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Environmental indicators for evaluating properties

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Abstract Property evaluation for tax purposes has traditionally relied on urban and building criteria, mostly resulting from concepts driven by the commercial attractiveness of the property under evaluation, its building and the site itself. Due to the world climate and ecological crisis, awareness has risen about the need for other indicators, which can evaluate the quality of a property, even referring to its potential environmental impact.

Technical standards for the evaluation of buildings' environmental sustainability, which have been developed since the first years of this century, both nationally and internationally, take into account the impact of the building and its relevance for the life-cycle of materials and elements, with reference to the three sectors of sustainability: environmental, economic and social. The social sector includes indicators referring to the user's health and comfort, which also interact with the morphological and spatial characteristics of the building.

However, there is a lack of methodological tools for the evaluation of said indicators and existing ones are mainly of a qualitative type. This paper suggests a methodological approach for the quantitative evaluation of sustainability indicators, relying on the accessibility of a site's climate resources by the property, as a criterion to evaluate the potential for the reduction of negative environmental impact, as well as a criterion to improve users' life quality.

INTRODUCTION: SUSTAINABILITY INDICATORS

Nowadays sustainability of buildings and civil engineering works can be evaluated according to a wide range of technical standards, developed by both ISO/TC59/SC17 and CEN/TC 350. These standards rely on an approach which consider environmental impacts over the whole life cycle (Life Cycle Assessment) of buildings/civil engineering works and includes the three performance sectors of sustainability: environmental, economic and social.

Different indicators were developed, which relate these sectors with several impact categories, as shown in Table 1, included in the standard of 29 September 2015 "ISO/DIS 21929-2: Draft of sustainability in buildings and civil engineering works – Sustainability indicators – Part 2: Framework for the development of indicators for civil engineering works".

The indicators mostly related to the field of property evaluation, with reference to the territory relevance, are those linked to the social sector, described in the standard "EN 16309: Sustainability of

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construction works — Assessment of social performance of buildings — Methods", which are listed in Table 2 and refer to the building use phase.

Amongst said indicators, some refer to morphological and location-related characteristics of the properties, such as: no. 8 Health and comfort – spatial characteristics; no. 11 Impacts on the neighborhood – glare, overshadowing; no. 18 Health and comfort – thermal comfort; no. 20 Health and comfort – visual comfort.

	ISSUES OF CONCERN								
ASPECTS AND IMPACTS	ENVIRONMENTAL			ECONOMIC		SOCIAL			
	Protection of Climate	Protection of natural resources	Protection of Ecosystems	Cost	Value	Health & Safety	Satisfaction	Population & Community	Cultural heritage
Use of energy resources		X							
Use of material resources		X							
Use of water		X							
Land use changes			X						
Emissions to local environment (soil, air and water)			X			X			
Noise and vibration						X			
Ecosystem processes and services			X						
Landscape changes							X		X
Global warming potential	X								
Ozone depletion potential			X						
Eutrophication potential			X						
Acidification potential			X						
Photochemical ozone creation potential			X						
External costs				X					
Life cycle costs				X					
Access to nature							X	X	
Population system								X	
Job creation					X		X		
Cultural heritage elements									X
Social inclusion and acceptability							X		
Risks and resilience				X		X		X	
Health and comfort						X	X		

Table1 Sustainability indicators in construction works according to ISO/DIS 21929-2

The above mentioned standard does not provide a specific method to analyze and verify these indicators, but describes general criteria and requirements, and suggests to referring to convenient methods and tools for their evaluation, which can be provided by public and private bodies in a national regulation framework, if existing.

This paper describes a method for the analysis and evaluation of properties, related to their morphological and spatial characteristics, which was developed by the environmental technology research group at DAD. The method relies on site-climate-building interactions and, despite being related to the above mentioned indicators, enables a wider evaluation which can also be used in a property assessment perspective.

Building life cycle stage: USE	
1.	Accessibility - Accessibility for people with additional needs
2.	Accessibility - Access to building services
3.	Adaptability - ease of potential for adapting to other use
4.	Health and comfort - Thermal characteristics
5.	Health and comfort - Characteristics of indoor air quality
6.	Health and comfort - Acoustic characteristics
7.	Health and comfort - Characteristics of visual comfort
8.	Health and comfort - Spatial characteristics
9.	Impacts on neighbourhood - Noise
10.	Impacts on neighbourhood - Emissions
11.	Impacts on neighbourhood - Glare/ overshadowing
12.	Impacts on neighbourhood - Shocks/vibrations
13.	Maintenance and Maintainability - Maintenance Operations
14.	Safety and security - Resistance to climate change
15.	Safety and security - Accidental actions (earthquake, explosions, fire and traffic impacts)
16.	Safety and security - Personal safety and security against intruders and vandalism
17.	Safety and security – security against interruptions of utility supply

Table 2 Sustainability indicators of buildings under use complying with standard EN 16309

METHODOLOGICAL APPROACH: MORPHOLOGICAL AND SPATIAL CHARACTERISTICS AFFECTING SUSTAINABILITY INDICATORS

The effects of shape, location and orientation of a building on the above mentioned indicators related to health and comfort, for both the building users and the inhabitants of the surrounding environment, are significant, also affecting relevant energy consumptions and, therefore, the environmental impact (polluting emissions, global warming from greenhouse gases, etc.). They are usually not considered by the current assessment and planning practice, which puts first the aspects related to construction and plant elements, together with economic and commercial ones.

Interactions between morphological and spatial factors, climate variables and sustainability – social and environmental – indicators are described in Table 3.

Morphological and locational factors		Climatic variables	Social and environmental sustainability factors	Mutual interaction between factors	Evaluation criteria
F	Plan shape (rectangular, squared, fragmented, curved, expanded, in line)	Sun exposure	Spatial characteristics Visual comfort	O	- Access to diffuse solar radiation in principal spatial units (average daylight factor)
			Spatial characteristics Thermal comfort		- winter access to direct solar radiation in principal spatial units - level of control of direct solar radiation in summer in principal spatial units
		Wind exposure	Spatial characteristics Indoor air quality	O	- yearly wind access in principal spatial units
			Spatial characteristics Thermal comfort		- summer wind access in principal spatial units
A	Height	Sun exposure	Impact on the environment	D	- winter solstice shadow depth on surrounding buildings and on vertical facades (negative effects on the building heating demand)
		Wind exposure	Impact on the environment	D	- wind wake core depth considering surrounding buildings in winter (positive effects on the building heating demand) and in summer (negative effects on the building cooling demand)
			Thermal comfort Indoor air quality	D, F	- number of spatial units that overpass the average surrounding buildings' height (increase in the pressure difference between windward and leeward facades)
O	Orientation of the main facades with transparent surfaces and openings (N, NE, E, SE, S, SW, O, NW)	Sun exposure	Visual comfort	F	- average daylight factors in boundary spatial units and glaring control
			Thermal comfort		- winter exposure to solar radiation of transparent elements localized in the SE-S-SW quadrant - level of control of the incident solar radiation reaching transparent surfaces localized in the SW-W-NW quadrant
		Wind exposure	Indoor air quality	F	- opening exposure in relation to the prevalent wind direction (entire year)
			Thermal comfort		- opening exposure in relation to the prevalent wind direction in summer - opening protection from the prevalent wind direction in winter
D	Urban plan density (distance between buildings)	Sun exposure	Impact on the environment	A	- increasing in shading depth on the surrounding buildings both in vertical and horizontal in winter (negative effect on winter heating need and on outdoor comfort)
		Wind exposure	Impact on the environment	A	- increasing in the wind wake core depth on the surrounding buildings both in vertical and horizontal plans in winter (positive effect on the building heating demand) and in summer (negative effect on the cooling demand and on outdoor comfort)
R	Surface/Volume ratio	Air temperature	Thermal comfort	F, A, C	- thermal losses through the building envelope according to the climatic zone
C	Coverage type (flat roof, pitched roof, pitched inclinations)	Sun exposure	Renewable sources (solar panel)	O	- amount of direct solar radiation reaching solar thermal panels (winter optimization of the slope of the pitched roof)
			Renewable sources (PV panels)		- amount of direct solar radiation reaching PV panels (optimization of the slope of the pitched roof)
		Wind exposure	Impact on the environment	O, A, F	- increasing in the wind wake core depth according to roof types (positive winter effect and negative summer ones)
			Thermal comfort		- increasing in the difference in the wind pressure between roof pitches and consequent effect on the wind-driven ventilation potential for inhabited attic

Table3 Interactions between morphological and spatial factors, climate variables and indicators of social and environmental sustainability

For contemporary building and civil engineering work assets, these interactions imply the adoption of a new diachronic approach to the analysis of environmental impacts, which is able to implement temporal dynamics and the circularity of processes connected to the buildings. This approach is necessary, due to the fact that current constructions – contrary to the "traditional" ones – have a finite useful life. It is based on life cycle assessment (LCA – ISO 14040-1 & 2) whose life stages are (CEN EN 15643 – Sustainability of construction works – Sustainability assessment of building) the following: production, building, use, maintenance-repair-replacement-refurbishment, end of life). The diachronic approach is founded on the analysis of impacts and energy-environmental flows, which affect buildings over their functional life cycle. Also in addition, during the phases of pre-production and post-end of life, scenario hypotheses could be drawn for the impacts of building's materials and elements. However, the analysis of said impacts shall also include factors concerning the synchronic assessment/planning approach, such as energy, comfort, waste, accessibility and transportation, materials and their *in situ* applications, on different scales. This double approach is not easily applicable in a general way, in the national property evaluation context. However, in the future, thanks to the adoption of specific standards and digital procedures which are able to implement knowledge structures in the geometrical model, a synergic interaction can be expected between the different indicators connected to the project and its evaluation.

ANALYSIS OF THE ENVIRONMENTAL QUALITY OF A BUILDING: THE "MICROCLIMATE MATRIX" TOOL

Due to its nature, the site of a building is an essential parameter, affecting several environmental aspects related to the construction work. For instance, with reference to microclimate, the existence of direct solar radiation (non-screened) affects thermal exchanges, user comfort (indoor and outdoor), the presence of glare, as well as the possible discoloration and useful life of materials. Moreover, the protection or direct exposure to prevailing winds affects outdoor thermal comfort (in summer and winter), thermal losses, natural ventilation, smoke, dust and volatile pollutant dispersion, and has effects on building structural design. The combination of said effects, which can be synergic or conflicting depending on the user needs and the seasonality of operations occurring in the building under examination, implies the potential of the building in relation to the site, with reference to the purposes of comfort and reduction of negative environmental impacts. Hereinafter this potential will be called "Site environmental quality" (SEQ) of the building.

The two main elements for the SEQ evaluation –solar radiation and air flows– can be analyzed and interpreted through the "site microclimate matrix" tool (Chiesa & Grosso, 2015). This tool, originally developed by Brown e Dekay (2001), was adapted for the SEQ evaluation, which shall be performed during the building programming phase (Grosso *et al.*, 2015; Grosso 2011), as shown below.

In order to build a site microclimate matrix, the results of two analyses shall be overlapped: of shadowing dynamics and of wind wakes. According to the building functions, or the activities to be carried out on the site, different overlapping conditions will result in a positive or negative judgment, in terms of SEQ.

The matrix tool refers to an analysis carried out in a specific temporal condition and therefore more matrixes shall be developed, relating to the most representative days and hours in the year, in order to achieve a synthetic framework on an annual or seasonal basis. For this reason, if the analysis period is the whole year, a minimum of four matrixes shall be considered referred to the shadowing conditions of the site in the two solstices (21 December and 21 June), in the morning (10 a.m. in winter and 8 a.m. in summer) and in the afternoon (2 p.m. in winter and 4 p.m. in summer), as well as the wind wakes resulting from prevailing wind in both winter and summer.

The microclimate matrix is developed through the following phases:

1. trace a regular grid (*e.g.*, with a 5x5 m mesh) on the analysis plane – generally at the ground level but possibly at any virtual horizontal plane corresponding to a building floor ;
2. draw shadow surfaces, projected on the analysis plane by obstructions surrounding the building under exam, in the four periods mentioned above;
3. draw the wind wake cores generated by obstructions on their leeward side along the prevailing wind in summer and winter;
4. overlap graphically the results of the three previous phases and classify all meshes according to the prevailing conditions in terms of occupied area (shadow-calm; sun-calm; shadow-wind; sun-wind);
5. assign a numerical score to the different classes, according to the different environmental indicators (shape-location of the building, outdoor comfort) and seasons;
6. build a seasonal or annual assessment framework, resulting from the algebraic sum of the partial scores, and from a SEQ value assigned to the building.

The drawing of the shadowing dynamics, for the most significant days and hours in the year, can be performed manually, *e.g.*, by using a descriptive geometry method adjusted to the microclimate purpose (Grosso, 1983 and 2011), or by using specific software. Many computer programs allow to drawing shadows depending on latitude, day and hour of the year.

As for the calculation of wind wakes, three methods can be applied: the use of CFD software (Computational Fluid Dynamics) –an expensive solution suitable to experts of this field; the use of a simplified method (Grosso, 2011), resulting from the reinterpretation of Boutet's results from wind tunnel tests (1987), described in a recent paper (Chiesa & Grosso, 2015); the intuitive drawing of wind effects around a solid obstacle through airflow lines empirical tracing (Brown & Dekay, 2001). For the sake of simplicity, in developing the microclimate matrix, the drawing of wind wakes around solid obstacles occurs only in downwind areas (downstream from the obstacle), with a discretized resolution depending on two alternative conditions: in wake core (calm) or in the presence of wind. The term "wake core" identifies an area in which the wind speed is reduced by 50% at least, due to the presence of obstacles, compared with the speed of an undisturbed flow.

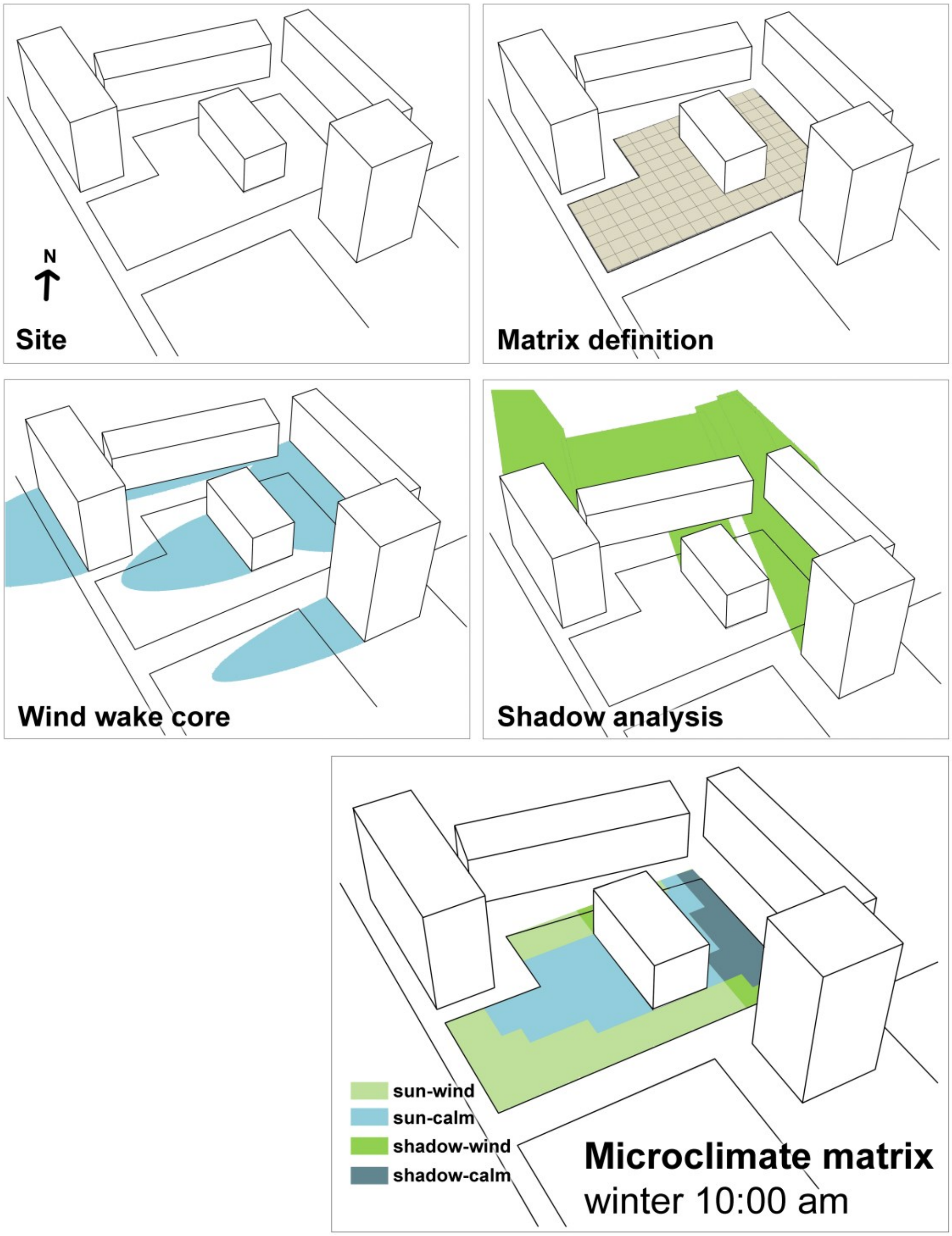

Figure 1 3D model of a site microclimate matrix, on the ground plane, referring to a lot located at 45' North latitude, with prevailing wind coming from the North-East

The overlap of wind conditions (calm or wind) and solar radiation (shadow or sun) creates a classification of the meshes, identified as cells of a 2x2 input matrix. The process is shown in Figure 1. For the purpose of SEQ, this classification is matched to a score system, subdivided in two main aspects, both related to thermal comfort conditions: a) optimization of the location of outdoor activities (Table 4, Grosso, 2008); b) optimization of the location of the building, according to an hypothesis by Brown and Dekay (2001) (Table 5).
The scores assigned to each cell, for each reference temporal conditions –i.e. for the four proposed matrixes– and for each analysis plane, can be seasonally or yearly summed, in order to get a synthesis SEQ indicator.

Activity		Season	Microclimate matrix and comfort conditions			
Metabolic rate	Possible activity		shadow-lee	sun-lee	shadow-wind	sun-wind
low	Stay or walk	Winter	2	5	1	4
		Summer	5	1	4	2
medium	Walk faster	Winter	2	4	1	5
		Summer	4	1	5	2
high	Run	Winter	1	4	2	5
		Summer	4	1	5	2

Table 4 Evaluation of the condition of thermal comfort according to activities and season –outdoor case. The different values shall be assigned to the classification applied for the site microclimate matrix. (Re-elaborated from: Grosso, 2008).

Climate	Season	Microclimate matrix and comfort conditions			
		shadow-lee	sun-lee	shadow-wind	sun-wind
Cold	Winter	2	5	1	4
	Summer	2	4	1	5
Temperate	Winter	2	5	1	4
	Summer	2	1	5	4
Hot and humid	Winter	2	1	5	4
	Summer	2	1	5	4
Hot and dry	Winter	4	2	2	1
	Summer	4	2	2	1

Table 5 Evaluation of the condition of thermal comfort referring to the building (re-elaborated from: Brown & Dekay, 2001).

The above mentioned procedure refers to the site-building microclimate interactions at a two-dimensional level, for horizontal sections corresponding to the floors of the examined building.
However, in order to determine a complete SEQ evaluation of the building, a 3D elaboration of the matrix method described above is necessary. This operation is carried out on buildings' façades, by elaborating a vertical microclimate matrix using the procedure described above. In this case, the shadows are projected from obstacles on the exposed façades of the examined building. Even in this case, shadows can be manually traced, e.g. through a graphic geometrical method base on reversal projection (Grosso, 1983, 2011) or by using calculators.

Analogously, wind wake cores on vertical building façades placed downwind of an obstacle along the prevailing wind direction can be determined using a simplified graphic tracing method resulted from a two-dimensional CFD simulation on a vertical plane as shown in Figure 2. The "calm" area develops in a prism shape, which gradually shrinks as the distance from the building increases.

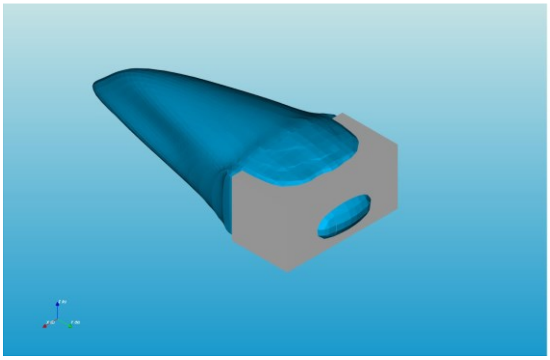

Figure 2a) Isosurface marking the wake core downwind an exemplifying solid hit by perpendicular wind (Karalit-CFD calculation software)

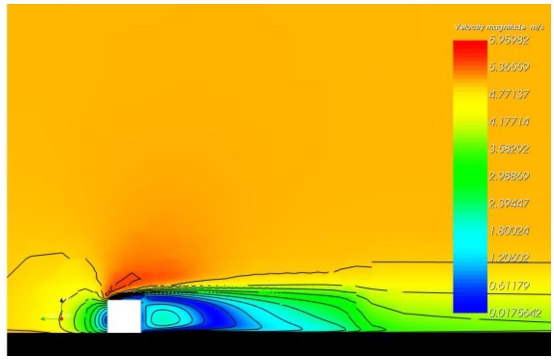

Figure 2b) vertical section of the wake induced by an obstacle along a perpendicular wind direction with undisturbed speed of 5 m/s (Karalit – CFD calculation software)

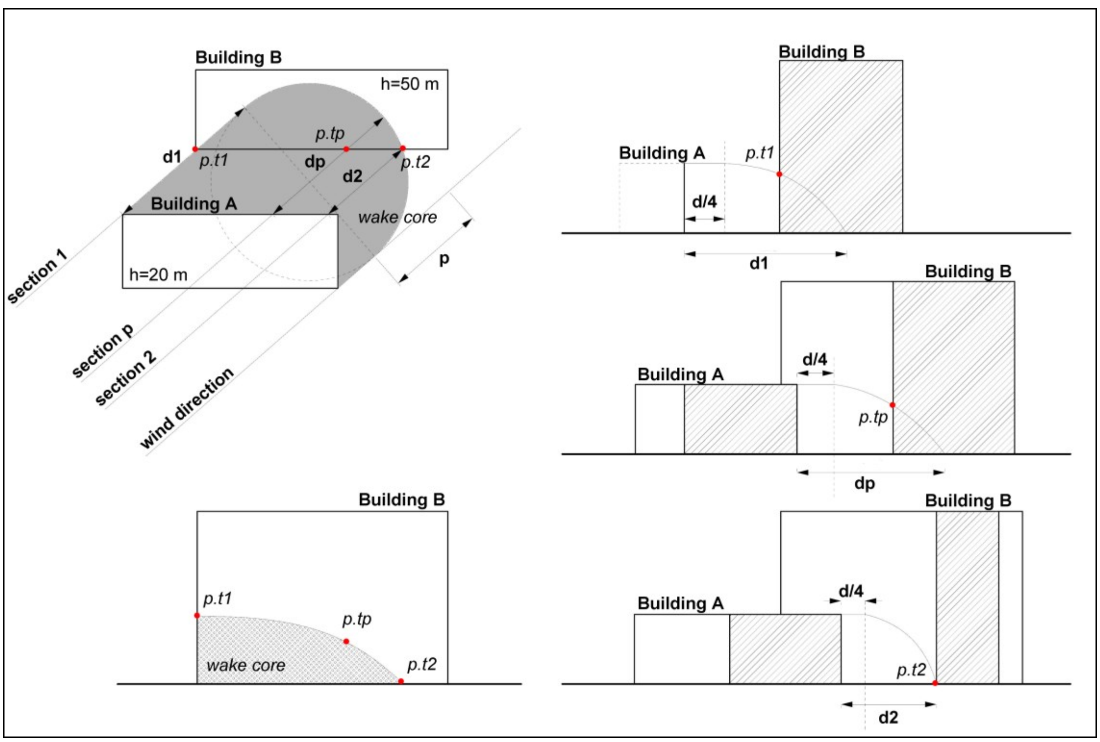

Figure 3 Graphical method for tracing the wind wake core determined by a solid obstacle on the vertical surface of a downwind parallelepiped solid

The graphic simplified procedure, shown in Figure 3, can be synthetised as follows:

- definition of the wind wake core on the horizontal plane;
- drawing of the sectioned shape of the wind wake on representative vertical planes;
- identification of the intersection points on the vertical section planes, between the examined façade and the wind wake core;
- drawing of the wind calm area on the examined façade.

Besides the elaboration of the microclimate matrix on specific vertical surfaces, such as building façades, a three-dimensional application of the tool to the whole examined lot can be envisaged. In this case, a virtual volume shall be built which, based on the two-dimensional matrix meshes calculated on the ground plane, consists of cubes, or prisms, of different heights, overlapped and placed side by side (Figure 4). Each cube will be classified according to the prevailing situation, similarly to what occurred in the case of the microclimate matrix on the horizontal plane. Necessary information for the characterization of 3-D cells, according to the 2x2 matrix (sun-wind), results from the elaboration of several matrixes placed on horizontal planes which are vertically shifted on intervals corresponding to the cell side which, if possible, equals to the average floor height of the examined building. This elaboration shall be verified by comparing it to the elaboration of the matrix on the façades, as it was described above. For a more in-depth analysis a simulation can be performed, by using CFD software.
Shadows and wind wakes identified on these planes depend on the virtual height of the buildings, which equals to the distance between their eave line (or ridge line, according to the type) and the specific calculation plane (Figure 5). The three-dimensional analysis enables the creation of a volumetric matrix which can be used to evaluate the SEQ of the whole building or some of its parts.

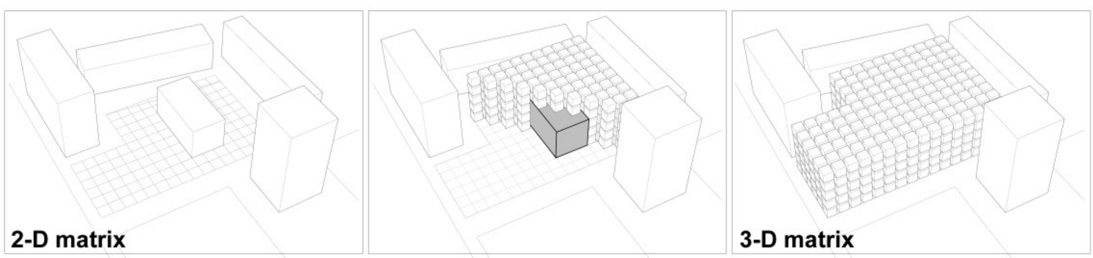

Figure4 Model of the three-dimensional microclimate matrix of a site

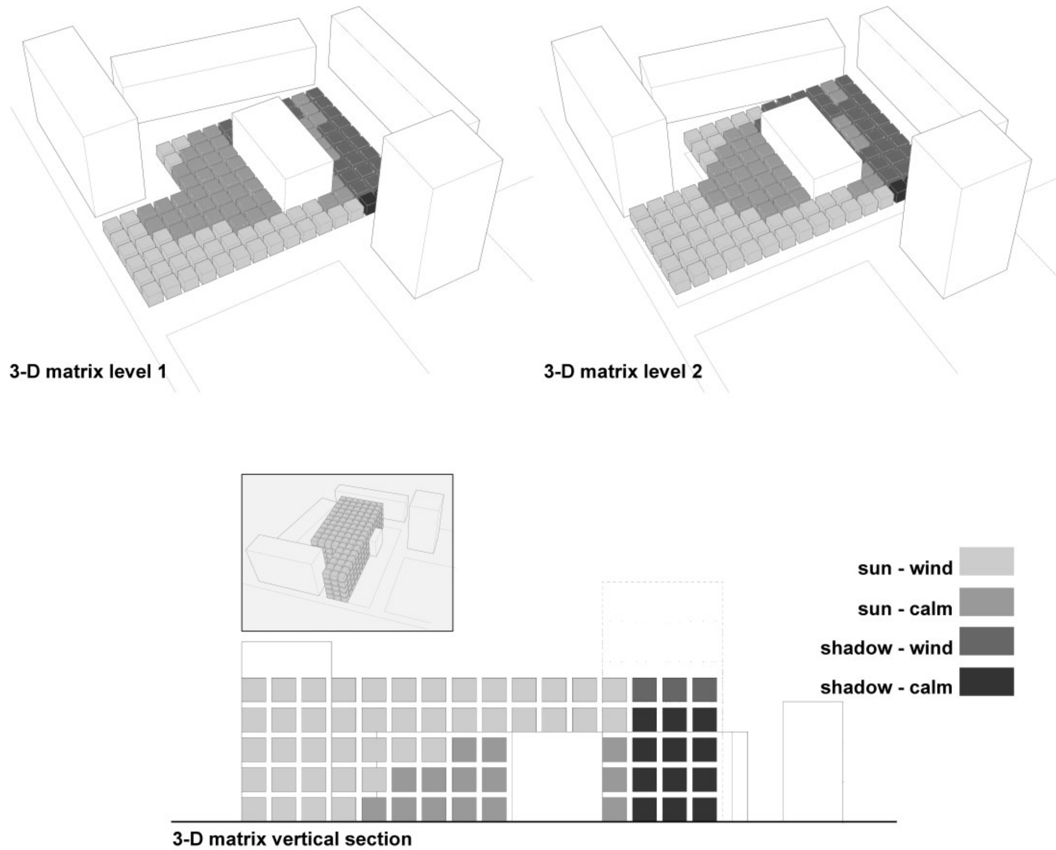

Figure 5 Planimetric representation of a 3-D microclimate matrix corresponding to the ground floor of a building (above) and the matrix's vertical section along the wind direction (below) – example carried out under the same surrounding conditions as in Figure 2.

CONCLUSIONS

The site microclimate matrix, in both its two-dimensional and 3-D applications, is one of the tools used to evaluate the environmental impact of the built environment on a specific building, with reference to two climate factors, such as sunlight and wind and their interactions with the shape, the orientation and the location of the building. The method suggested leads to the evaluation of the SEQ (Site Environmental Quality) for the whole building, or parts of it (e.g. apartments), according to classes of values, related to local climate conditions, destinations and time of use. This is one of the indicators, which can be found in the field of property estimation, together with other urban and economic indicators. The importance of the SEQ indicator, compared with others, as well as its elaboration in a combination, classification and statistical-probabilistic analysis process, represent a stimulating perspective for research which, once developed, might enrich the sectors of environmental, estimating and property evaluation.

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