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RICERCA

An integrated methodology for the simulation of buildings and open spaces interaction to define climate adaptive strategies: the case study of the Duchesca district in Naples, Italy

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Abstract

The research is motivated by the current shortage of theoretical methods and technological tools to investigate the relationship between the indoor and outdoor microclimates and to anticipate climate changes and their impact on urban environments.
It has been defined a methodology that, making use of appropriate IT tools (ENVI-met, Ecotect Analisys, Grasshopper 3D), and exploiting the interoperability of their outputs, reveals the quantitative and qualitative impact of outdoor environmental conditions on indoor comfort. This goal is achieved by collecting the outputs of different simulations and environmental analyses into a single parametric virtual environment.
The methodological process supports the definition of the urban regeneration project of the Duchesca district in Naples, Italy, showing how climate-adaptive design solutions for outer urban spaces to reduce thermal comfort (PMV) respectively by 61.5% in 2015 and 57.2% in 2050s, to ensure a simultaneous improvement of indoor comfort in the analysed building with a reduction of 80% in 2015 and 74% in 2050s.

Introduction

The effects of the current climatic changes, and the rise in the global average temperatures impacts urban environments, resulting in phenomena of microclimatic alterations (UHI, heatwaves, etc.) which ultimately lead to thermal discomfort and health problems for the users. The low adaptability (in terms of performances) of buildings and open spaces, together with the lack of maintenance and the antiquity of the technical solutions, is making highly urbanized environments critical places to live, especially during the summer season. The tendency of temperatures to increase (RCP 8.5 Scenario, AR5 - IPCC, 2014), in case the scheduled reduction in CO_2 emission (cf. COP21, 2015 United Nations Climate Change Conference. Paris) should not be realized, will have a noticeable impact on urban life, both in open space and in indoor environments.
In this historical period, when the economic reprise is still slow, and when performance retrofit interventions are therefore hard to implement, intervening on open spaces through *climate adaptive design* for outdoor requalification can turn out to be an effective strategy on improving urban comfort. The enhancement of the environmental conditions in the open space generates effects of microclimatic mitigation, which bring a notable improvement on buildings' performance (namely, on indoor comfort). As the effects of Climate Change are becoming a central issue in the world politics and the cities management, it is necessary to take them in account into the design process. Moreover, these phenomena have effects both on the outdoor and indoor environments, bringing the designers to the necessity of considering them simultaneously. “Only recently, research communities and professional organisations have started to incorporate the factor of climate change in software-based environmental simulation with a view to inform adaptation planning and design” (Peng and Elwan, 2014). Though, we still assist to a shortage of theoretical methods and technological tools to investigate the relationship between the

indoor and outdoor microclimates and to anticipate climate changes and their impact on urban environments. While it is assured that an improvement of the outer thermos-hygrometric conditions ensures an improvement of the inner ones, few researches, aimed to establish not only the qualitative but the quantitative relation between outdoor and indoor environments, have been conducted (see Peng and Elwan, 2012 and 2014).

Forewords and objectives

The only significant case in the previously described filed is the research “An outdoor-indoor coupled simulation framework for Climate Change–conscious Urban Neighbourhood Design”, (Peng and Elwan, 2014), in which, “Utilizing two existing software systems, ENVI-met for urban neighbourhood outdoor simulation and Ecotect for building indoor simulation” it was demonstrated “how a workflow can be implemented to play out climate change scenarios on urban neighbourhoods and the buildings located within” (Peng, Elwan 2014).
On the other hand, the workflow described in “Parametric Environmental Climate Adaptive Design: The Role of Data Design to Control Urban Regeneration Project of Borgo Antignano, Naples” (Ambrosini, Bassolino, 2015), provides and approach that, using different software environments, enables the development of open space optimization solutions for the reduction of the urban Heat Island phenomena, while maintaining that fundamental characteristic of interoperability between data, thanks to the organization of the information in a parametric work environment.
Taking in account the results of these previous studies, the following research is aimed to define a methodology that, making use of appropriate information technology tools, and taking in account the interoperability of their outputs, ensures a simultaneous monitoring between different parametric software environments and the determination of the quantitative and qualitative impact that the outdoor environmental conditions produce on the indoor comfort.

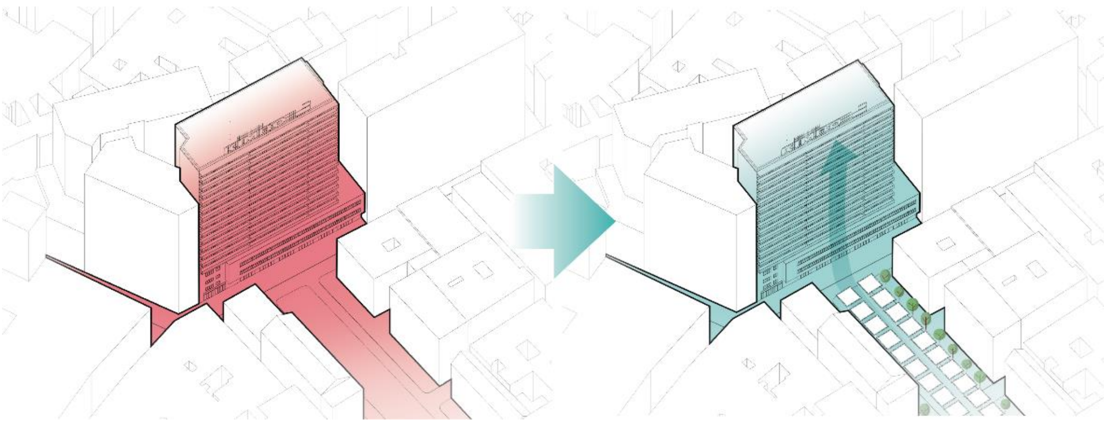

Figure 1. Interaction between outdoor and indoor environments.

Definition of the methodological workflow

The specificity of the software that simulate separately outdoor and indoor environments requires the simultaneously use of different tools, with the necessity of exporting and importing different files and then repeat the operation, until the definition of a final solution. In order to overcome the fragmentation of different outputs and files and to ensure the exchange between different software environments, it was decided to use the software environment Rhinoceros 3D and the graphical algorithm editor Grasshopper 3D for parametric modelling, which “provide a platform for data exchange between different software [...] and many Grasshopper’s plug-in” (Bassolino and Ambrosini, 2016).

On the other hand, the use of the software ENVI-met for the outdoor comfort simulations allows “to produce simulated urban micro-climate conditions specific to any locations” and “generate localized weather data specific to the building's immediate outdoor surroundings" (Peng and Elwan, 2014), despite the usual weather files generated by weather station, which are often based on environmental condition different from the ones of the urban assets.

In this way, it is possible to directly relate the outdoor environmental comfort data, produced by ENVI-met, to the indoor comfort analyses, generate in the environment Grasshopper 3D-EnergyPlus thanks to Grasshopper's plug-ins Ladybug and Honeybee. The possibility of working in a parametric virtual environment ensures the interoperability of the different outputs and to read the results of the analyses on the same model where the design is defined.

The application of the previous defined methodology to a regeneration project of the Duchesca district in Naples, Italy, shows the feasibility of the workflow as integration of the design process.

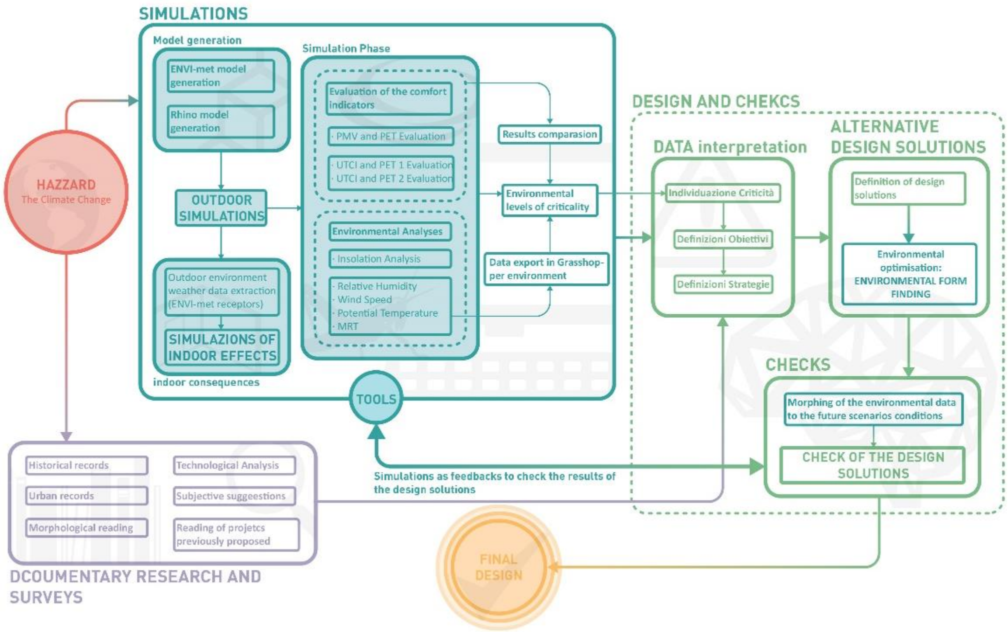

Figure 2. Synoptic flow chart - Definition of the methodological workflow applied.

The case study of the Duchesca district in Naples

Modelling the study area

The case study of this research process is the Duchesca district of Naples, an area of the city of Naples the historic centre and the western periphery. Here, the lack of green infrastructure and the dense overbuilding contributed to alter the local microclimate and rise the temperatures. The first step was to create a 3D model of the area, by using the official cartography of the municipality of Naples and surveys *in situ*. The model, which was generated in the Rhinoceros 3D, was used as base for any prior environmental analyses, to simultaneously read the results of outdoor and indoor analyses and to define all the design proposals.

Outdoor microclimate analyses and generation of the local weather file

The second step consisted in the outdoor microclimate simulation of the analysed area, using the holistic simulation software ENVI-met. Once modelled the area in the ENVI-met interface, it has been set up the configuration file for 2015 with: 1) wind speed = 2 m/s; 2) wind direction = 247°; 3) air temperature = 300 K (26.85 °C); 4) relative humidity at 2 m = 47.15%; 5) specific humidity at 2500 m = 2.8731 g/kg; and, not modifying the data for wind speed and direction, for 2050s with: 1) air temperature = 302.4 K (29.25 °C); 2) relative humidity at 2m = 47.15%; 3) specific humidity at 2500m = 3.3272 g/kg, that are mean values of the 24 hours before the starting time of simulation at 6 am. To determinate the thermal comfort of a generic person, it was considered an adult man, (whose characteristics are: 35 years old, 175 cm high, 75 kg), who is walking at a speed of 0.83 m/s and has an activity of energy exchange of 116 W/m² with the environment and a corresponding clothing factor of 0.5. After that, it was possible to start the simulation, obtaining a large volume of outputs which described the locale microclimate. In particular, the Predicted Mean Vote - PMV (Fangers 1972, UNI-EN-ISO 7730: 1994) and the Mean Radiant Temperature - MRT (UNI-EN-ISO 7726: 1998) indexes showed a critical situation and high summer heat stress with simulated mean values of PMV respectively of 5,87 in 2015 and 6,40 in 2050s and MRT values of 87,9 °C for 2015 and of 88,1 °C for 2050s. By defining an algorithm in Grasshopper, the results of the simulation were import in the Rhinoceros' three-dimensional model, allowing to read the data directly on the surfaces of the model and to generate the data for the Physiologically Equivalent Temperature - PET (Mayer, Höppe 1987; Höppe 1999; Matzarakis et al.1999), and specifically obtaining mean values of PET respectively of 43,37 °C in 2015 and 43.90 °C in 2050s.

By placing some "atmospheric receptors" around a specific building, a tabular system, which describes the urban microclimate condition of the specific area, was generated. This data were then converted into a weather file in format .epw by the use of Ecotect's weather tool and EnergyPlus' EP Launch.

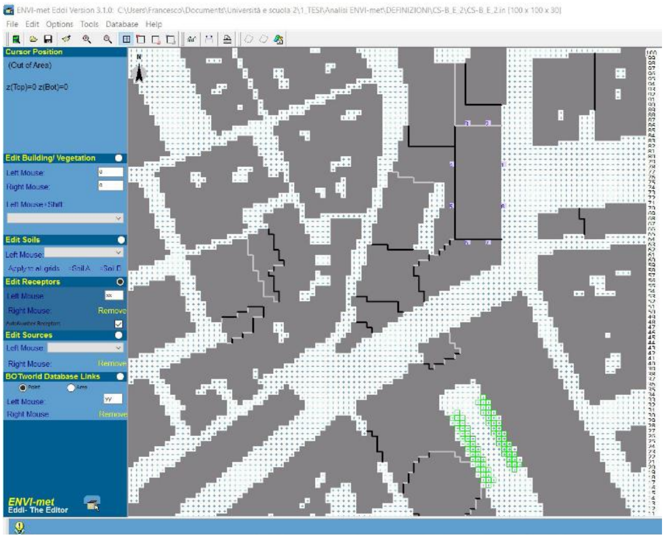

Figure 3. ENVI-met Analyses interface. Set-up of ENVI-met receptors.

Indoor microclimate analyses

The case study chosen for the indoor analyses is the known as "Palazzo Kimbo", a concrete building of the fifty years surrounded by the analysed context. Basing on the results of some surveys, an apartment type of the chosen building was drawn and modelled in the Rhinoceros environment. The software used for the simulation is EnergyPlus, thanks to Grasshopper's plug-ins Ladybug and Honeybee, which generate a bridge between the different software environment. Once defined EnergyPlus based construction's properties, the energetic model of the indoor environment has been simulated. Instead of defining the single materials of the building's constructions, thanks to some technological surveys, it was possible to just define the single U-values of the technological parts of the building: 1) U = 1,98 W/m²·K for the ceiling construction; 2) U = 1,54 W/m²·K for the walls construction; 3) U = 4,08 W/m²·K for the windows. The weather file used for these simulation is the one generated through ENVI-met data.

The reading of the PMV, MRT and PET indexes once again reveals a situation of high summer stress (respectably of the PMV of 1,50 in 2015 and 2,30 in 2050s, for MRT of 30,60 °C in 2015 and 31,50 °C in 2050s and 31,1 °C in 2015 and 33,00 °C in 2050s for PET), as consequence of the constructive characteristics of the simulated environment and of the outer local microclimate.

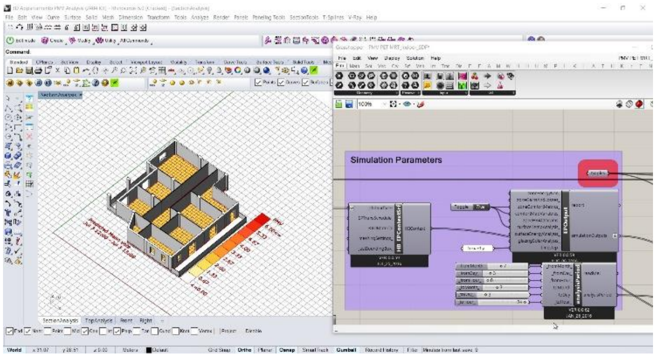

Figure 3. Indoor Simulation in Rhino-Grasshopper environment.

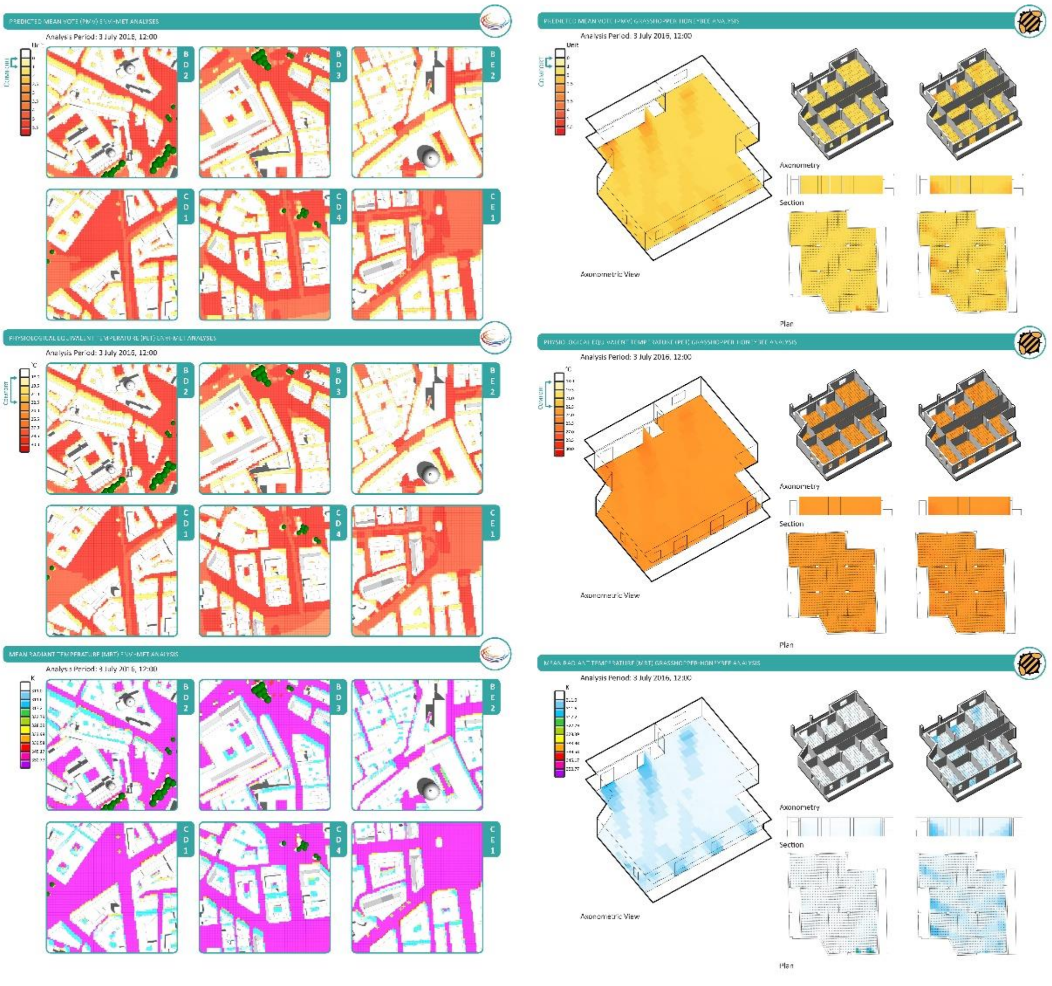

Figure 4. Outdoor and indoor environmental comfort index analysed at the starting conditions in 2015.

Iteration of the process and definition of the final solution

By iterating the previous process for any design proposal, a solution, which contributes to increase the outdoor and indoor comfort condition, could be found. For each proposal, a different weather file was generated, so that the indoor analyses was directly related to the outer improvements. In the final solution, in particular, it was noticed that the reduction of PMV index in the outdoor environment contributes to a consequential decrease of the inner comfort index, without intervening on the built construction. The same circumstance was also highlighted by the index MRT and PET. The values of the previous index are contained in Table 1 (as regards the outer space) and in Table 1 (for what concerns the inner environment).

Table 1. Results of the outdoor environmental comfort analyes .

	Outdoor comfort index			
	Before		After	
	2015	2050s	2015	2050
PMV	5,87	6,40	2,5	2,74
MRT	87,90 °C	88,10 °C	44,90 °C	45,42 °C
PET	43,37 °C	43.90 °C	30,16 °C	39 °C

Table 2. Results of the indoor environmental comfort analyses.

	Indoor comfort index			
	Before		After	
	2015	2050s	2015	2050
PMV	1,50	2,30	0,3	0,6
MRT	30,60 °C	31,50 °C	26,90 °C	27,40 °C
PET	31,10 °C	33,00 °C	27,60 °C	28,10 °C

Thus, the possibility of working in a parametric environment and to read the results directly on the surfaces of the model guarantees an immediate and better undertraining of the relation between indoor and outdoor environment and of the effect that outer conditions produce on the inner space.

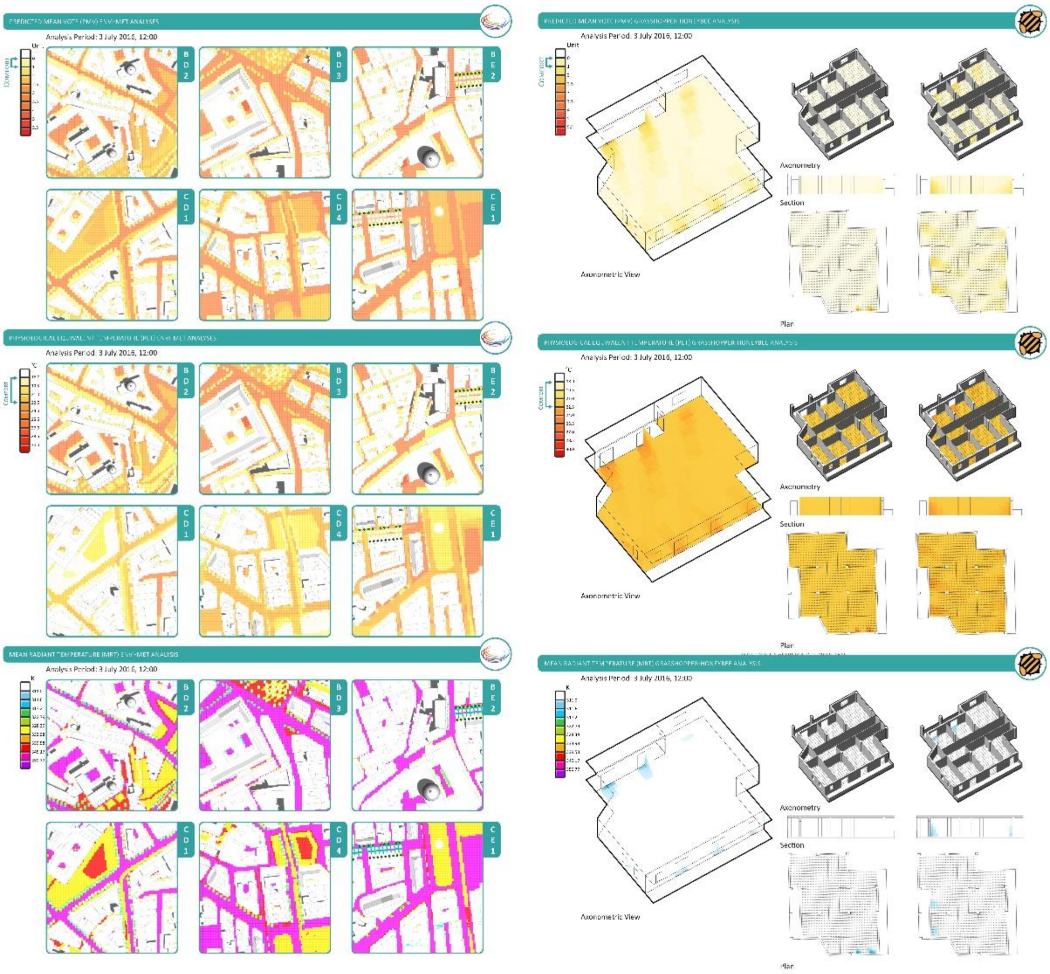

Figure 5. Outdoor and indoor environmental comfort index analysed at the final solution conditions in 2015.

Conclusion

The results obtained from the iterative simulation process between outdoor and indoor (both in the current scenario and in the prospective future scenario) highlighted a reduction of the PMV values of 61.5% in 2015 and of 57.2% in 2050s, of the MRT values 49.0% in 2015 and of 48.5% in 2050s and PET values 30.0% in 2015 and of 11.2% in 2050s for the outdoor environment, while a reduction of the PMV values of 80% in 2015 and 74% in 2050, of the MRT values 11.5% in 2015 and of 14.0% in 2050s and of the PET values 12.0% in 2015 and of 16.0% in 2050s were obtained for the indoor simulation.

Those results were obtained by the regeneration of the surrounding area around the analysed building with adaptive strategies aimed to reduce perceived thermal comfort and finalized to a significant improvement of outdoor comfort conditions. The permeability of soils was raised by increasing permeable pavers and green areas, which reached the 30% of the whole horizontal surfaces. Trees and rain garden systems were placed to avoid urban flooding and increase shadowed areas. Similar effects were obtained through the installation of shelters and artificial tree structures, which guaranteed control of solar radiation and wind factor. The thermal load on urban surfaces was reduced using cool pavers, with high albedo values.

The application of an iterative simulation methodology outdoor-indoor to the project for the requalification of the Duchesca district shows the validity of computational design and of data exchange across different IT tools, but most importantly it shows the real benefits of a *climate adaptive design* approach, as well as its social and economic feasibility. The project proposal for the open space can guarantee, by itself, an actual improvement of the indoor environmental conditions to the surrounding buildings, making up for the lack of initiatives for requalification, and improve the urban comfort conditions, also in view of future climatic scenarios.

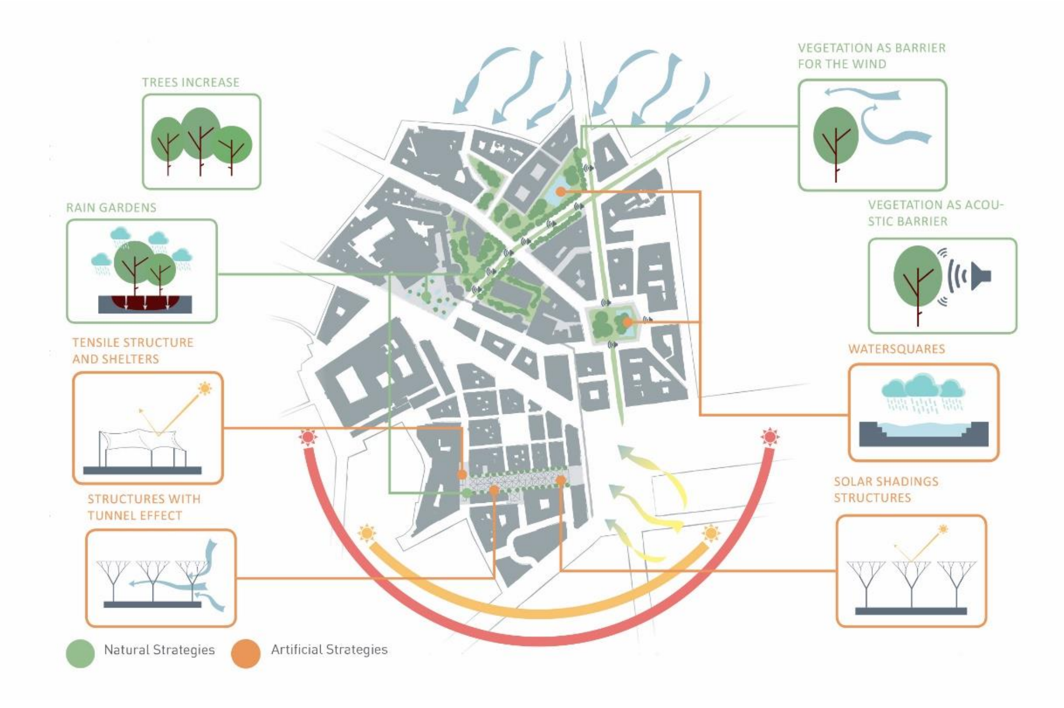

Figure 6. Synthesis of the main adaptive design strategies applied in the project.

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