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Simulations beyond the building, identifying climate adaptation scale jumping potentials to district level. Research by design for the city of Monterotondo (Italy)

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Abstract

With the increasing relevance of positive energy districts and complexity embedded in multiple buildings retrofitting strategies, the opportunities and demand for modelling and simulation tools have increased. This paper presents a workflow for dynamic simulation of energy demand for cooling and heating for the industrial district of Monterotondo, located in the outskirt of Rome (Italy). This dynamic framework was supported by Rhino's 3-D modelling tools, and by the visual programming tool Grasshopper. Temperature, energy and UTCI were subsequently investigated, and different building and open space retrofitting strategies were compared, highlighting expected scaling up potential for the entire district.

Key Innovations

The following aspects have been introduced, compared to the business-as-usual approach to building design and district renovation:

- Focus on challenges that are intertwined and cross disciplinary boundaries.
- Innovative ways to visualise and use of visualisations to explain performances that might be difficult to understand through metrics and indicators.
- Multi-layered parametric workflow based on data exchange defined in Grasshopper.
- Step-by-step description of case study to encourage adoption of evidence-based multi scale design.

Practical Implications

The requirements related to the growing scope of parametric simulation tools, the intuitive use of software and plugins, the timing of analyses, and the effectiveness in terms of results' validation, have increased considerably.

It must then be taken into account that:

- Approaches to such tools often require interdisciplinary knowledge, ranging from the field of computer science to plant engineering.
- When integrated tools are used from the beginning of the design process, the data input and computation phases can be time-consuming.
- Access to unbiased and high-quality data is a further potential issue, as no tools are specifically made to warrant data soundness.

Introduction

Centres for public and private services, as well as hubs for local and regional knowledge production, innovation and infrastructure, small and medium-sized cities (SMC) constitute the building blocks of metropolitan areas, and lend character and distinctiveness to their environmental, social and economic landscapes.

Several SMC are currently doing substantial efforts in adapting their 'urban envelope' to increase community resilience, boost smart energy development, mitigate and adapt to climate change, with increasing relevance of innovative paradigm such as the 'Positive Energy Districts' (Monti, 2016).

On this basis, the objective of the proposed contribution is to illustrate an applied research case study regarding the effectiveness of simulation tools aimed at supporting climate adaptation design strategies at building and district scales for an existing industrial district of the 'satellite city' of Monterotondo, belonging to the metropolitan area of Rome. Critical issues and opportunities for climate adaptation and smart energy development are presented and discussed in the following sections, together with a detailed illustration of the simulation workflow and its results supporting integrated pilot actions for the identification of best operational methods for the retrofit of existing non-performative buildings and open spaces.

Figure 1: The industrial area of Monterotondo. Google Earth, 2020.

The recently affirmed 'Smart Energy City', as a concept, ambitions, deployed technologies and programmes, rapidly gained traction in Monterotondo from 2012

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onwards. In 2016, the new Civic Tower was built, following the principle of sustainable design for construction, management and maintenance of buildings. Multiple advantages of the LEED ‘Platinum’ certified (2019) building originated more specifically from the implementation of bioclimatic design, sustainable water management solutions, the use of recycled or renewable materials, and a regenerative and self-sufficient production of energy. Current priorities of Monterotondo’s urban agenda regard the identification of scale jumping potentials from building to district and city level sustainability, and encompass testing and implementing technologies and design strategies for improving energy efficiency that supports both solutions and application development for urban services.

Case study

Simulation at district scale

The climatic data relative to the monthly air temperatures were defined accessing the Windfinder platform and referring to the Guidonia airport (10km far from the study site) (Figure 2).

Figure 2: Maximum, average and minimum, day (top) and night (bottom), monthly air temperatures registered at the Guidonia airport station. Windfinder, 2019.

It should be noted that the summer season in Rome is quite warm, with an average daily temperature of 29°C during the months of July and August.

The geometric model that served as a base for the full set of algorithms was created in Rhinoceros 6, a commercial NURBS 3D software. The geometrical design, available in DXF format, was at first included in the tool, and all the thermo-physical properties of the district environment were determined. The metrics and information provided in Table 1 focus on the inputs of the simulation settings in the evaluation modules. Among them, the albedo values of wall and roof materials, together with the values of emissivity, anthropogenic heat, vegetation cover, and other generation parameters related to heating and cooling.

Morphological parameters for the industrial district have been obtained from equations (1) and (2):

$$Site\ coverage = \frac{\Sigma A_{buildings}}{A_{site}} \qquad (1)$$

$$Façade\ ratio = \frac{\Sigma p x h_{weighted}}{A_{site}} \qquad (2)$$

Where:

$A_{buildings}$ = Building plan surface (m^2)

A_{site} = Site plan surface (m^2)

p = Building boundary (m)

$h_{weighted}$ = Average building height (m)

Table 1: District weather generation parameters.

	Industrial district
Reference site	
Latitude (°)	42.05
Longitude (°)	12.62
Area	
Site coverage (-)	0.28
Façade ratio (-)	0.24
Average height (m)	8.00
Tree cover (%)	4.00
Anthropogenic heat (W/m^2)	8
Buildings	
Day-time heating set-point (°C)	18
Night-time heating set-point (°C)	15
Day-time cooling set-point (°C)	26
Night-time cooling set-point (°C)	35
Heat released to the canyon (%)	50
Elements	
Wall materials and thickness	Concrete 30 cm
Wall albedo (-)	0.20
Roof materials and thickness	Concrete (insulated), 40 cm
Roof albedo (-)	0.08
Road albedo (-)	0.08
Rural	
Albedo	0.2
Emissivity	0.95
Vegetation cover	48

Different tools were then applied to test the design characteristics of the industrial district, such as Ecotect (Marsh, 2006) to study the sun shadow range (Figure 3, 4), and Ladybug (Roudsari and Park, 2013) for thermal radiation (Figures 5-7), and sunlight hours (Figures 8, 9).

Figure 3: Shadow range Dec. 21st 8:00a.m – 5:00 p.m.

Figure 4: Shadow range June 21st 6:00a.m – 8:00 p.m.

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Shadow range analyses (Figure 3, 4) allowed to check the amount of sunlight that affects the areas and buildings under study. The red color highlights the post-meridian shadows, the blue the anti-meridian ones. Their overlap indicates those surfaces in shadow throughout the day, therefore of particular importance for multiple design purposes.

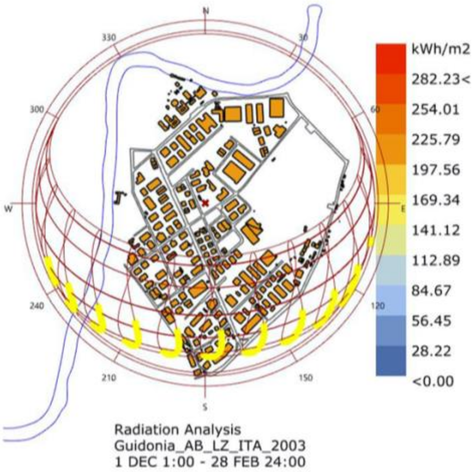

Figure 5: Solar radiation analysis, winter. Ladybug.

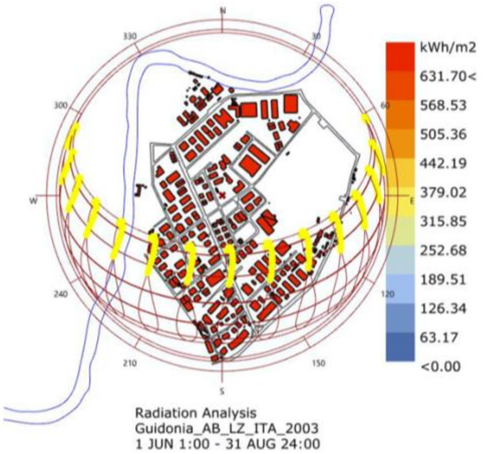

Figure 6: Solar radiation analysis, summer. Ladybug.

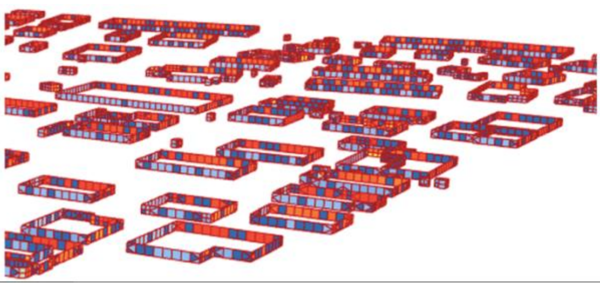

Figure 7: Solar radiation analysis on vertical envelope, November 1st-April 15th. Ladybug.

The horizontal buildings' envelope (Figures 5, 6) results affected by a particularly significant solar radiation in summer (about 650 kWh/m^2), as well as in winter (about 230 kWh/m^2). Similar observations can be made for the period November 1st-April 15th, with respect to the large and regular building façades, as evidenced in Figure 7.

By extrapolating and adding the values of the incident solar radiation of the envelope surfaces and dividing the result by the number of geometries on which it was calculated, an average incident solar radiation index of 159.24 kWh/m^2 was obtained (Figure 8).

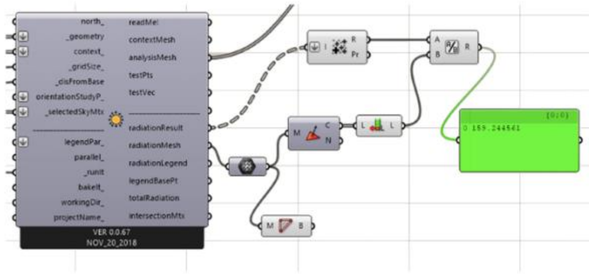

Figure 8: Incident solar radiation index generation flow. Ladybug.

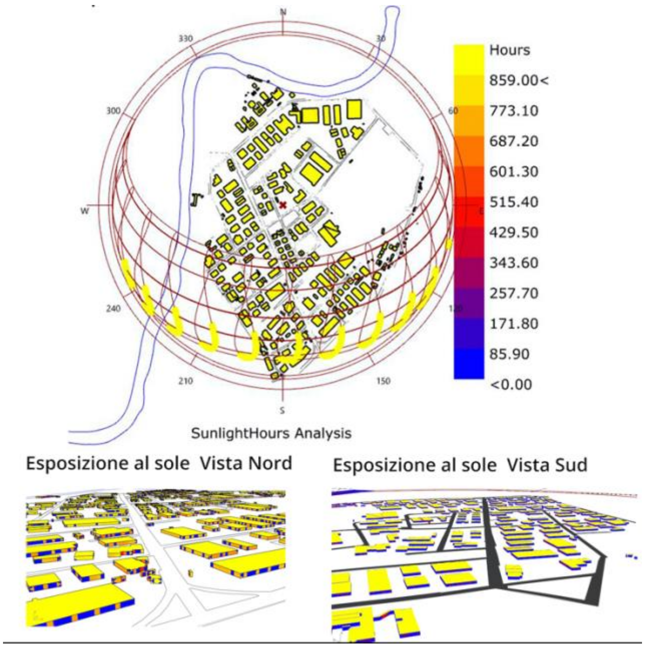

Figure 9: Sunlight hours analysis, summer. North view (bottom left) and south view (bottom right). Ladybug.

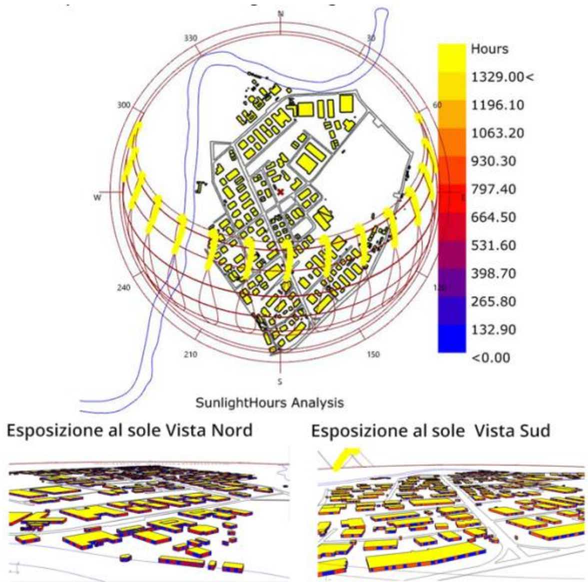

Figure 10: Sunlight hours analysis, summer. North view (bottom left) and south view (bottom right). Ladybug.

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The sunlight analyses (Figures 9, 10) confirm a relevant average seasonal amount of daylight hours affecting the buildings, and especially their roof (around values of 1,438 and 926 hours, in summer and winter, respectively); the building façades also show significant average seasonal values (586 and 372 hours, in summer and winter, respectively), thanks to the wide distance between buildings that avoids shading, most of the time (Figures 9, 10).

On the basis of the solar radiation and sunlight hours analyses, and the photovoltaic surface already installed on the buildings' roof (54,000 m^2), 7.9 million kWh were estimated, able to satisfy about 9% of the overall energy demand (87,674 million kWh).

The same analyses highlighted the opportunity to expand the photovoltaic energy source, with further 200,000 m^2 of roof PV cover, thus satisfying more than 50% of the total energy demand for electricity and thermal needs.

Simulation at building scale

One building within the area of interest was subsequently explicitly modelled with the graphical algorithm editor Grasshopper (Figure11).

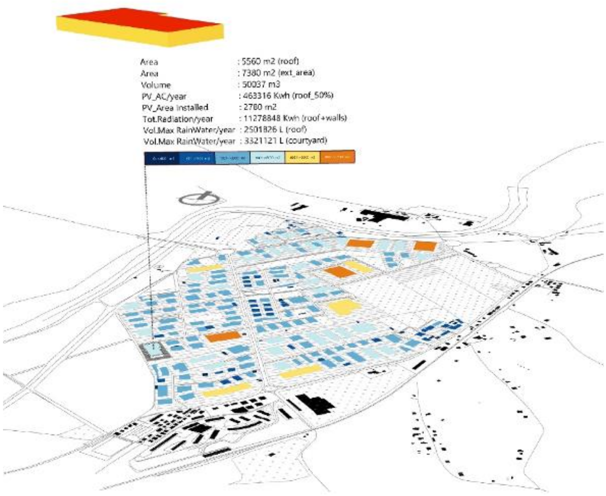

Figure 11: Building selection visualization. Grasshopper.

Table 2: Building performance simulation parameters.

	Industrial building
Operation	
Occupancy (m^2/person)	30
Occupancy schedule	08-20
Infiltration (h^{-1})	0.5
Ventilation (h^{-1})	0.8
Heating set-point	20
Cooling set-point	24
Internal gains (W/m^2)	6
Total floor area (m^2)	5,560
Envelope	
U wall (W/m^{2}K)	2.83
U roof	2.83
U floor	2.83
U windows	2.15
Glazed surface (%)	31

The use of the parameters related to the building, such as the thermal transmittance of the envelope, and the free internal contributions deriving from lighting and machineries used in industrial processing, allowed to evaluate the energy demand and thus define design strategies aimed at reducing consumption.

A medium-sized industrial building plot (13,000 m^2) was selected, hosting a building with a volume of circa 50,000 m^3, featuring an external vertical envelope made of prefabricated panels (30 cm) in reinforced dark concrete, a flat roof (5,560 m^2) in prefabricated slabs with bituminous coating, and an external open space of 7,380 m^2, covered with dark concrete (Figure 12).

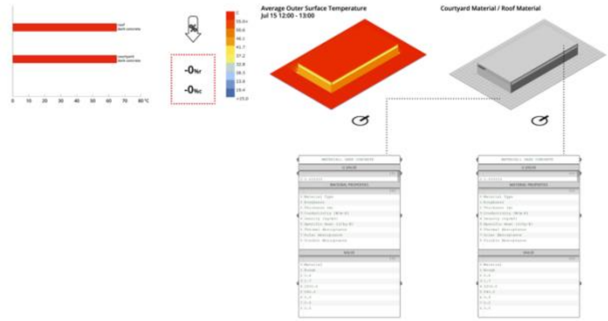

Figure 12: Building cover and open space average outdoor temperature analysis, current state. Honeybee.

Subsequent analyses of the average outer surface temperature (°C) were then performed for the building roof and the courtyard, under three different hypotheses.

The first building re-design strategy encompassed a tree planting intervention in the building courtyard. This noninvasive microclimatic design strategy allowed to register a reduction of the outer surface temperature of the open space of about 25%, on July 15th, between noon and 1:00 p.m. – assumed as the hottest summer day and hour – thanks to the benefits from shading and evapotranspiration provided by broadleaf adult trees (Figure 13).

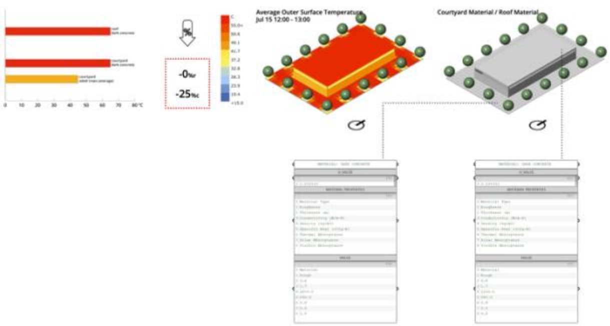

Figure 13: Building cover and open space average outdoor temperature with tree planting in courtyard. Honeybee.

The second re-design hypothesis encompassed the application of high albedo coatings for the roof, capable of efficiently reflecting solar radiation (i.e., integrated hemispherical reflectance within 0.28 and 2.8 micrometers), resulting in a reduction of the roof surface temperature of about 45% (Figure 14). Changing roof coatings or modifying R-values could be part of regular building maintenance.

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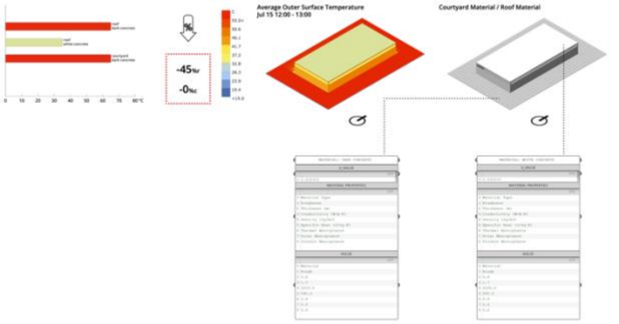

Figure 14: Building cover and open space average outdoor temperature with cool roof. Honeybee.

The third hypothesis involved the retrofit of the roof cover with the installation of a high albedo coatings – with similar characteristics compared to what was envisaged in the second strategy –, coupled with a new courtyard surface, featuring an extensive permeable grass cover. This building roof-courtyard integrated re-design strategy, according to the simulation – conducted, similarly to the others, with the Grassopper plugin, Honeybee – registered an expected reduction in the roof surface temperature of 45%, and of the courtyard avaerage surface temperature equal to 30% (Figure 15).

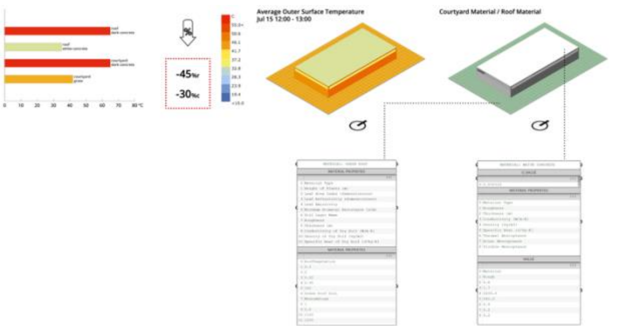

Figure 15: Building cover and open space average outdoor temperature with cool roof and extensive courtyard greening. Honeybee.

In Figure 16, the analyses of average outer surface temperature (°C), and area normalised surface energy loss/gain (kWh/m2) were combined, confronting ex-ante and ex-post values under hypothesis three (cool roof and extensive courtyard greening). The results show a forecasted reduction in floor normalised cooling load (kWh/m2) from circa 85 kWh/m^2 to 71 kWh/m^2, equal to a total expected reduction in energy demand for cooling of 16% (Figure 16).

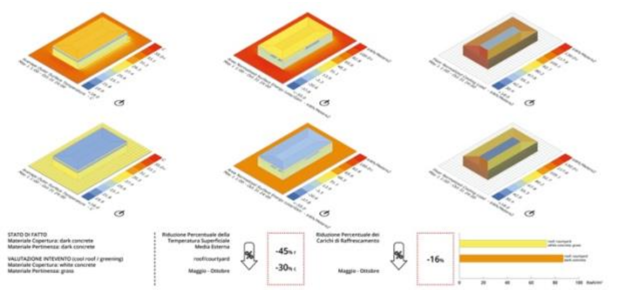

Figure 16: Simulation of thermal load and energy demand for cooling under hypothesis three (cool roof and extensive courtyard greening). Honeybee.

Figures 17 (all cases) and 18 (July 15th, 5:00 to 6:00 p.m., only) finally illustrate relationships between average outer surface temperatures and the UTCI Universal Thermal Climate Index (Park, Tuller and Jo, 2014), highlighting hourly (from 11:00 a.m. to 6:00 p.m.) coupled variations on July 15th, in ex-ante and ex-post conditions. The simulation results confirmed the higher effectiveness of an integrated bio-climatic design strategy for people and the environment (Olgyay, 1962; Santamouris, 2014; Coccolo, Kampf, Scartezzini and Pearlmutter, 2016)

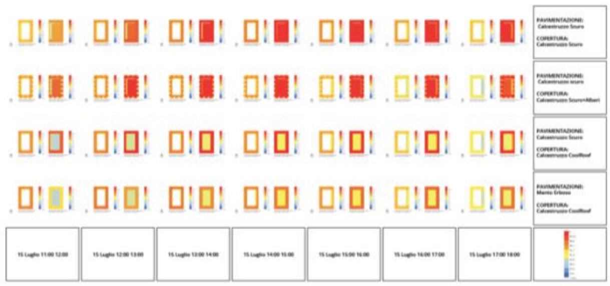

Figure 17: Relationship between average outer surface temperatures and the UTCI Universal Thermal Climate Index, in ex-ante and ex-post conditions – July 15th, 11:00 a.m.-6:00 p.m., hourly values. Honeybee.

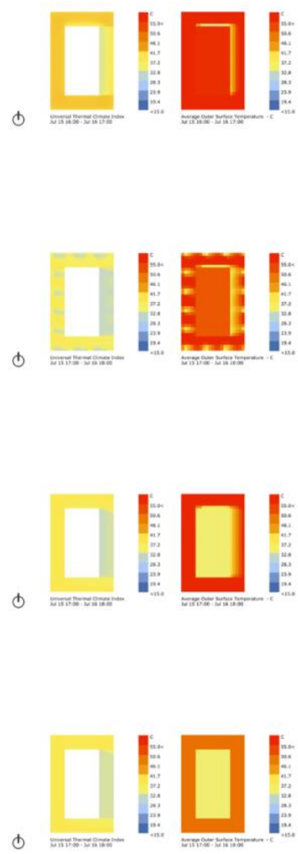

Figure 18: Relationship between average outer surface temperatures and the UTCI Universal Thermal Climate Index, in ex-ante and ex-post conditions – July 15th, 5:00 p.m.-6:00 p.m., hourly values. Honeybee.

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Discussion

Grasshopper is a graphical algorithm editor tightly integrated with Rhino's 3-D modelling tools. Unlike RhinoScript, Grasshopper requires no knowledge of programming or scripting, but still allows designers to build from simple to awe-inspiring solutions. Of all of the available Grasshopper's environmental plugins, Ladybug Tools is among the most comprehensive, connecting Rhino interfaces to validated environmental simulation engines. The Ladybug Tools family of plugins that have been applied includes Ladybug for climate data, and Honeybee for daylighting, energy modelling and thermal modelling, As such, Rhino, Grasshopper and Ladybug Tools are interconnected.

Relevant environmental performances and design goals were translated and integrated into a digital workflow that not only responds to the needs of researchers and practitioners that are accustomed to digital processes supported by algorithmic and parametric design – but that is also meant to support decision makers through intuitive visualizations of pre- and post-operam metrics. The workflow represented in Figure 19 illustrates in synthesis the applied plugins, and the simulation inputs and outputs.

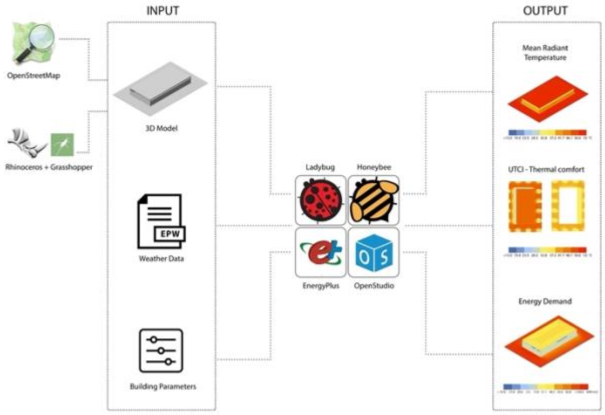

Figure 19: Workflow illustrating plugins and simulation inputs and outputs.

Conclusion

The research, exploring different environmental technological solutions, and urban green blue infrastructure as an integrated design approach to urban regeneration at building and district scale, aimed at contributing to the dissemination of the relevance and replicability of socio-technological innovations for a low-carbon future in small and medium-sized cities.

The contribution, at first, introduced different simulation tools and the applications developed at district and building scale to support climate adaptive transformations for the industrial district of the city of Monterotondo. Subsequently, the expected results of the selected interventions were presented in detail and selected multiple co-benefits for people and the environment were discussed.

Decisive for the prospects for economic development, the industrial district – spread over an area of about 230 hectares, with 250 companies already settled, including those belonging to the Artisan and Industrial Consortium of Monterondo – has been the subject of a study for an articulated environmental and energy redevelopment plan. The integrated intervention would eventually realize an eco-industrial park (Butturi et al., 2019), the expected benefits of which are to be related to the reduction of energy demand, air pollution and heat concentration levels, the widespread environmental quality, and a better reconnection of the areas with the urban ecosystem.

Scope for future research

Even if the peri-urban (sprawl) context of the industrial district of Monterotondo, and the footprints and building types of the studied district (low-rise buildings) do not seem to determine irradiation trapping, it is likely that the increased urban surface temperature and longwave irradiation to the ambient air contribute to a warmer micro-environment and local atmosphere.

Further steps to improve this research in the near future have consequently been identified:

- Literature review, i.e., studies that have introduced the processes to simulate or measure the long-wave radiant heat exchange between buildings, and their surrounding urban surfaces (e.g., Gros, Bozonnet, & Inard, 2011).
- The application of urban building energy modeling (UBEM) tools that authors have already successfully developed (e.g., Evins et al., 2014; Miller et al., 2015; Hong & Luo, 2018; Naboni et al., 2019) and reviewed (Li et al., 2017; Torabi Moghadam et al., 2017; Luo, Hong & Tang, 2020; Hong et al., 2020), in order to simulate an urban district considering energy flow between buildings.

Acknowledgement

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Author Contributions

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Buildings To Positive Energy Districts: Knowledge sharing, ideas exchange, resources pooling, new methods experimentation and novel co-creation solutions towards a climate neutral European economy", Principal Investigator Maria Beatrice Andreucci.

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