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Introduction

Aspects concerning the well-being of people in both outdoor and indoor spaces are relevant in trying to enhance the environmental quality of urban spaces. In fact, the delicate relationship existing between the assessment of the urban fabric and the design of open spaces defines the urban environmental quality and assesses the success of a city. This careful balance inside the urban form is surprisingly tangible in numerous historical city centres, and was generated through a long process of transformations over time. Today, cities evolve rapidly and the slow process of adaptation of urban shape to meet human needs and sustain ecological diversity is no longer feasible.

Why was the technique created?

The proposed set of tools is presented as an alternative way to manage the complex set of environmental variables in the frame of rapid urban change. It allows us to investigate simultaneously different environmental aspects, such as solar access, cross-ventilation, energy consumption, etc., in relation to the arrangement of the urban fabric. Algorithms defined in the Matlab environment and derived from image-processing can work with very simple raster images of the urban texture stored in bitmap format. Potential users might simply use the proposed set of tools, or implement new algorithms to meet their needs and compare different design solutions from the environmental and morphological viewpoints. In fact, using this set of tools, a new paradigm for assessing the environmental consequences generated by the urban texture is investigated. This is centred on the relationship existing between environmental indicators and urban morphology: the question is if – and in what measure – the correct arrangement and the shape of the urban fabric alone might improve the environmental behaviour of the city. With the aim of creating effective environmental quality starting just from morphology, several design tools can be developed, assessing new potentialities related to the form of human settlements. For instance, the energy-based morphogenesis of the built environment could be intended as the first step towards the improvement of the sustainability of cities with no additional cost due to the application of complex technologies.

The technique revealed itself to be useful for simulations on alternative design schemes over large-scale masterplans and for extensive and complex urban areas, helping to make decisions supported by measured quantification. In particular, the technique demonstrates the potential of digital urban models based on raster images for the analysis of the city, which brings with it many advantages such as fast computability, flexibility, precision and comparability of results obtained from several algorithms.

The tools were initially created to compare the environmental behaviour of different urban configurations. In fact, the technique might be desirable in comparative studies, whereby environmental indicators can be mapped and visualized for different design projects, and consequently critical situations can easily emerge. Especially in a case of limited resources, the identification and quantification of environmental deficiencies on the urban texture could help in programming intervention phases more efficiently. In fact, the rapid measurability of several environmental indicators on each point of the urban space is simply based on the same digital support as the unique input, which is analysed and processed through a series of imposed algorithms.

We focus on the city and its development scenarios for the future. Further work and applications of the proposed technique might promote a new concept of urban environmental architecture, based on new design strategies and generative rules for the prediction of innovative morpho-typological solutions derived by environmental indicators.

For whom was the tool created?

An optimal site or design solution is almost unachievable. Often, requirements for different environmental issues are in opposition. For instance, the exigencies of indoor spaces and outdoor spaces differ, since good exposure to the sun can reduce energy consumption inside buildings, but at the same time this action can limit the environmental quality of the resulting shaded open spaces, which suffer from the reduction of the sky-view factor. Also, a higher level of compactness reduces heat losses, but also reduces gratuitous gains from solar irradiation and does not encourage natural ventilation.

In spite of the impossibility of achieving the optimal urban design scheme from the environmental viewpoint, urban designers should not give up looking for best practice in relation to the aim of sustainability. The intention is to propose a technique which enables the analysis of the many aspects involved in the assessment of urban environmental quality, in the belief that only a wide spectrum of environmental indicators can support conscious design choices.

The technique described here was created in an effort to provide quick but reliable tools for academic and research purposes in the field of environmental design, with the aim of making them accessible to both public administrators and practitioners. On the one hand, decision-makers and public administrators could use them in evaluating the impact of different design solutions on the urban fabric and finding more sustainable design alternatives; on the other hand, urban designers could make use of the proposed tools at the initial design process, in order to take advantage of local environmental opportunities. At the least, the proposed analyses, based on the comparison of alternative design solutions from the viewpoint of urban environmental quality in the heuristic phase, could mean a significant improvement in terms of energy efficiency and environmental comfort.

Urban design students could also benefit from the diffusion of the low-cost library of functions, which might integrate traditional approaches to urban planning with a higher consciousness in the field of urban environmental sustainability. In fact, an open-source initiative could diffuse, ameliorate and increase the now available set of tools, making the technique become more sophisticated.

How does it work?

The methodology is based on the use of very simple raster models of cities, called digital elevation models (DEMs). DEMs reproduce the geometry of the urban fabric and are produced by regularly spaced matrices of elevation values, which contain 3D information on 2D digital support, stored in bitmap format. Implementing software algorithms derived from image-processing, it is possible to develop efficient strategic tools for analysing and planning the sustainable urban form, measuring geometric parameters and assessing radiation exchange, energy consumption, wind porosity, visibility, spatial analyses, etc. Results are extremely fast and accurate. However, their application to architecture and urban studies has not yet been fully explored. The first application of DEMs in architecture originated at the Martin Centre, University of Cambridge (P. Richens, C. Ratti and K. Steemers), and explored the potentialities of this low-cost and powerful technique.

Today, through the increased availability of DEMs from LIDAR(laser imaging detection and ranging, i.e. a technology that determines distance to an object using laser pulses), the proposed technique could open the way to new low-cost raster-based urban models for planning and design.

In the absence of satellite imagery, the DEM can be derived from the digital 3D model produced with CAD and rendered with software such as 3D Studio Max that enables a view from the top and from infinite distance to be generated and at the same time differentiates the elevations of buildings on a grey-scale map. Once the plan with the heights of the objects is created in a bitmap format, the latter can be easily processed by the proposed algorithms that read the image as a square matrix. Environmental indicators are the subject of the algorithms defined in the Matlab environment.

An application of the technique

The tools reveal themselves to be a feasible way to assess the environmental quality of urban spaces. Under the broad definition of environmental quality, aspects related to both energy efficiency and human comfort are taken into account: on the one hand, the aim is to quantify the potential energy efficiency derived from the capacity of the urban fabric to take advantage of passive gains at the city scale; on the other hand, aspects of perceived comfort in urban open spaces are investigated, among others or through visual preference analyses, through the definition of thermal conditions.

Environmental parameters include solar access (solar paths, mean shadow density, solar gain through solar envelopes, sky-view factors), energy consumption (surface-to-volume ratio and passive/non-passive zones), cross-ventilation, wind porosity, urban canyon height-to-width, pedestrian accessibility and visual perception of open spaces through isovist fields.

For instance, algorithms explore rules based on natural rhythms that define the morphogenesis of buildable volumes in the city and encourage the solar access of the urban fabric (for temperate climates) through an energy-based reinterpretation of the 'solar envelope' concept ('iso solar surfaces'), first introduced by R. L. Knowles (1974, 1981) (Plate 9).

Not just the sun, but other natural forces as well help in modelling the urban environment: the urban metabolism, in particular the thermal exchanges and the natural ventilation occurring over cities, generates macro- and micro-climates, influencing the perceived comfort and the environmental quality in general.

Moreover, algorithms based on the calculation of 'sky-view factors' over extensive urban portions enable the urban form to be linked with the generation of the urban heat island. In fact, the phenomenon of the urban heat island is related to those environmental indicators which profoundly depend on design choices, such as urban materials on horizontal and vertical surfaces, the vegetation density on open spaces and the shape coefficient of street canyons. Maps containing the identification of critical situations are produced, in order to define strategies of intervention in large urban areas.

Furthermore, the broader definition of environmental quality considers human well-being in open spaces, in particular the psycho-physiological aspects related to the perceived experience of the urban form. Useful tools for measuring pedestrian accessibility, visual perception and visibility of open and built spaces through isovist fields and the reinterpretation of Lynch's (1960) visual elements are presented. Isovists describe the field of vision of the observer located at a specific point in space, and represent for instance the base unit for the construction of the model. Starting from the analysis of the geometrical characteristics of these figures, and from the sequence along a visual path, it is possible to draw a conclusion on the visibility analysis of the built urban fabric (Plate 10).

References and further reading

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