i (h_i - h_\alpha)^2 * l_i^2}}{\sum_i * l_i} \quad [m]$$

$$P_o = \frac{\sum_{open\ spaces} \pi * r_{hi}^2 * L_i}{\sum_{open\ spaces} V_i + \sum_{built} V_j} \quad [/]$$

$$S_\theta = \frac{\sum_{segm.\,rues} L_i * \cos^2(\theta_i)}{\sum_{segm.\,rues} L_i} \quad [/]$$

$$O_c = \frac{1}{N_{HorizCuts}} * \sum_{N_{HorizCuts}} \frac{P_{built}}{P_{unbuilt}} \quad [/]$$

$$C_f = \sum_{buildings} \frac{A_{ext}}{V^{2/3}} \quad [/]$$

$$C_t = \frac{\sum_{buildings} \frac{A_{adj} * A_{floor}}{A_{vert}}}{\sum_{buildings} A_{floor}} \quad [/]$$

$$A_s = \frac{\sum_{ExtWalls} A_i * C_{contigiity} * C_{orientation} * C_{shading} *}{\sum_{ExtWalls} A_i}$$

$$M = \frac{A_T - \sum_i A_u}{A_T} \quad [/]$$

Figure 4 A set of indicators simplified morphological characteristics of the energy performance and urban climate.

The assumption of urban canopy being a rigid porous structure makes possible the differentiation of climatic conditions over the roofs and in the canopy, and to consider that over the rooftops, weather conditions are dependent on the general climatic conditions (regional) and local conditions related to the topography of the site (the variable height of the mineral and plant canopy) [10]. It leads to a slower speed quadratic air compared to a rural site undisturbed, which may be assessed by a first indicator, the roughness. Our basic assumption brings also the ability to distinguish among the open spaces, the open ended items. The urban fabric is built up with "open" spaces, streets or boulevards, similar to pores of the environment and "closed" spaces (or partially closed) that are the inner courtyards, gardens at the bottom of plot : the urban cavities. The pressure gradient in the open spaces can be easily approached by a front surface of the street, and the inclination of the road compared to lines of flux. In closed spaces, we consider that the air is heavier than in open spaces, and the propensity to remain stagnant is such as to neglect their effect on the general pressure gradient. These two aspects are embodied in our model by two indicators that are the porosity and sinuosity.

Turning now to another climate solicitation, namely air temperature, we are not taking into account the effect of human activities such as transport or industrial processes, and our approach is only limited to buildings, vegetation, and water. For the former, our assumption is a given technology, proportional to the outside area of buildings (the surface of non-contiguous to neighboring buildings wall). Therefore we define two parameters: compactness and contiguity of the built environment.

Turning finally to the sunlight solicitation, both in terms of incident heat absorbed and reflected, and natural light available, we make the assumption that a critical parameter of a given urban fabric is the sky view factor. Difficult to calculate precisely, this angle may be, however, approached by a simple parameter based on the distribution of perimeters of buildings according to altitude: the occlusivity.

To assess the ability of the urban fabric to capture solar radiation, the traditional modeling tools can enable us to evaluate precisely for each building, the solar input integrating masks, multiple reflections in the streets, the albedo of each surface and then we can compile these values for the whole fabric considered. But the accuracy of this approach is inconsistent with the available urban data. Therefore, we evaluate this energy balance with a simplified indicator, the solar admittance, calculated empirically from the orientation of the facades, their rate of contiguity, a coefficient of reduction due to the so-called "distant masks ", and the average albedo of the urban fabric. The two last parameters can be empirically evaluated from the density of buildings.

Finally, vegetation and water surfaces plays a role in urban areas heavily mineralized, both in terms of moderation in the solar storage in the walls (horizontal and vertical), alteration of hygrothermic exchange(effects of evaporation), and modification of the ground sealing with complex impacts on the humidity, heat island, as on the dilution of pollutants. To simplify the characterization of this parameter, our hypothesis is that one can evaluate the mineralization of a fabric from the working surface of water, or areas planted trees.

This set of indicators has been implemented in a software platform based on GIS, Morphologic, and applied to the analysis of various urban fabrics [3].

But these integrators based solely on morphological properties of urban areas do not reflect the space qualities felt by users. Therefore, either by simultaneous "path surveys" and climate surveys, or through analysis of discourse, we tried to correlate morphology and urban environments [2; 7, 11]. We have thus been demonstrating on various sites in Toulouse, Marseilles and Algiers, strong correlations between aspect ratio and stress, leading users to speed up or never stop in "canyon" streets. These places, especially at night and poorly lit, are often distressing places. In contrast, there was no correlation between thermal comfort and experienced users of certain emblematic heritage areas: in Toulouse, for example, the Place du Capitole, totally mineralized and very uncomfortable, during summer, is an important spot for socialization, as it represents the urbanity of the city [2]. In colonial patio buildings under Mediterranean climates, it was shown that inhabitants are preferring closing their windows because of the noise coming from the patio, rather than maintaining comfort in their homes with an adapted natural cross-ventilation [11].

Finally, it seems fundamental to propose systems of morpho-climatic-energy indicators hierarchical structured, built as an aid for both the evaluation of actual urban projects, by comparing these values to a system of generic values [12], common to several urban designers, and decision support by comparing various project together [5, 13]. These tools include mechanisms for multi decision support (weighting, taking account of the indifference or incomparability ...) [4,6].

CONCLUSION

A sustainable city is an energy efficient city, but not only. Indeed, energy performance is the result of a simultaneous work on the quality of open and built spaces, and the quality of urban networks, including the street network. The quality of a built space refers to the morphological and technical performance of buildings and their interrelationships through open spaces, at various geographical scales, from micro to macro-local. The quality of urban networks, including the street network in terms of regularity, orientation, sinuosity, etc.., is also involved in reducing the ecological footprint of the city.

But the sustainable city cannot limit itself to a formidable machine to save energy or greenhouse effect gases. Sustainable development also calls for an integration of the cultural or social dimensions of development. There is no point in building highly efficient cities, if they are not appropriate by their users, or if the spaces created do not meet their expectations or the representations associated with such places.
Therefore, we think that it is necessary, in this complex field of research, to mix bottom-up down and top-down approaches.

Indeed, we developed basic top-down researches from various academic fields, engineering, and human sciences, or science of the universe (eg, Climatology, Urban Planning, Architecture, Physiology, Sociology, Psychology, Geography ...) to address the complex link between urban morphology and environmental quality. Given the complexity of the subject and the approach used, we try to develop simplified models compatible with the level of information available during the design process.

We mixed these top-down approaches with bottom-up multidisciplinary approaches, based on analysis or evaluation of existing or ongoing projects, at different spatial scales.

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