Bioclimatic simulation, environmental based urban design and architectural redevelopment in the Mediterranean Area: a didactic approach for the training of future professionals

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Abstract

The study presents a synthesis of the didactic experience called "Bioclimatic simulation, environmental based urban design and architectural redevelopment in the Mediterranean Area", in which, among others, the case study of the Tor Fiscale district in Rome was addressed; the latter deals with the theme of the self-reliant city, of the heat island effect mitigation, and of the energy and environmental efficiency of buildings from passive energy efficiency and smart grid point of view. The learning process tested on students is based on the study and simulation of climate, urban and local microclimate factors, of the utmost importance for the training of future professionals with a strong environmental sensitivity, in addition to the traditional analysis of a typical urban fabric characterized by strong historical, archaeological and environmental features. The microclimate area simulation is used as a decision making support tool aimed at deepening the critical-knowledge on the area and the proper formulation of objectives and strategies through a process characterized by a flexible and adaptive approach with the aid of retroactive feedback. The study sets out the specific biophysical and bioclimatic features to consider when developing objectives and strategies of intervention in a portion of urban tissue. The case study of Tor Fiscale is analysed in its peculiar characteristics of an area substantially closer to the centre of Rome, characterized by a strong presence of archaeological and natural values, together with a context of strong environmental degradation and unauthorized building construction. The paper concludes with assessments developed within the framework of the didactic process, along with a report on the teaching experience for further didactic improvements and three design results directly related to the analysis and the didactic process.

Framework definition and question remarks

In Europe the energy consumption of the building sector accounts for about 40% of the overall demand for energy; buildings consume 40% of the incoming material into the economy and generate approximately 40-50% of the greenhouse gases produced (Ardente et al. 2011). Cities host now more than 50% of the world population (UN 2012) and although they take up less than 3% of the earth's surface, they consume 75% of the total energy produced and produce 80% of all greenhouse gas emissions (Brown 2001) (European Commission 2010). The European Directive 2010/31 has already set ambitious targets for reducing energy consumption for the building industry and a central role for the achievement of these objectives will increasingly be carried out also by the evolution and development of the city not as a sum of individual buildings but as a system of interrelated energy flows as much as possible self-reliant, that is tending to prefer the local production of services, goods and energy according to the well-being of the community (Shuman 2000). A further articulation of this principle applied to energy requires the consideration of geography and natural resources both as a mean to meet the energy demands of the city (Grewal and Grewal 2013) and as a mean to transfer the principle of the energy efficiency of buildings to the energy efficiency of the urban fabric through its passive behaviour, as the latter is capable of significantly reducing energy consumption of the buildings within it at the source (Yang et al. 2012). The urban climate is strongly influenced by natural and anthropogenic factors dependent on the density and the heat storage capacity of the built fabric, the presence of mineralized or green surfaces and pollutant emissions. The heat balance of a city is very different from that of a suburban area and the phenomenon is called the "heat island" effect. The urban heat island is the best example of increased energy consumption of a city due to anthropogenic-induced changes in microclimate and local climate (Gartland 2008, Grimm et al. 2008). The triggering factors related to the effect of urban canyon, the decrease in convective exchanges data from the wind and pollution, are summarized in the table below (D'Olimpio 2008, RUROS 2004).

Studies show that mitigation of the heat island can produce savings in energy consumption for summer cooling between 20 and 30% (de la Flor and Domínguez 2004, Akbari, Pomerantz, and Taha 2001).

Factor	Cause
Increase in absorbed solar radiation (shortwave) and increased heat storage	**Morphological:** the urban geometry develops a greater sun exposed surface compared to a flat surface and determines multiple reflections of radiation (canyon effect). **Constructive:** the high heat capacity and low albedo of construction materials increases the heat storage capacity of the urban fabric modifying the thermal balance.
Decreased thermal radiation loss (long wave)	**Morphological:** the urban canyons (related to a low sky view factor) cause a decrease of the radiative exchange with the sky (heat sink) and an increase in radiative exchanges between the buildings themselves. **Anthropogenic:** the pollution reduces the energy dissipation capacity of the system to the sky (the greenhouse effect)
Increased radiative flux from the sky	**Anthropogenic:** the pollutants discharged into the layers of urban atmospheres that have absorbed direct solar radiation, increases the thermal radiation emitted from the air (increased greenhouse effect)
Decreased evapotranspiration of soil	**Constructive:** the high rate of impermeable mineralized soil surfaces at the expense of green permeable soil and the decrease of evapotranspiration from plant species heavily decreases the cooling properties of urban tissue.
Decrease in convective heat dissipation	**Morphology:** The roughness of the urban fabric decreases the air velocity and thus the capacity of the winds to disperse by convection heat loads in excess.
Increase of anthropogenic heat radiation	**Anthropogenic:** the thermal conditioning of buildings, transport and manufacturing processes help to increase the thermal balance of the city.

The support of manuals and rules of thumb, that are still the prevailing approach and often cause misleading results, is not enough for a bioclimatic design methodology that in addition to managing the highest number of phenomena involved in urban design is also able to mitigate the heat island effect. The support of computational simulations capable of treating the complex interactions between heat exchanges, air flows and evapotranspiration as a system of related optimizable items, and not as the sum of a number of elements designed and optimized separately for subsystems, is needed (Hensen 2004). This approach, down to an appropriate scale of depth, goes beyond the given climate statistics to the study of the urban microclimate. It is important simulations are involved in the decision-making process from the early design stage, and not relegated, as it normally happens, to the final stages when they have a very limited impact on the final result (Lechner 2009, Reiser et al. 2008, De Wilde, Augenbroe, and Malkawi 2014). Unfortunately, the designer that generally manages the early stages of the project is rarely a simulation expert capable of determining the appropriate simulation for the decision support required. Overcoming the above mentioned obstacle in the application of simulation tools in professional practice is one of the objectives of the educational approach described here. An analysis approach must always be supported by simulations, used as decision making support tools (Morbitzer 2003), that lead to a better formulation of objectives and strategic guidelines for the design of urban transformation. The training of future professionals with a strong environmental sensibility and a basic understanding of building and urban environmental simulation process, capable to go beyond these limits, should start in university, through courses with a strong emphasis on the application of simulation tools and their harmonization within the design process.

Definition of the methodological approach

After the definition of the framework the didactic scheme for urban microclimate design approach is presented through 6 steps of progressive analysis:

In step 1 students are asked to briefly develop individual concepts based on the first impressions arising from the area survey and from the dossier provided by the course. This step is ice-breaking and helps students to become familiar with the complexity of the area and the multitude of linked factors.

In step 2 students are divided into seminars, each of which is assigned a particular in-depth topic of the district. Within each seminar students are divided into groups of 2-3 people and are asked to start their group analysis on the area according to the scheme proposed by the course. From this point onwards, the students inside groups will continue to work together until the development of the final work for the examination. The data collected allows the students to comprehend the dynamics of the environment in general and define the climate type and the general strategy of reference (in this case, with distinct approaches in summer and winter), with particular attention given to the thermal range above a certain threshold (14 ° C in the case of Rome) that allows for an optimal use of cooling mechanisms based on thermal inertia of urban materials. Subsequently the students are asked to analyze the biophysical factors of the area (step 3), hydrological basin and geomorphologic condition paying particular attention to the characteristics of the vegetation species. These factors are analyzed both from a botanical point of view and in terms of design with a focus on factors such as:

- stress resistance to the wind;
- permeability to the wind;
- permeability to solar radiation and *habitus* (evergreen or deciduous);

- characteristics of the root system for integration into a built contexts;
- resistance and adaptability to the climate of reference.

In step 4, four bioclimatic factors are thus analyzed. The sunshine is analyzed in its critical summer and winter condition both in relation to the public space (localized heat island effects or perennial shadow areas), and in relation to the solar exposure of the built fabric (analyzing the potential use of passive strategies and systems of active energy production from renewable sources). The analysis of the urban microclimate is further detailed in step 5 by adding to the effects of solar radiation, wind flow around buildings, steam and heat exchange between soil and surfaces, heat exchanges and water vapour of vegetation and climate, thanks to the CFD freeware software ENVI-MET (Bruse 2010). The software is used to verify the information resulting from step 4 and obtain additional information on the prevailing winds in the urban fabric – an important element for a suitable design of external environmental comfort and natural ventilation in buildings - on the hygrothermal and radiant conditions relative to the albedo of urban materials, vegetation and of any water bodies. With step 6 an outline of bioclimatic factors is added to the traditional analysis on the functions and uses of the area, the infrastructure and character and identity of places, to produce five guidelines for urban planning and buildings design which are later developed in the examination papers.

Step	Analysis	Design	Tools
1	Concept works on first impressions arising from the area	Analysis and development of the material provided to the students from the course	Dossier of the area, on site survey
2	Climatic data and definition of the climate (solar radiation, temperature and temperature range, humidity, prevailing winds)	Selection of the general strategy based on the type of climate	Statistical data
3	Biophysical analysis	Hydrographic survey, geomorphology and vegetation analysis from a botanical and design point of view	Thematic maps
4	Bioclimatic analysis: sunshine	Identification of critical areas from the point of view of the excess of sunshine in summer or of perennial shade in winter, analysis of the radiative flux on the surfaces of buildings	Sunshine simulations of a three-dimensional reconstruction of the urban fabric
5	Bioclimatic analysis: ventilation and urban microclimate	Identification of issues resulting from a problematic interaction of morphological construction elements and plants	Computational fluid dynamics (CFD) simulation of the microclimate behaviour
6	Analysis outline and development of strategy	Summary of information derived from previous analysis in integration of urban planning traditional analysis subsystems	Data post-processing and critical synthesis of analysis

Case study of Tor Fiscale: area description

Rome is one of the largest and most ancient cities in Europe, characterized by a very complex landscape generated from a hilly volcanic area crossed by the river *Tevere* and its smaller affluent. The area of about 130 hectares is characterized by 5.4% of historical or archaeological urban fabric, 27.6% of modern urban fabric, 31.7% of green areas and agricultural protected areas and 3.4% of industrial productive urban fabric. The resident population is of 2,640,000 inhabitants.

The *Tor Fiscale* district is about 1.34 square kilometres wide with a population of 2,234 inhabitants and a density of 2.4 inhabitants per square km, that is far below the average of the surrounding areas of the city, which is around 17.75 people per square kilometre (U.O. Statistica Roma Capitale 2013). The area is connected to the rest of the urban fabric only by a corridor to the Northeast. The North western margin consists of the archaeological park of *Tombe di via Latina* to the east the district is divided from the rest of the city by two ancient aqueducts and a railway. The aqueduct of Claudius dating back to 38-47 AD belongs to the Roman period, while the aqueduct of *Felice* built in 1585 is from the Renaissance period. The railway runs through the Regional Park of *Appia Antica* that also acts as a margin for the district to the south and west, crossed by the road *Appia Nuova* which links the centre of Rome with the Southern periphery. The district is crossed by the *via Latina* of the Roman period (fourth century BC), an ancient road 4 meters wide which was the oldest infrastructure of connection with the south of Italy; the path

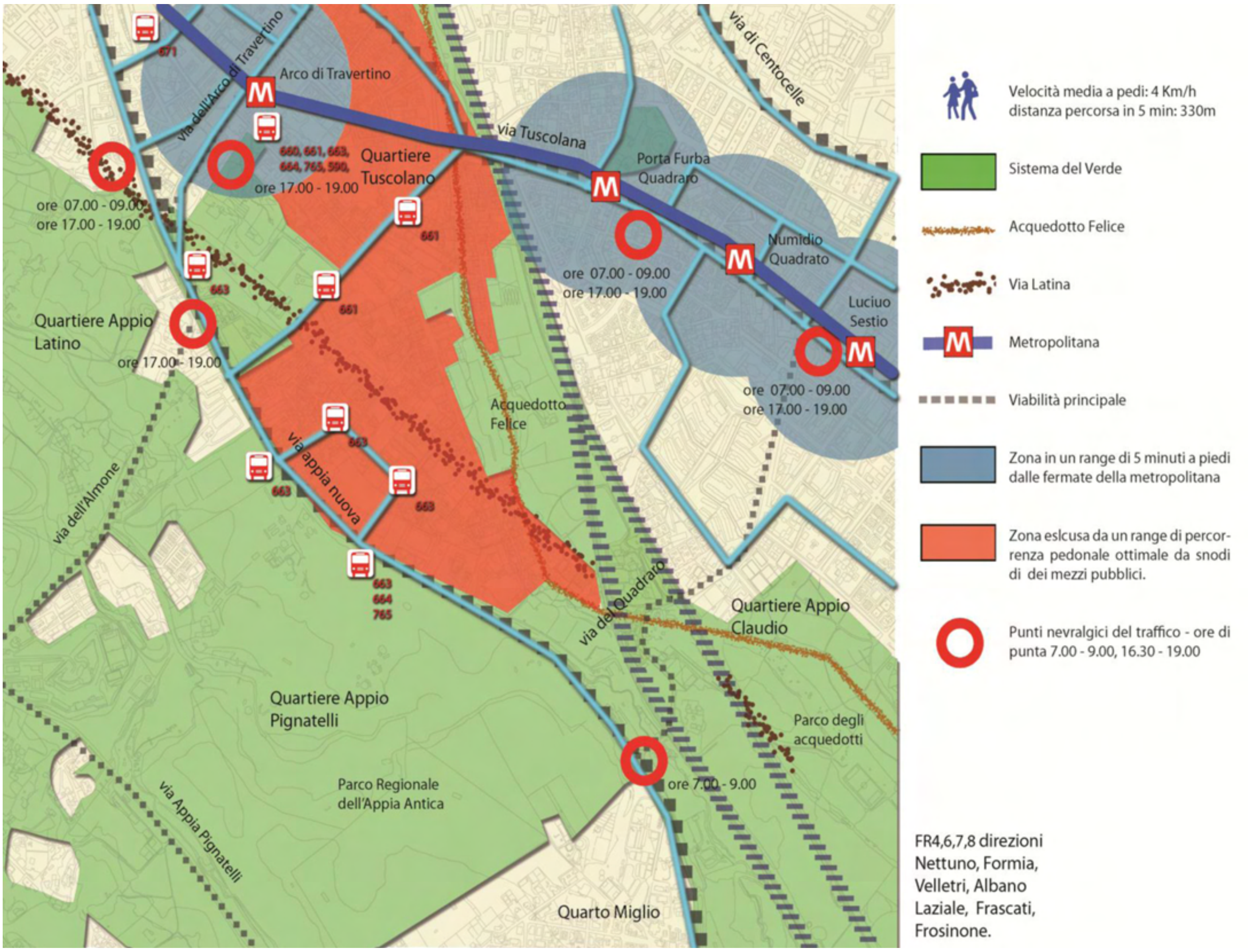
is still visible in the archaeological park, while it's covered with unauthorized buildings within the district. Finally, at the intersection between the two aqueducts stands the *Torre del Fiscale*, a surveillance tower of the medieval period (XIII cent.) that gives the name to de district. The tower is 30 meters high with a square base built of tuff blocks. The urban fabric has developed spontaneously from a series of historic farmhouses with a strong acceleration during the second world war, which catalyzed the population fleeing from the *San Lorenzo* district under bombardment. The people took refuge in the shacks close to the Roman aqueducts. The existing built fabric is mainly residential with a low to medium density without an adequate supply of services and public transport connecting this area to the rest of the city (despite the relative proximity of a underground station). The area close to the *Via Appia* (Southwest) and aqueducts (Northeast) is still characterized by unauthorized settlements both residential and productive. A lot of urban laws insist on the area, mainly with hydrological and archaeological constraints, and recently the "Integrated Program for the redevelopment of the city to be restored" (PRINT) has been activated; the latter is characterized by a good degree of flexibility and a particular focus on the environmental and archaeological features of the district.

Climatic analysis

In terms of climate Rome can be assimilated to the category of sub-coastal climate that includes hilly areas and low mountains of Lazio. The average maximum summer temperature is of 30,4 °C while the average minimum winter temperature is of 2,6°C; the daily thermal range of the area is greater than 14 °C (suitable for the use of the thermal inertia in passive strategies), the annual rainfall is around 876 mm with limited rainfall in June, July and August. The average relative humidity during the year is 72.9%. The prevailing winter winds come from the North-East, while the prevailing summer winds come from South-West, both with an intensity of 4,4 m/s according to the meteorological stations of the nearby *Ciampino* and *Roma Urbe* Airports.

Biophysical analysis

As in most European cities, in the *Tor Fiscale* district there is a single network for waste-water management. This configuration of the network of waste-water along with the population growth and the unauthorized urbanization has generated a great deal of pressure on water resources. Over



time this pressure caused an effect of urban stream syndrome (Willuweit and O'Sullivan 2013, Grimm et al. 2008, Walsh et al. 2005) and therefore an increase in groundwater pollution and a loss of biodiversity of which we have clear evidence at the river *Almone* flowing nearby within the Regional Park. At geomorphologic level the East margin, with its aqueducts and railway, is raised above the central urbanized area and the rest of the Regional Park of Appia Antica. The vegetation is characterized by the presence of riparian forests on the floodplains, turkey oak hilly Tyrrhenian deciduous forest and sub-Mediterranean middle Italy turkey oak.

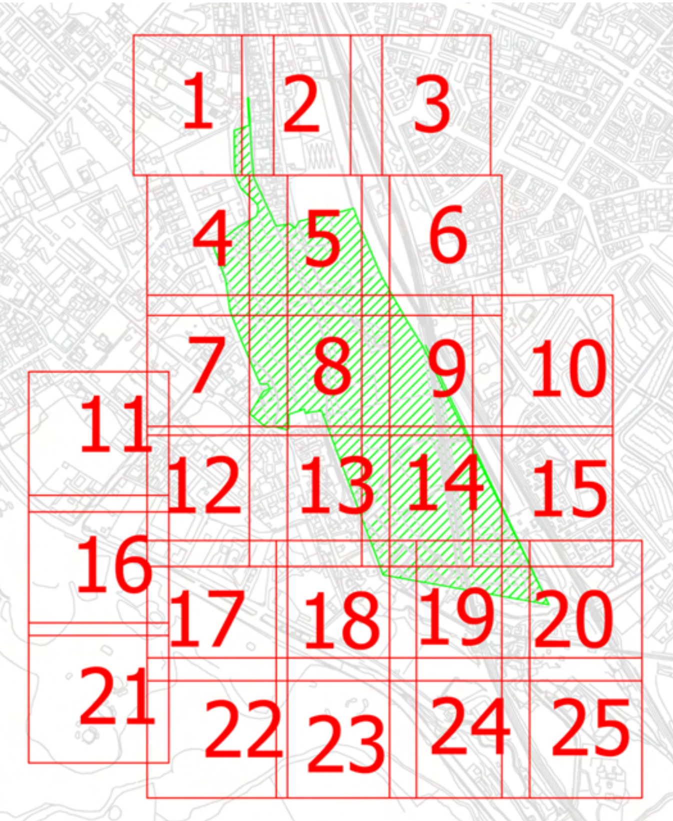
Bioclimatic analysis: sunshine

The urban fabric has been reconstructed in two three-dimensional models with different foliage of deciduous plant species between summer and winter, with a simulation software and the use of satellite imagery and an on-site surveys. The analysis did not reveal any particular critical situation in winter because of low construction density. In summer, the shading of the area depends exclusively on tall tree plant species, which are present in the parks but almost absent in the portions of urban fabric under study, resulting in the generation of numerous local heat islands.

Bioclimatic analysis: ventilation and urban microclimate

To simulate the microclimate behaviour of the area, given its size and the computational capabilities of the software, it was necessary to divide the area into quadrants, partially overlapped to limit quadrants boundary discontinuities typical of a CFD simulation (as shown in the picture on the right). For each quadrant, summer and winter simulations were carried out and their results were graphically reconstructed in thematic maps of the performance of the prevailing winds, relative humidity and temperature of the area (table on the next page).
The temperature analysis confirms the presence of heat island effect in the unauthorized urban fabric, with rates of relative humidity lower than the surrounding green areas. The prevailing winds in summer, due to the district roughness, never reach the levels observed at the meteorological station

of Ciampino, and stand at around 2.6 m/s in summer and 3.6 m/s in winter at eye level. The most critical areas were then subject to further investigations.



Decision support tool and processing strategies

Design strategies are then identified and adapted to positively influence the urban microclimate in terms of buildings energy consumption and comfort of outdoor spaces, through a retroactive feedback process. The design strategies modify sunshine loads on the area, shield winter prevailing winds and direct summer prevailing winds towards existing or new buildings in order to use natural ventilation systems. These strategies are analyzed running simulations on *post operam* models with different morphology of vegetation and albedo of surfaces. A set of objectives for the environmental and energy optimization of the neighbourhood is developed, supplementing the current planning instrument in force. The new objectives that foster a new and environmentally conscious design approach to the urban fabric are divided into five main categories:

Microclimate And Environmental Comfort

Objectives: landscape and environment valorisation; improvement of urban comfort; reduction of heat island effect; reduction of noise and air pollution resulting from the Via Appia.
Strategies: densification of evergreen plant species to shield winter prevailing winds; densification of deciduous vegetation on identified Southwest Northeast channels to strengthen wind flow (wind canyon effect) to be exploited for passive cooling of the heat islands while cleaning the air from the smog particles in suspension; use of water masses for summer wind cooling purposes; creation of a filter space between the road *Appia Nuova* and the rest of the neighbourhood, by means of earth movements, to mitigate noise and air pollution; reduction of mineralized surfaces with low albedo and gradual replacement with high albedo surfaces, or green surfaces.

Vegetation And Urban Ecosystem

Objectives: reconnection between the two edges of the regional park and the archaeological park of *Tombe* di via Latina through ecological corridors; promotion of biodiversity.
Strategies: creation of a hierarchical network of different types of vegetation integrated with microclimate optimization objectives, giving priority to indigenous species to foster the continuity of the Regional Park.

Water

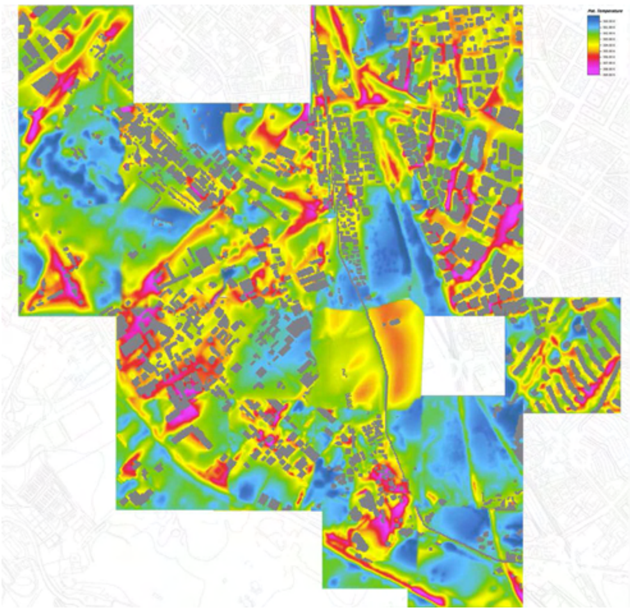
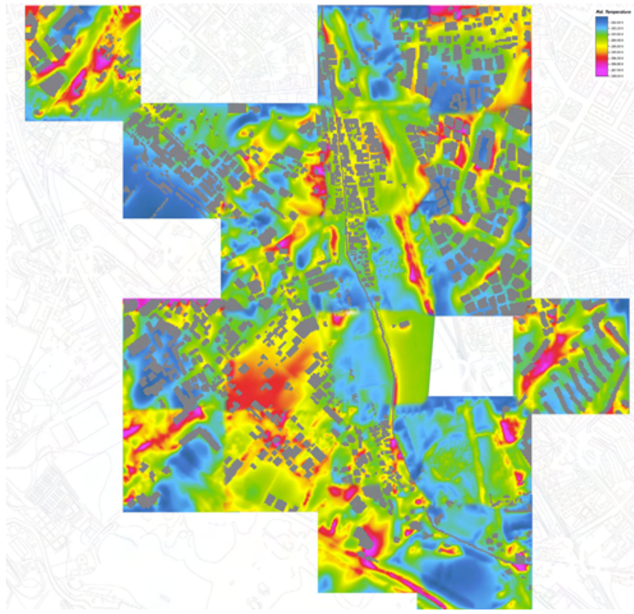
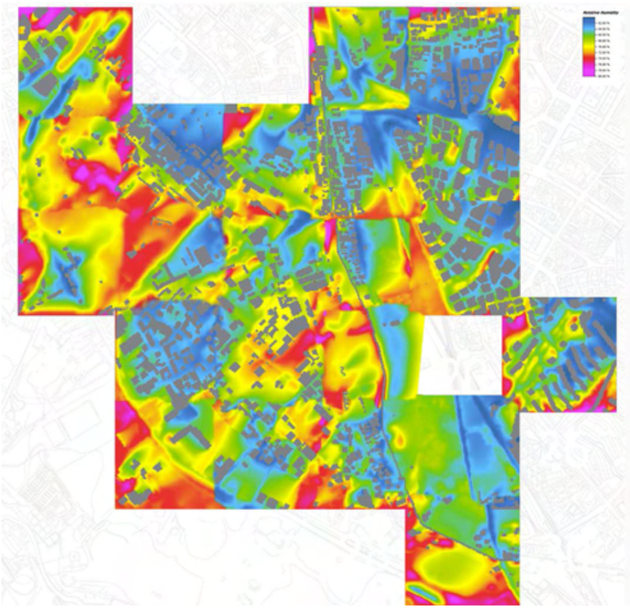
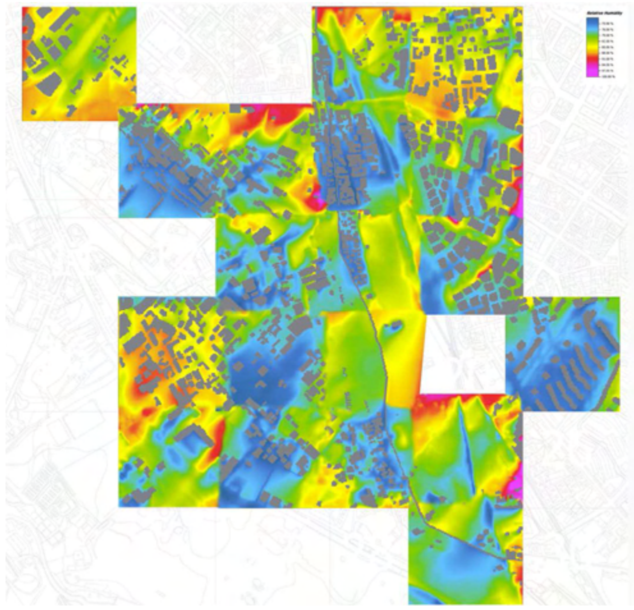
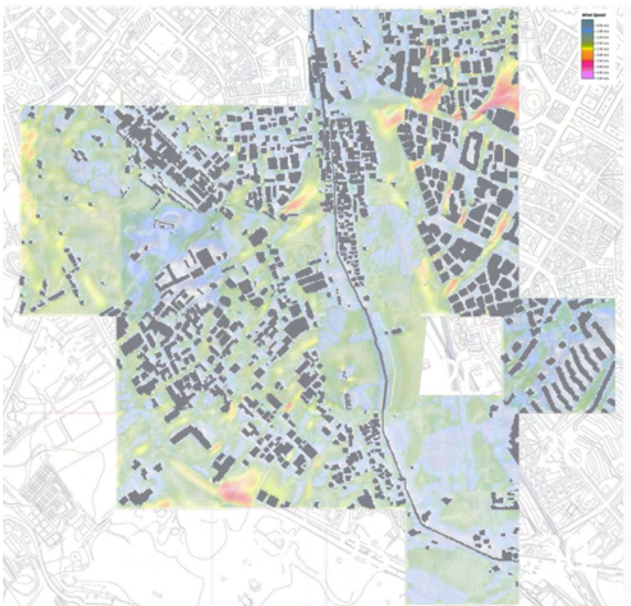
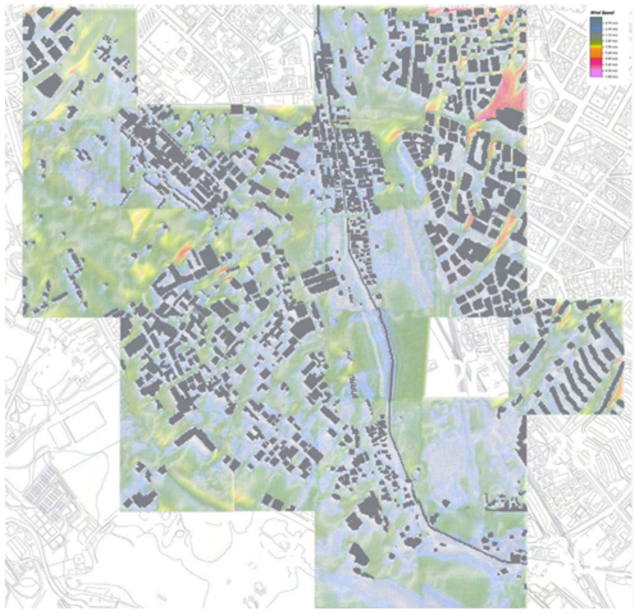
Objectives: achievement of the principle of hydrological invariance of urban fabric transformation and mitigation of urban stream syndrome.
Strategies: protection of the drainage basin through specific management of first rainfall water and redirection of rainfall into the ground through an increased number of permeable surfaces and rain gardens; in new buildings introduction of grey and black waste-water management using constructed wetlands for herbal purification; rational use of water to reduce drinkable water consumption by encouraging the use of storm water collection systems for irrigation of green areas.

Energy and Light

Objectives: reduction of energy consumption and production of energy from renewable sources; integration of production processes to meet the energy demands of the residential sector.
Strategies: reduction of energy consumption in buildings by optimizing the summer passive behaviour of the urban microclimate; use of natural ventilation strategies to redesign the flow of summer prevailing winds and strengthen their intensity; installation of photovoltaic panels on public surfaces; use of the waste energy from the productive sector to meet the energy requirements of the residential sector; use of low consumption artificial urban lighting.

Infrastructures

Objectives: rationalization of private vehicular traffic flows and strengthening of sustainable mobility.

	SUMMER	WINTER
Temperature		
Relative humidity		
Prevailing wind		

Strategies: reorganization of the road network in accordance with the demolitions to be carried out on the ancient path of Via Latina; reduction of private car traffic using traffic calming areas; increase of connections with the underground station through neighbourhood electric shuttle; creation of exchange nodes to access the regional and archaeological parks; strengthening of public links with the city's public transport network within these nodes.

Functions And Uses

Objectives: reorganization of the urban fabric based on the ancient Via Latina road and aqueducts; reconnection of *Tor Fiscale* with the route of the *Via Latina* in the archaeological park; creation of a network of spaces and public services based on the route of the *Via Latina*, with demolition and relocation of the unauthorized buildings.
Strategies: demolition of unauthorized buildings constructed on the ancient route of *Via Latina* and injection of primary functions in the district; creation of a hierarchical network between the functional nodes/green nodes, archaeological park and public transport, enhancing the "green island" character that is already present, albeit latent, in the current configuration of the district.

Conclusions

The introduction of the environmental subsystem analyzed in its biophysical and bioclimatic factors, introduced in a didactic experience with students coming to be professionals has led to an enrichment of their specific skills, also determined by learning a software capable of simulating the energy and microclimatic behaviour of the city.

In terms of direct consequences on the breakdown of teaching hours, the addition of the above-mentioned content produced the following changes:

- removal of 15% of the original course hours reserved to lectures, in favour of specific lectures, which resulted in the need to of synthesize aspects of the original lecture series;
- removal of 20% of the course hours originally reserved to consultations on projects, in favour of specific consultations on simulations and interactive lectures in which the class is asked to comment on the results of the simulations;
- introduction of a specific figure among the teaching assistants, with the role of coordinator of the simulation aspects for the entire course and the specific task of supervising the work of individual students;

For the students this entry led to:

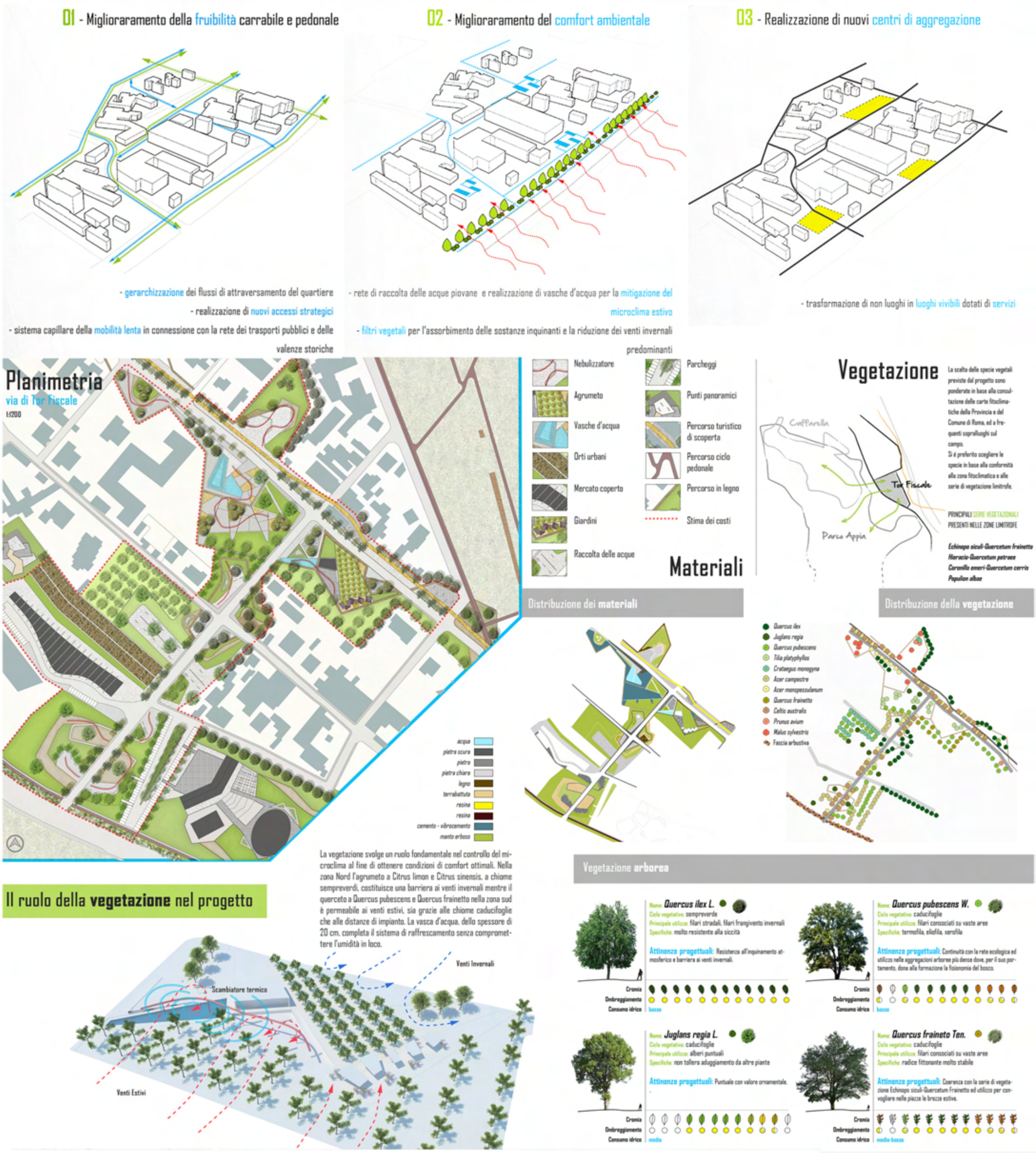
- the improvement of the environmental sensitivity that is no longer based on manuals and theoretical knowledge but on the actual possibility of testing in reality (albeit virtual) their project proposals;
- the ability to quantify the improvements in terms of microclimate conditions with *post-operam* simulations compared with *ante-operam* simulations, a factor that sparked in some working groups a positive competitive spirit in the pursuit of the better bioclimatic design of the area with a great improvement in the final works.

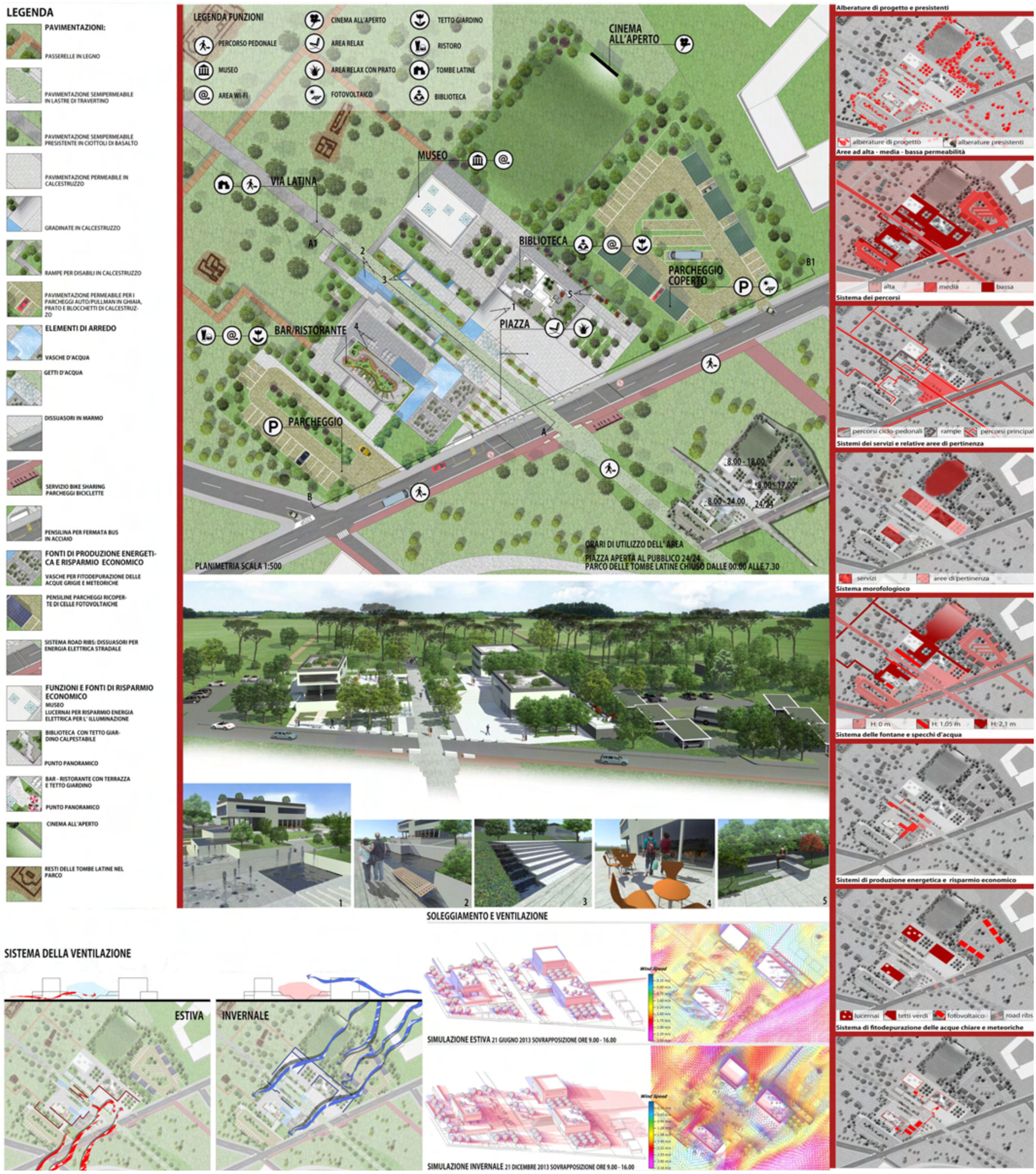
Overall, this type of educational organization, despite an increased use of human resources and the need for greater coordination of teachers, has produced a very positive response in students: there was an increased participation compared to the traditional course in the development of the design theme and in the production of final works for the exam, which reached high standards despite despite the vastness of implicated design factors.

Design Results

The three following images represent some of the results of the didactic process.

1. Entrance to the district and its relationship with via *Appia Nuova* (Di Cosimo and Conti, 2014).
In this design approach the theme of the entrance to the neighbourhood and the filter space between the road *Appia Nuova* and the urban fabric is solved through native vegetation design, which combined with an appropriate selection of materials based on urban albedo and inclusion of water surfaces, improves urban outdoor comfort in summer while shielding at the same time the urban fabric from the winter prevailing winds.





2. Relationship between the archaeological park of *Tombe di Via Latina* and the ancient underground route of the *Via Latina* (Danielli and Iacomini, 2014).

This design approach addresses the, currently non-existent, relationship, between the archaeological park of *Tombe di via Latina* and the ancient route of the *Via Latina* with a series of demolitions along the axis and the creation of a service area to the park that is also open to the rest of the neighbourhood. The diagrams on the right represent a schematic overview of the issues involved: pre-existing vegetation, permeability of the areas, the path system, system services, and related areas of relevance, morphological system, the system of fountains and ponds, systems for the production of energy from renewable sources and energy saving, system of constructed wetland, gray water and rainwater, along with a schematic time line of the intended use of the area. Sun path and microclimate simulations of the area contribute to the verification and tuning of the design process.

3. Reconnection of the green system with *Torre del Fiscale* (Giannetti et al. 2014).

The plan, that is supported by conceptual schemes, describes a design approach based on reconnection of the two green edges that surround the area, through a series of green punctual injections, linked by the thread of the ecological network and enriched by the pre-existing archaeological architecture, to return *Torre del Fiscale* to its role as landscape landmark, as the Southeast entrance to the city of Rome.

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