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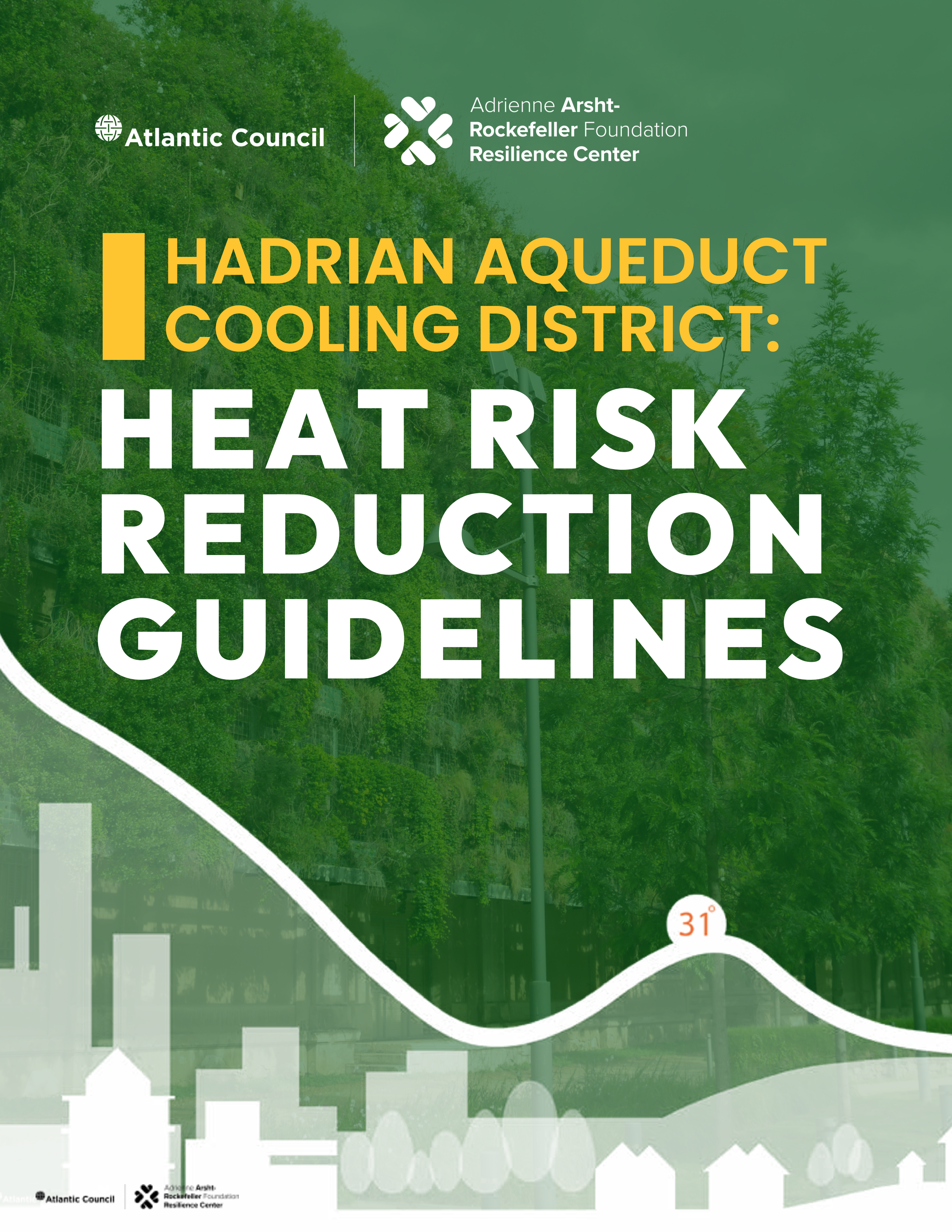
HADRIAN AQUEDUCT COOLING DISTRICT:

HEAT RISK REDUCTION GUIDELINES



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Hadrian Aqueduct Cooling District:
Heat Risk Reduction Guidelines
Γαλάζια και πράσινη ζώνη Αδριάνειου Υδραγωγείου:
Κατευθυντήριες Οδηγίες Μετριασμού Θερμότητας

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FOREWORD

Context of the heat risk reduction guidelines development

Climate change has caused the unprecedented exposure of people and ecosystems to extremely high temperatures. Cities around the world, from Canada and England to China and Australia, are experiencing unprecedented temperatures with heat waves lasting longer and occurring more frequently. Long periods of high temperatures endanger people's health, disrupt economic prosperity and social cohesion, undermine the safety of city dwellers, and cause new and unforeseen challenges for policymakers. Although heat waves in the climate change era are responsible for alarming mortality rates, the threat and impact of this phenomenon are usually overlooked.

The city of Athens is increasingly characterized by very hot summers with frequent heat waves and extremely high temperatures. In the summer of 2021, the city of Athens experienced record-breaking temperatures, reaching 45°C. The number of hot days in Athens exceeding 35°C is currently averaging around eight days each summer. Without action to reduce greenhouse gas emissions and help the city adapt to climate change, that tally for very high temperatures could reach fifteen to twenty days per year by 2050.

The densely built urban core of Athens is dominated by concrete and asphalt, trapping man-made heat from cars and air-conditioning and radiating it back into the city, which adds to the temperature increase. In addition, the density of the city leaves little space for parks or tree-lined boulevards, which could provide shade for buildings, streets, and residents. This phenomenon—the urban heat island (UHI) effect—makes the city center much hotter than the suburbs and is intensified by climate change. The most densely populated areas of central Athens are already reaching temperatures that are up to 10°C higher than in surrounding areas.

Athens' resilience to very high temperatures and the impacts on the health, social, and economic life of the city will depend in part on redesigning the built environment. Using nature-based solutions (NBS) and blue-green infrastructures can redefine the construction of public spaces, minimizing hard surfaces and the primacy of cars.

This report's heat risk reduction guidelines are key to the new approach to public space design to reduce urban temperatures. This is a manual of technical specifications concerning the use of urban nature, water, and special water-permeable materials to reduce temperatures, geared to different urban Athenian typologies. These specifications will be applied initially to the Hadrian Aqueduct Integrated Territorial Investment projects, which the New Metropolitan Attica Development Agency submitted for European Union structural funding. The city of Athens, located in the region of Attica, intends to champion these design guidelines beyond its metropolitan area, modeling ways to achieve a cooler urban center. The adoption of some or all of the proposed measures (a summary of which can be seen on page 91) by the municipal councils of the thirty-eight municipalities of metropolitan Athens will institutionally enshrine the new logic of redesign in the era of climate change.

In expectation of a greener and cooler Athens,
Eleni (Lenio) Myrivili
Global Chief Heat Officer,
UN-Habitat and Adrienne Arsht-Rock Resilience Center

INTRODUCTION

The Hadrian Aqueduct

Rendering of Hadrian Aqueduct's Temple of Minerva

Hadrian Aqueduct in the area of the Olympic Village in Thracomacedones

The Hadrian Aqueduct, commissioned in the year 140 AD during the reign of the Roman Emperor Hadrian, stands as an exemplary and enduring feat of engineering and infrastructure. As the largest surviving ancient aqueduct still operational in Europe, it extends over a length of 23.5 kilometers across Attica, with the majority of its course hidden underground. The aqueduct originates in the outskirts of Parnitha and terminates at Hadrian's reservoir located in Dexameni (or Reservoir) Square within Kolonaki. Along its course, it traverses the municipalities of Acharnai, Kato Kifissia, Metamorfosi, Heraklion, Maroussi, Halandri, Neo Psychiko, and Ambelokipi.

The Hadrian Aqueduct served as the main source of water supply for the region until the beginning of the Ottoman Empire in the mid-fifteenth century. From then until the early twentieth century, it was used by municipal authorities only at times of acute water scarcity In the early twentieth century, it was closed completely.

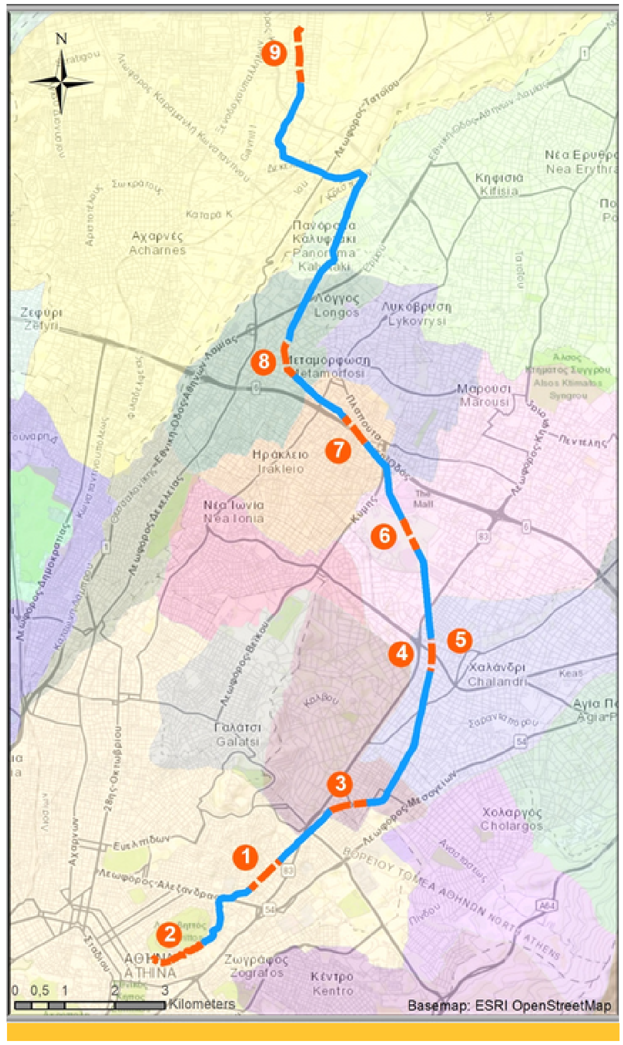
In the mid-1990s, the Metamorphosis municipality started using water from this historic aqueduct exclusively for the irrigation of green spaces. In the summer of 2020, the Halandri municipality embarked on a project to not only restore the Roman aqueduct as a prominent landmark but also integrate it into the daily life of the city.

At the heart of the strategy behind the Integrated Spatial Investment Area of the Hadrian Aqueduct (OXE-BAA) lies the objective of promoting the aqueduct as a historical monument and harnessing its potential as an environmental resource through the most comprehensive utilization of its aquifer.

Source: New Metropolitan Attica

The role of the Hadrian Aqueduct in urban rejuvenation projects

The Hadrian Aqueduct has the potential to provide a new, highly efficient, and sustainable source of water to the nine municipalities it crosses: Acharnes, Kifissia, Metamorphosis, Heraklion, Maroussi, Halandri, Filothei, Neo Psychiko, Athens. The vision of the special development zone of the New Metropolitan Attica Area is the promotion of the Hadrian Aqueduct as a historical monument and as an environmental "tool" to maximize the potential use of aquifer water in urban areas for irrigation and cooling. As such, it could provide a new parallel irrigation system, separate from the existing drinking water distribution system of the national Greek water company, EYDAP. Most importantly, it is the first time such a system will be implemented in Greece. Furthermore, as a flagship project, the Hadrian Aqueduct could catalyze more sustainable urban development in Attica.



The areas with the greatest intermediate redevelopment potential in each municipality crossed by the Adriatic Aqueduct, as presented in the Design Charette. From north to south, it crosses the municipalities of Acharnes, Kifissa, Metamorphosis, Heraklion, Maroussi, Halandri, Filothei, Neo Psychiko, and NS Athens.

The zone of influence of the aqueduct has not yet been defined but is calculated as one kilometer offset to the left and right of the indicated line of the aqueduct's pumps in the diagram on the right. In parallel with the urban redevelopment studies in the zone of this aqueduct by New Metropolitan Attica and EYDAP, the present set of guidelines for urban planning and urban design have been developed. These guidelines seek to provide solutions to reduce extreme heat-related risks in Athens. The solutions presented include t

The use of water elements to cool the surrounding areas, the introduction of high biodiversity aimed at creating favorable microclimates, and ways to optimize the heat impacts of urban elements ranging from playgrounds to paving.

The overall aim of the project is to establish a framework of technical specifications for the design and implementation of sustainable and climate-responsive parks, squares, streets, and public spaces. The project provides climate change adaptation measures to support heat mitigation, flood prevention, water availability, habitat biodiversity, and human well-being. The guidelines will be applied in the development of sustainable public spaces in the areas within the zone of the Hadrian Aqueduct. These solutions can also be transferred to other neighborhoods in Attica.

Guidelines Structure

The guidelines present different measures to transform urban areas along the Hadrian Aqueduct into new, green, cool, and resilient urban centers. The document is structured into the following four chapters:

- Water elements.
- Green elements.
- Materials and urban equipment.
- Municipality policies.

Chapters one through three detail the design and integration of water elements, green elements, and materials as well as the urban equipment to support climate change adaptation. The fourth chapter focuses on the policies for heat risk reduction for the City of Athens and the other municipalities in the Athens metropolitan area. Furthermore, Appendix A provides a detailed plant palette of trees, shrubs, and grasses that can withstand extreme heat conditions. Their shading potential and their benefits for microclimate are also described.

These guidelines have been created specifically for the climatic, geographic, geological, morphological, and hydrological conditions found in Attica and in the zone of the Hadrian Aqueduct.

A major aim of the guidelines is to present a wide range of feasible and applicable solutions for typical urban situations in Attica including parks, squares, and streets. Particular streets or squares that fall within the presented categories of solutions will be named indicatively. However, the available options are not limited to these indicative names only. There are many other options, including squares and parks, that may fall into these categories.

Finally, the guidelines are formulated in three tiers of instructions:

Must: required to enable the implementation of the project.

Should: advisable for planners, designers, and contractors when implementing the project.

Can: consider in order to create additional benefits and synergies for the implementation of the project.

The cooperation and involvement of stakeholders is of great importance for integrated spatial planning in Attica. Therefore, this planning should include:

- A traffic and integrated transport study.
- A comprehensive watershed approach to urban planning (which often goes beyond the boundaries of specific projects or municipalities).
- Stormwater management issues and the need to address flood-prone areas.
- Socio-economic assessments.
- Organization of public participation events and consultations.
- Digitalization of data, mapping of data in the same geographic information system (GIS) files, and communication between authorities for easy access to information on:
- Connectivity of green spaces.
- Shading elements for public spaces.
- Ecological and landscape education topics.
- Inclusion of solutions (e.g., green walls) in new funding tools.

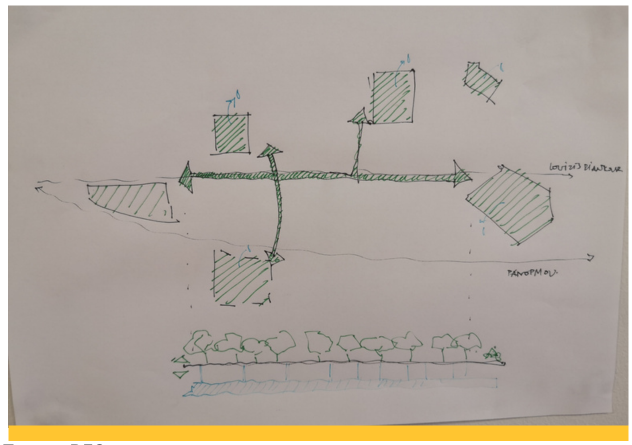
Inclusion in the digital archive of farmers' market areas.

Design Charette

As part of the development of the design guidelines, the project team, in cooperation with New Metropolitan Attica and the Adrienne Arsht-Rockefeller Foundation Resilience Center, organized a two-day workshop. This design charette involved stakeholders from all nine of the municipalities through which the Hadrian Aqueduct traverses.

During the workshop, we presented draft guidelines and divided the participants into four groups, which were tasked with using the information to redesign Louis Riancourt Street. The sketches below illustrate their thoughts on redeveloping the street using water from the Hadrian Aqueduct. The guidelines now include participants' comments.

Team RES

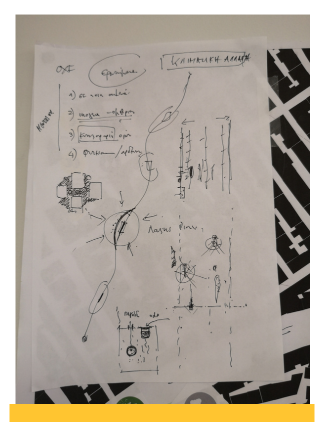


Team RES

Team FLOW

Team Cool Innovation

Team Four



Team Four

Climate in Athens

In Athens, the capital of Greece, the Mediterranean climate is mild, with moderately rainy winters and hot, sunny summers.

The city is located near the thirty-eighth parallel, in the plain of Attica, which is surrounded by mountains on three sides and overlooks the sea to the south.

Even though the winter, which takes place from December to mid-March, is mild, outbreaks of cold air from the Balkan Peninsula lowers the temperature and can even bring snow. Snowfalls occur more often in the northern part of the city; at the city center, a snow-covered Acropolis is a more common sight than its lower surrounding areas.

A particularly abundant snowfall, which also affected the southern and coastal areas, occurred in February 2008. In that case, the temperature dropped to -4°C (25°F).

Summer is hot and sunny. Athens ranks as the hottest capital of Europe in summer. In July and August, the temperature easily reaches 35/36°C(95/97°F). During heat waves, it has reached up to 40°C (104 °F). The highest-ever temperature of 43 °C (109.5°F) was recorded in August 2021.

I WATER ELEMENTS

WATER ELEMENTS

Role of water elements for heat risk reduction

Water is an important resource for life and well-being. Its presence provides an element of attraction and regeneration. and refuge from heat in the city. Too little or too much water brings problems: Attica has been facing staggering challenges in recent years including major fires, heat waves, and floods. The phenomenon of the urban heat island, combined with air pollution, rising temperatures, and increased humidity in Attica creates an unpleasant environment that puts vulnerable groups of the population at risk.

Water is a limited resource that plays a critical role in the resilience of the city. Public services in Attica supply potable water of very high quality. However, it is very expensive in terms of energy, as it comes from freshwater lakes far away from Attica. Amid the rising challenges of climate change, using potable water for irrigation and urban water features is becoming increasingly expensive for the city to maintain. This is why the Hadrian Aqueduct (HA) provides the city with a rare opportunity to create a complementary irrigation system for greenspaces and water supply for water elements in squares and playgrounds.

The introduction of water elements in urban areas can reduce ambient temperature by up to 5ºC, and thus significantly contribute to thermal comfort in the area. Similarly, water can be used to reduce urban heat islands (UHI). Bodies of water can function as a heat sink, as water heats and cools more slowly than surrounding pavement or the built environment; that heat sink effect is especially pronounced where trees shade the body of water. When cool water evaporates, it increases humidity and reduces air temperature.

This chapter describes the role of water in the city and includes the following sections:

- Typologies of urban cooling systems using water.
- Typologies of water elements in playgrounds.
- Typologies of irrigation systems.
- Guidelines for the distribution of drinking water fountains in the city.

Urban typologies along the Hadrian Aqueduct

The urban uses and the structure of the urban fabric in Attica include three main types of urban spaces that will be presented in these guidelines:

- Streetscape typologies.
- Plaza typologies.
- Park typologies.

For each of these typologies, the guidelines present suitable design solutions and principles for the integration of different water elements into the design of urban spaces tailored to their spatial constraints.

The suitable design of water elements requires a study of the slope of the terrain and the role that the specific targeted area plays in the watershed and catchment.

Sustainable water elements are directly related to green elements. They often go beyond sustainable urban drainage solutions as they can have many different characteristics (e.g. type or amount of vegetation and size) and provide different benefits to the public space. These types of solutions have been an integral part of sustainable landscape architecture and urban design solutions worldwide and have many names, most commonly referred to as water-sensitive urban design or blue-green infrastructure. While they are fairly new topics for urban design and planning in Greece, there are many case studies globally, including in regions with climate conditions similar to the Greater Athens area.

These design solutions describe principles by which green spaces can be used to convey, detain, retain, and store water, in order to slowly return it to the groundwater reservoir, to purify it to a level fit for a certain purpose, and to reuse it. Green spaces can be designed to retain large amounts of water in the event of heavy rainfall. Sunken paved areas in the urban environment can be used to store water during extreme rain events. These types of solutions will be presented by urban typology in this chapter.

Streetscape typologies

Plaza typologies

Park typologies

Streetscape typologies

Several types of water elements are suitable even for densely built urban areas, where open space is limited, such as in the densely populated Greater Athens area. Small water elements are suitable for these areas.

- Along the streets through which the HA passes, a linear water feature or a bioswale (see page 25) could be installed to indicate the line of the underground aqueduct on the city's surface.
- Streetscape design should consider the location of the watershed and how the street conveys water during heavy rainfall and in the event of flooding.
- Small water elements can be distributed across dense urban areas. Local thermal effects of small urban water bodies themselves can be negligible, but their effect is enhanced through shading from trees, natural ventilation, fountains, sprinklers, or mists. Fine water spray induces absorption of latent heat from surrounding moist air. Misters are particularly efficient since individuals can come in direct contact with them and their cooling effect. They can cool down ambient air by 7°C to 10°C. Misters are already frequently placed in cafes in Attica.

Other solutions include:

Water sprinklers or evaporative misters:

- Very suitable for dense areas as they can be suspended without compromising walkable land.
- Can be placed at bus stops and along pedestrian networks.
- Must be operated with potable water to avoid nozzle clogging.
- Requires electricity supply for small internal pumps and motors; PV panels can provide decentralized power.
- Components: nozzle heads, wiring, brackets, and mist pumps.

Wetting pavements:

- A study in Paris, France, found that wetting pavements reduces daytime temperatures by up to -1.5°C Universal Thermal Climate Index (UTCI), which describes human comfort under conditions including temperature, humidity, wind, and radiation.
- Applying 6 millimeters (mm) of water to pavements for ten minutes in the morning, preferably between 8 a.m. and 10:00 a.m., guarantees maximal evaporative cooling for twenty-four hours during a heat wave. Rainwater and treated wastewater are suitable water sources.

Example of bioswale

Example of wet pavement

Plaza typologies

A plaza is an urban design typology that provides a flexible and extensive hardscape open for different kinds of uses. In the context of the Athens metropolitan area, such design solutions must include design elements that respect the need for shading, water-permeable paving, increased green surface coverage, and the inclusion of water features.

To ensure sustainable water use and avoid water use trade-offs and competition for limited resources, most of the water elements proposed in this chapter avoid the use of potable water and instead involve water from the HA or rainwater. Rainwater can be collected and purified in the plazas themselves by natural or engineered means. Water from treated wastewater can also be used. Depending on the water quality, further purification steps can be installed in squares or proximately. The images on the right display a small underground reservoir that can collect rainwater from the square and surrounding buildings. The collected water can be used for irrigation of surrounding green spaces as well as to supply the following water features:

- Water mirrors (e.g., reflecting pools), water screens (e.g., projecting images on water droplets), or shallow ponds:
  - Depending on the size of the square, its uses, and its layout, part of it can be converted into a small pond or a very shallow layer of water that serves as a play and cooling element for people of all ages.
- Surrounding and aquatic vegetation:
  - A barrier of dense vegetation around a water mirror or pond helps to contain the water flow and increases the cooling effects.
  - Technical components of a pond include a pond liner or prefabricated pond basin, sand in the bottom layer (if a pond liner is used), stones to fix the liner, gravel at the bottom of the pond, aquatic plants for water purification, and surrounding vegetation.
  - The water element can include an underwater filter and waterfall pump.
  - Water fountains: In-ground fountains can be incorporated as water elements as well as elements for wellness and temperature reduction. Countless commercial products and forms of play fountains that can be integrated into paving.

Plaza with water mirror

Plaza with water fountains

Plaza typologies

Linear water element or constructed stream:

- Shallow linear water elements can indicate where the water passes underground along the corridor of the HA, and also provide an axis of water movement from a larger water body to a smaller one.
- These streams can be constructed as gray infrastructure or embedded in green infrastructure.
- It is very important to consider the natural slope in the design, with respect to the flow direction and velocity.
- Benches and various types of seating, as well as shading, should be provided alongside these linear water elements. For example, they can be designed to allow people to put their feet in the water while sitting on a bench under the shade to cool off.

Plaza - Linear water element / stream

Fog, water mist, water sprayers, or evaporators:

- A very suitable solution for densely populated areas as they can be suspended without using the square's ground level.
- The direction of strong winds in the summer must be considered for adequate design and location of water spray or water vapor elements.
- They need to operate with sterile water as airborne water particles can be inhaled.
- The water also needs to be free of solids to avoid blockage of nozzles.
- Power supply is required for small internal pumps and motors; PV panels can provide off-grid power.
- Technical components include nozzle heads, wiring, brackets, and mist pumps.

Plaza - Fog or water mist

Water-permeable paving materials should be used on hard surfaces of squares:

- Water-permeable pavements have aggregate that can treat and retain runoff, while providing compact surfaces necessary in plazas, for example.
- Rainwater can permeate the surface and flow into an underlying storage layer for reuse or permeate the ground, and flow into the aquifer.

Park typologies

Parks are a typology of urban design characterized by extensive green spaces and paths. Materials are softer, paving is minimized, and biodiversity can be high. All the following solutions can be implemented with soil bioengineering techniques (the use of living plants and natural materials to prevent erosion and stabilize soil), which is highly recommended.

The following water elements are suitable for parks:

Urban lakes:

- A naturally sloping pond for runoff and stormwater management is an ideal solution for parks.
- Lakes are suitable for new urban development or suburban areas.
- They have large cooling effects due to their size, suitable for new urban development areas or peri-urban areas.
- Densely planted trees and shrubs around the water body form air circulation (ventilation corridors) and thereby transport cool air from water surfaces to greater distances.
- Riparian, submerged, and floating vegetation is needed to continuously purify water and maintain good water quality for full regenerative effects. Water features can include underwater filters and waterfall pumps.

Constructed wetland

Constructed wetlands:

- Ideally, such wetlands should connect directly to an existing pond or a newly constructed artificial pond, but they also can be constructed independently.
- They offer the greatest benefits among water elements for biodiversity, carbon sequestration, flood regulation, and coastal protection.
- These wetlands are suitable for peri-urban areas or large parks.
- Their selected substrates and dense, tall planting can clean water from a range of heavy metals and other prevalent contaminants.

Lake

Constructed wetland / different wetland substrate

Park typologies

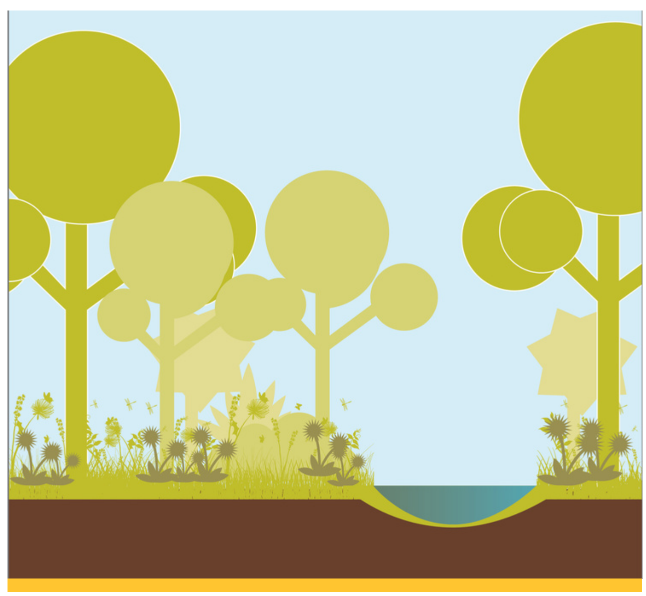
Rain gardens:

- Rain gardens are vegetated shallow depressions that collect and filter runoff. They should be sited and constructed based on the topography and land uses.
- Plans should be formulated after studying stormwater in heavy rainfall events and correspond to drainage systems planned and implemented at the municipal level, to alleviate underground pipe networks.
- Rain gardens provide natural runoff.
- They slow down and concentrate water to avoid flooding at lower points in the urban watershed.
- Plantings can be highly biodiverse and include plants that can withstand flooding and drought in the Attica climate.
- Increased biodiversity and retention of water in rain gardens increases evapotranspiration, contributing to a pleasant microclimate.
- Rain gardens also can be integrated into urban blocks.

Creek, river, stream, canal:

- The HA intersects the Kifissos River in Metamorphosis. Downstream in Halandri, it passes near the Halandri Creek. In these areas, riparian, nature-based solutions can be placed, with the following characteristics:
- The high density of vegetation surrounding the river helps to maintain water flow and increases cooling effects, biodiversity, and improved air quality in the area.
- It can be supplied with rainwater and treated wastewater.
- Flooding does not affect these solutions as they are designed according to the shear stress of the riverbanks, the slope of the terrain, and the velocity of water flow.
- Technical components include lining the stream or channel with sand at the bottom, adding stones to fix the lining and gravel at the bottom of the stream, plus aquatic plants to clean the water and surrounding vegetation.

Rain garden



Creek, stream, river, canal

Typologies of water playgrounds

Playgrounds are important urban features that enable children and young people to socialize in open public spaces, play, and exercise. Children's exercise is critical to the health of young members of society, and the fact that Greece has one of the highest rates of childhood obesity in Europe indicates the gravity of the issue. In Athens in summer, playgrounds burn and repel their young visitors, as they are exposed to the sun all day long, most of them without shade, trees, or water features. Especially for the poorest families, who do not have the option of a vacation or holiday home, public spaces such as playgrounds are the only places for recreation in summer. Unfortunately, they are often too hot in the daytime and are only accessible at night.

To mitigate temperature rise, all playgrounds should have a section for water play, i.e., water-based games, supplied with water from the HA. All water features can be combined with an interesting lighting design at night.

The design of the playgrounds should take into account the following green elements: biodiversity, seasonally blooming colors, and textures in plants, avoiding thorns and toxic plants, avoiding plants that cause common allergies, avoiding species that attract bees and wasps, and aesthetic criteria.

Moreover, other design criteria include shading of the playground, protection from vandalism through a selection of robust natural elements, safe use of play elements, inclusion of very fine gravel, sand, or ethylene propylene diene monomer (EPDM) surfaces, a synthetic rubber, to prevent injuries, a selection of design elements and planting that requires low maintenance, and the integration of many seating elements in a shaded area for the parents.

Age-appropriate playgrounds should be fenced, operating rules displayed on signs, and pest management measures implemented. The types of available playground elements are constantly increasing and developing through the design innovation of new products, so research should be carried out in cooperation with playground design experts to develop play areas with a special and specific character, especially in areas where children have no other outlets or play opportunities.

Typologies of water playgrounds

Water mirror:
- A thin layer of water (up to 5 centimeters) that can collect rainwater and store it for purification and reuse, or direct use of the water from the HA.
- It is a play surface.
- Children can play with a ball or a bicycle.

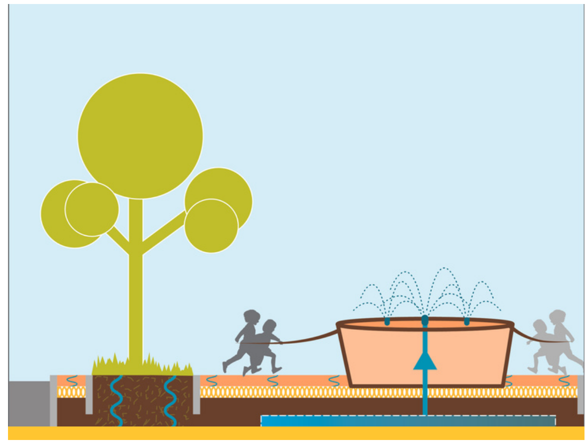
Manual water pump:
- A pump structure that pulls water directly from the HA and uses it as an educational play element.
- The hydraulic pump moves the water through a manual pump, which can also be used as an exercise tool.

Archimedes screw:
- Another pump construction that pulls water directly from the HA, the Archimedes screw also provides an educational play element.

Landforms and high fountains:
- These small artificial concrete hills have embedded fountains that throw water high as play elements for children.
- Safety must be considered. The surfaces must not be slippery, which requires maintenance and cleaning.
- Artificial hills should have different colors and heights, possibly with ropes or nets so that children of different ages can play and exercise.

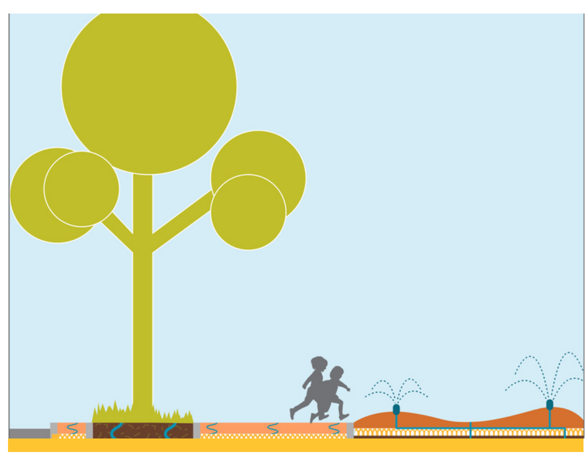
Water fountains:
- In-ground fountains are elements of play, but also elements of wellness and temperature reduction.
- There are many products and forms of play fountains on the market, which can be integrated into paving in different ways.

Small lake or pond design:
- A small pond with a raft and rope to cross the pond.
- Technical characteristics of the pond: Lining of the pond or prefabricated pond basin (sand in the bottom layer if pond lining is used).
- A maximum of 30 cm of depth for safety reasons.



Water playground: Water pump

Water playground: Water mirror



Water playground: Landforms with integrated water fountains

Typologies of water playgrounds

Linear water element, constructed stream:

- A sloping water line can be a unique feature in a playground, either as a linear or free-flowing curvilinear element. It can be a standalone feature or part of a system that includes a small lake and other water features (see above descriptions).
- Children can play in this creek and bring their boats. The creek is particularly interesting for children to play with when diverse elements are integrated, such as different heights that result in changes in water velocity, or a small bridge.
- It should be fed by rainwater or from the HA.
- Components include a lining of the stream element, with sand in the bottom layer; stones to fix the lining; gravel at the bottom of the stream; vegetation with aquatic plants to clean the water; and other riparian vegetation in the surrounding area. It is also possible to have such a stream integrated with natural stone or concrete elements and have a more urban character.

Water playground: Linear water element as a play water stream for children's boats

Fog and water mist:

- For all air-borne applications of water, the sterility of the water needs to be assured.
- Water must be free from solids to prevent the nozzles from blocking.
- The direction of strong winds in summer must be considered for functional design and the location of spray or water vapor elements.
- These elements are very suitable for dense areas as they can be suspended without using the playground level.
- A power supply is required for small internal pumps and motors. Photovoltaic panels can provide decentralized electricity.
- Components include nozzle heads, wiring, brackets, and mist pumps.
- Splash parks are an alternative option. In these parks, more intense versions of the misting system are often integrated into unique, playful designs, and other playground equipment.

Water playground: Fog or water mist

Typologies of irrigation systems

The Greek climate requires urban green spaces to be irrigated to ensure their survival. The time and schedule of irrigation is of great importance. The following advice is based on research in other European countries and the United Arab Emirates, and it is of great importance that similar research and experience from gardeners in Attica will be included in the municipalities' irrigation schedule. The following irrigation systems are proposed for the three urban typologies:

Street tree alleys:
For street trees, it is difficult to implement a permanent irrigation system. A Municipal vehicle is required to water the plants using a hose.

Squares and parks:
Where possible, a permanent automatic watering system improves maintenance efficiency. Automatic systems also tend to achieve better water conservation. There are two options available:

- Drip irrigation, which involves a system of pipes and nozzles (sprays) that allow for varying water supply.
- Wetting pipes, which are tubes that release water directly into the soil and are more efficient than nozzles. Water supply, however, cannot be regulated.

Irrigation needs:
- Irrigation is required to mitigate plant stress during dry periods.
- Irrigation water demand depends on plant type, soil, and drainage properties, shading, and wind exposure.
- Shading grass areas, e.g., through trees, can reduce the irrigation needs of grass by 50 percent.
- Native species are adapted to local climatic conditions and therefore generally require less irrigation.
- Plants with higher water demand, and in turn higher evapotranspiration, have a greater cooling effect; lack of irrigation, however, negatively affects the thermal environment.
- Young trees require irrigation for the first five years, especially amid the current and expected increasing frequency, duration, and intensity of high temperatures.
- Soil additives that aid water storage include attapulgite, zeolite, and biochar. Soil organic carbon improves water storage and nutrient uptake capacity.
- "Sponge city" policies (i.e., urban surface water management approaches) entail nature-based solutions to collect, store and purify rainwater, thus conserving water locally and reducing external irrigation needs (see sustainable drainage systems in the section below).

Typologies of irrigation systems

Sprinkler irrigation:

- Distributes water like rain over a land surface.
- Sprinklers work even on irregular topographies (unlike drip irrigation systems and hoses), but are vulnerable to windy conditions.
- Water should not contain even the slightest residue, as troubleshooting a jammed sprinkler head is very difficult.

Drip irrigation:

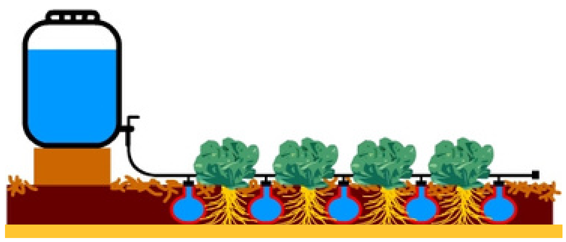
- Microirrigation systems are generally much more efficient than sprinkler irrigation.
- Low discharge pressure makes them relatively energy efficient, but installation takes time and is costly.
- Drip irrigation using nonconventional water sources (rain- water, treated sewage, wastewater) requires industrial nozzles given the potential presence of small particles in the water.

Water wetting or diffusion systems (spray irrigation):

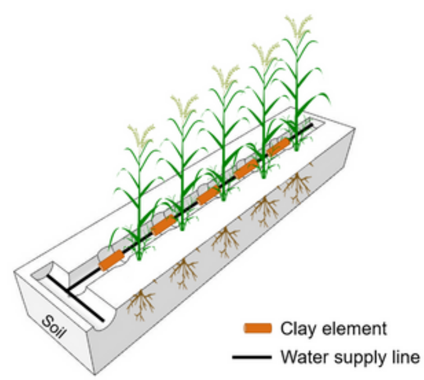
- Systems are placed underground or with light ground cover to mitigate damage and degradation from solar radiation.
- A porous pipe or container emits water over its entire surface.
- They can be made of clay, possibly locally sourced, and are regarded as the most efficient method of irrigation, saving up to 70 percent of water consumption compared to drip irrigation systems.
- The coverage radius is not as wide as with drip systems.

Overflow drainage pipes and nutrient capture:

- Smart irrigation systems reduce overwatering by assessing the specific water requirements of plants and adjusting water application, thus optimizing irrigation. Examples include:
    - Underground, clay-based irrigation systems (e.g., EU-funded project DIVAGRI, divagri.org).
    - Open furrow irrigation (traditional).
    - Stone canal irrigation (like the ancient Inca systems, for example).
    - Pumps for water supply, with attention to the salinity of brackish water, which requires special pipes (invented in Israel) to remove salts.
    - Water tanks (underground mini stone caves) for parks and sloping sites, which allow for filtration and storage of rainwater and overflow for irrigation.



Clay irrigation



Clay-tube irrigation (SLECI), DIVAGRI, MED-WET

Typologies of irrigation systems

Tree watering bags:

- Tree watering bags are designed to wrap around trees and release water over time. They must be filled with a hose of water and then the bag slowly directs the water into the tree root system.
- Watering bags can prevent over-irrigation as well as underwatering, both of which should be avoided with young trees.
- Disadvantages:
    - Not a long-term watering solution.
    - Must be removed during the winter.
    - It does not work well with large/mature trees.
    - They sometimes puncture/leak.
- Usage:
    - Most tree watering bags hold somewhere between 75 and 200 liters of water. The average bag only needs to be refilled once every week or two, based on typical water requirements.
    - In a heat wave, water can be poured into the bags every one or two days to hydrate and cool the root zone of the tree. Newly planted fruit trees need bag replenishment every one or two days for the first month.
    - They last for about ninety days. Direct sun exposure warms them up during the day and they become cool again at night. Physical stress takes a toll on the lightweight material.
    - Watering bags for trees should be removed at least once every season. For example, a bag placed on a tree in the spring should be replaced after about ninety days. Tree watering bags should be removed during cold and icy winter months. Sometimes the bags are damaged by a fallen branch or a rock thrown by a lawn mower, for example. In these cases, the bags must be removed and replaced immediately.

Tree watering bag

Typologies of alternative water sources

The use of alternative water sources plays a very critical role in coping with urban heat, droughts, and fires, which are projected to increase. It is urgent and critical to bring about a change in mindset about using alternative water sources to save drinking water for human consumption.

The availability of water is a major constraint in reducing urban warming in the Mediterranean region. What's referred to as blue infrastructure —to manage urban wastewater and rainwater— opens up possibilities. Unconventional water sources such as rainwater and treated wastewater can replace potable water where potable water quality is not required. The HYDROUSA project has shown many fold applications of nature-based solutions for all non-conventional water resources in the Mediterranean landscape. The HOUSEFUL project has shown these solutions at the building level.

Alternative or unconventional water resources:

- Suitable for nonpotable uses such as irrigation of green spaces and green walls (i.e., structures covered with vegetation).
- Can be used after ultraviolet (UV) light treatment or chlorination for various water-based heat mitigation features such as water playgrounds.
- The price of the HA water is currently being discussed in aims to provide it at as a substitute for tap water for nonpotable uses for potential stakeholders that own adjacent plots to the HA zone.

Rainwater:
Rainwater is a relatively clean and free source of water. Rainwater harvesting requires only simple technologies that are easy to maintain.

Treatment systems include planted drainage systems with the collection or treatment devices listed below, such as UV lights, chlorination devices, and post-filtration equipment. Prefilters, drains, and storage tanks can be used and, depending on whether the system is under pressure, pumps.

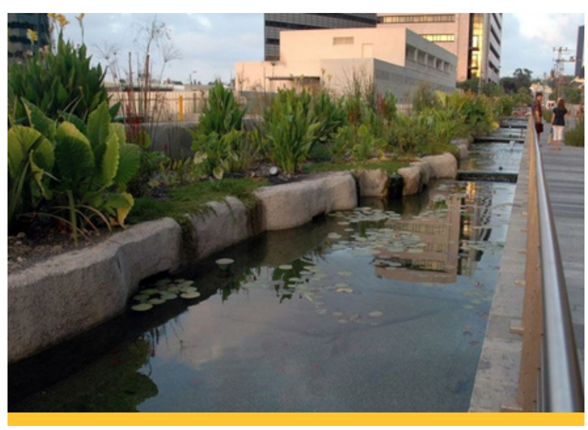
The Rooftop systems:

- Rain barrels.
- Dry" system: large barrel with collection pipe from roof gutter.
- Distributed-over-roof tanks enable energy savings compared to underground tanks, below-roof tanks, and block tanks. Their improved weight distribution across the building reduces reinforcement needs.

Surface water collection:

- "Wet" system: Rainwater fills underground piping and the water rises in vertical pipes until it spills over into the tank.
- Sustainable drainage systems (SuDS): water flows through piping and is stored in tanks (i.e., cisterns).

Rainwater storage



Collection of surface water, water networks

Typologies of alternative water sources

Treated wastewater:
Reuse of treated wastewater (also referred to as reclaimed water) turns waste into a valuable resource and frees up freshwater for uses that require drinking water quality. Treated and recycled wastewater provides a cost-efficient supply that decreases the freshwater demand and alleviates stress on groundwater, rivers, and reservoirs.

Treated municipal wastewater can be more suitable for irrigation than drinking water, as it contains nutrients. Many industrial purposes, such as cleaning streets or industrial sites, or cooling of thermal power plants, do not require drinking water quality and could instead use reclaimed water. Another advantage of treated wastewater, in contrast to rainwater, is the steady availability that matches the relatively constant water demand throughout the year.

Components of a treatment system for wastewater reuse:

Collection
- Piping for treatment on site or transport to a treatment plant.
- Separate piping for separate collection, treatment, and reuse of gray water and black water (i.e., wastewater).
- Gray water is less contaminated as it does not include wastewater from toilets and is therefore easier to treat than black water or unsegregated domestic wastewater.
- However, the interventions needed for separate collections make this more suitable for new buildings or buildings that are renovated.

Liquid waste storage

Decentralised wastewater treatment

Mechanical filters
- Mechanical water filters remove larger suspended material from water, such as sediment, solid organic matter, and accidentally flushed items and often fat and grease that floats to the surface.
- When used in combination with other water treatment equipment (as is often the case), they can be helpful to remove dissolved or very fine particles that do not settle/sediment in solely mechanic systems. For example, mechanical filtration steps can remove iron, manganese, or hydrogen sulfide after they are converted from dissolved to particulate states by separate oxidation.

Typologies of alternative water sources

(Bio)chemical filters

- The treatment process of road runoff is easier than that of gray water, which in turn is easier to treat than domestic wastewater. These reclaimed water resources face different levels of acceptance by residents.
- Nature-based solutions for treating wastewater or gray water for reuse include engineered wetlands with specific adaptations for limited space availability (e.g., vertECO® from alchemia-nova GmbH or greenhouse wetlands such as the Food Chain Reactor from Organica Water (see Figure 4; also see Section 2 for green elements).
- Treatment wetlands have no odor, visual, or noise pollution and are robust and low-maintenance technologies with additional ecosystem services as co-benefits.
- Activated sludge treatment is a type of constructed wetland. Sludge treatment wetlands (STW) or reed bed filters can also be used for this purpose to dehydrate the sludge and retain solids to produce compost for fertilization.

Tertiary treatment or polishing for high-quality reuse

- UV disinfection.
- Ozonation.
- Reverse osmosis.
- Membrane filtration.

Storage

- Reclaimed/reused water storage tanks are used to store treated wastewater effluent for a variety of nonpotable uses such as irrigation, industrial process water, and fire protection systems. The sustainability of agricultural, industrial, and other water uses is increased by using sources other than the traditional potable water system.
- Separated wastewater streams are easier to treat and reuse (e.g., street runoff is easier to treat than greywater, and greywater is easier to treat than domestic wastewater), and face different levels of acceptance among inhabitants.

Centralised wastewater treatment plant

Sustainable urban drainage systems

The following solutions are feasible in dry and very dry climates. Plants with these characteristics survive in these conditions.

Constructed wetlands:

- A constructed wetland (or treatment wetland) is an artificially engineered wetland to treat a wide range of wastewater flows, such as sewage, stormwater runoff, and industrial wastewater, as well as sludge. Constructed wetlands are a sustainable way to treat polluted water with minimum operational effort and cost.
- The shallow ponds, beds, or trenches feature floating or emergent rooted wetland vegetation, combined in a way that creates optimal physical, chemical, and microbiological processes naturally present in the root zones of marshes.

Components of constructed wetlands for wastewater treatment typically include:

- Pond liner or impermeable layer of clay to line the wetland basin.
- Soil/gravel substrate.
- Ground vegetation: aquatic plants, most commonly macrophytes.

Different forms of constructed wetlands include:

- Stormwater treatment units (i.e., bioswales, rain gardens, and wetland green roofs) and biofilter strips.
- Subsurface and surface flow treatment wetlands.
- Natural swimming pools with planted biofilters for water regeneration requiring no chlorine treatment.
- Floating islands.
- Reed bed sewage sludge treatment.
- Treatment wetlands as a tertiary treatment process after activated sludge processes at conventional wastewater treatment plants.

Water retention and detention basins:

- Retention basins help attenuate flows by retaining surface runoff and allowing settlement and biological treatment of pollutants.
- Detention ponds are designed for infiltration, while retention ponds are lined even if the soil is considered to have low permeability.
- Detention ponds provide a cost-effective storage unit for large volumes of water, mimicking natural ponds, promoting biodiversity, and providing aesthetic value.
- They also provide pollution control: Pollutants are mainly contained in sediments traveling as suspended solids, which settle in ponds. Aquatic or semiaquatic vegetation helps remove pollutants from the sediment via nutrient uptake and microbial degradation.

Wetlands on green roofs:

- Wetland green roofs can be designed to retain and filter rainwater.
- They can function as a water storage unit, with slow discharges to lower-lying vegetation in between rainfall periods.
- The vegetation on green roofs reduces the heat storage of the surface and therefore reduces the urban heat island effect while insulating the building.

Sustainable urban drainage systems

Bioswales:
Bioswales are strips of vegetated area that collect and filter runoff water from impermeable surfaces such as roads and parking lots. The substrate and vegetation infiltrate the stormwater runoff while also filtering pollutants carried by the runoff.

- In parallel to roads, bioswales can filter pollutants from street runoff and reduce flood risks.
- Slanted walls direct the runoff into vegetated ditches or depressions.
- Information about local rainfall and evapotranspiration patterns as well as existing infiltration capacity of other existing drainage systems are needed for site selection, capacity planning, and design.
- Some soil types and plants have higher infiltration capacity than others and should be selected accordingly, with a preference for native species and those that absorb more water and prevent erosion.
- Typical construction steps:
    - Dig a linear depression with slope walls;
    - Add a layer of gravel for stabilization and drainage;
    - Install perforated pipe underdrains;
    - Add a layer of a soil-compost mix;
    - Plant vegetation;
    - Build check dams (i.e., a small dam) to further reduce flow velocity, if necessary;
    - Add overflow structures to help handle runoff from bigger storms.
- Maintenance measures can include the removal of invasive plant species, cleaning to prevent clogging and improvements of stormwater direction into the depression.

In periods of drought and heat, vegetated channels are slow to dry out, retaining moisture within their structure and aided by biodiversity from different forms of grasses. They are therefore of great aesthetic interest even in periods of drought. In the Mediterranean climate, they act like greenbelts around streams that remain green even when the streams are dry for months.

Bioswale

Bioswale after rain event

Sustainable urban drainage systems

Rain gardens:
Rain gardens, like bioswales, are essentially made up of a constructed soil material and plants.

Biofilter strips:
These biofilter strips (also known as vegetated strips) are vegetated sections of land over which stormwater flows.

- Engineered soil is used in these strips, which are suitable to seam long impervious surfaces such as streets and sidewalks, to capture and filter runoff.
- They are not suitable for steep sites or for draining hot-spot runoff locations or where there is a risk of groundwater contamination because their small size limits retention and treatment capacity.
- When placed in between streets and sidewalks, or car lanes and bicycle lanes, these functional greening strips also serve as an effective road safety measure.

Permeable pavements:
- Permeable pavements with aggregate subbases can treat and retain runoff while providing solid surfaces necessary for streets, sidewalks, and parking lots, hence using space more efficiently.
- The rainwater can filter through the surface into an underlying storage layer and be reused or filtered through the ground (Chapter 3).

GREEN ELEMENTS

GREEN ELEMENTS

Role of green elements for heat risk reduction

Increasing urban green areas is considered one of the most effective strategies to mitigate the urban heat island (UHI). Increasing the number of urban green spaces, parks, street trees, vegetated areas, and green roofs can significantly and appreciably reduce ambient air temperature and, therefore, UHI through three processes:

- Evapotranspiration.
- Increasing direct shading on urban surfaces.
- Effect on air movement and heat exchange.

Based on several studies, the temperature reduction in tree-shaded urban environments can be as much as 4ºC. This depends on the size of the shaded area, the number of trees and green coverage, and the species selection.

This chapter presents different typologies of green spaces that can provide shade, coolness, and heat protection for citizens. Furthermore, Appendix A presents the selection of species according to different water availability in three scenarios: high, medium, and low water availability, specifically in relation to their evapotranspiration performance, heat risk resilience, and their ability to survive in the scorching heat of the Attica landscape.

This chapter describes the role of green in the city and includes the following sections:

- Determination of the tree coverage (continuous tree canopy) of public spaces
- Guidelines for urban green elements of the city
- Plant species selection table and good practices
- Guidelines for green roofs in private and public buildings
- Guidelines for green walls in private and public buildings, green pergolas, and green balconies

Role of biodiversity for heat risk reduction

The region of Attica should adopt the practices of many other European cities and commit to the establishment and enhancement of biodiversity in Attica.

It is urgent and critical to change the mindset of citizens about what is beautiful in urban nature and what deserves protection. Nature in the city is very important for ecosystem services ranging from water purification to recreational space, and it is often neglected in the Greek context. Wild nature in the form of grasses, herbs, and forbs that can withstand high temperatures and periods of drought, as well as biodiverse combinations of broadleaf and coniferous trees, have adaptive eco-system benefits as well as an aesthetic appeal.

Nature works in a complex and systemic way and many of its processes are not yet known. The scientific community is constantly discovering new structures essential to the functioning of ecosystems, with interconnections and critical synergies that are still to be understood.

For ecosystems to function optimally, there are specific species of flora and fauna that serve as the cornerstone. These species are presented in the literature as keystone species and help to define an entire ecosystem, without which the ecosystem would be dramatically different, or would cease to exist altogether.

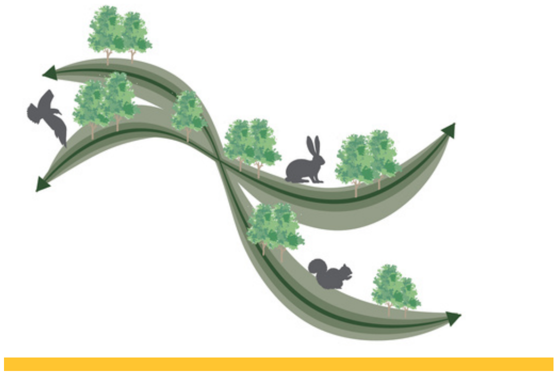
This chapter will present various typologies of green infrastructure. Green infrastructure is defined as strategically planned networks of natural and semi-natural areas, with other environmental attributes that are designed and managed to provide a wide range of ecosystem services, such as water purification, air quality, recreational space, and climate change mitigation and adaptation.

1Urban island effect diagram (UHI)

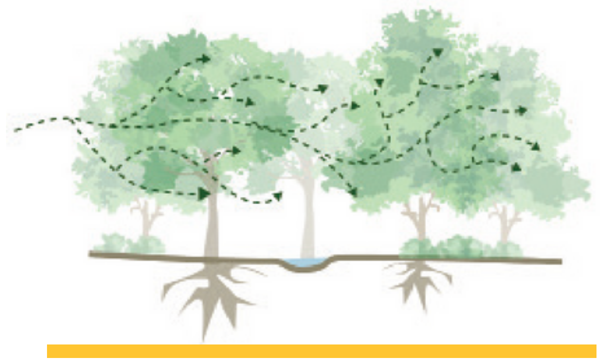
Role of biodiversity for heat risk reduction

The Heat Risk Reduction Guidelines for Green Elements in the city presented in this technical guide respect the following biodiversity principles:

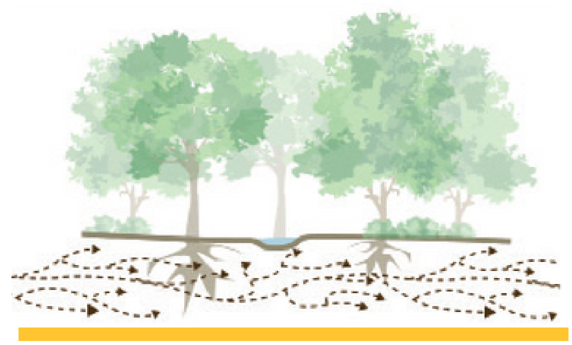
- Green spaces in the city should be connected to better co-regulate their ecosystem components.
- A healthy ecosystem can self-regulate; it has its own dynamics and can survive under extreme conditions autonomously. Animals, birds, and pollinators play a major role in the ecosystem's self-regulation and maintenance.
- Green corridors must serve and accommodate pollinator species, birds, and small animals.
- Supporting biodiversity creates competition and a reduction or even elimination of undesirable species (mice, cockroaches, pigeons) that have adapted to urban conditions.
- Green corridors should offer the layering of planting and linking of different vegetation strata occupied by different species.
- The integration of water features along these axes is of significant importance for the survival of species during heatwaves.
- Shrubs and hedgerows are habitats of immense importance for cities since they provide protection and habitat for small animals and birds.
- Root connectivity is of huge importance for communication between plants, ecosystem regulation, and the survival of plants during heat- waves.
- An ecosystem of high biodiversity has the potential to compensate for carbon dioxide by acting as a carbon sink.



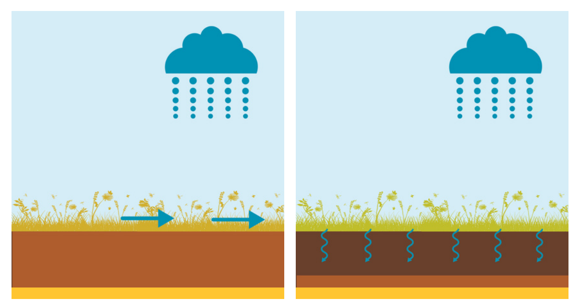
Green connectivity and areas for small animals and birds



Connectivity of greenery and pollinators



Root connectivity



Loss of soil permeability due to extreme heat

Green coverage

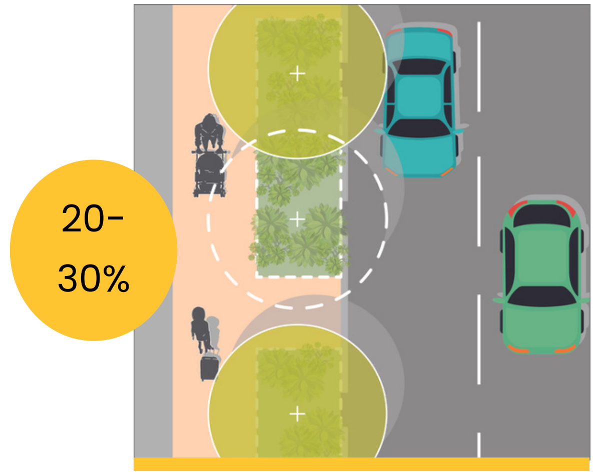
The first and most important directive for heat risk reduction in Attica is the maximization of green cover. The target is 30 to 40 percent green cover and/or permeable surfaces for the city of Athens by 2030. This target should become the new minimum for the whole region.

To achieve this target, we propose the following approaches to the three typologies of urban space:

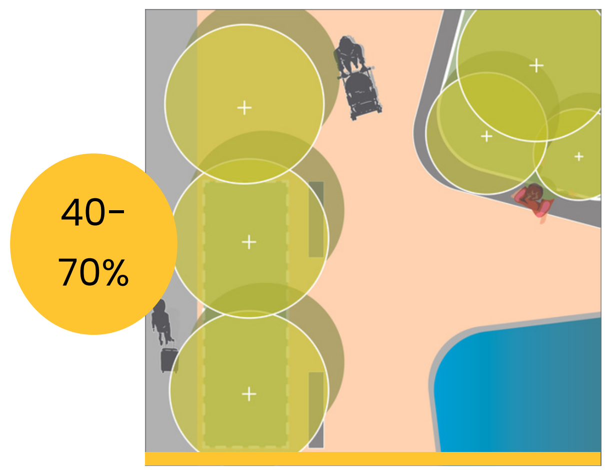
- Along streets: Increasing greenery through the planting of new trees, creating bioswales systems, or integrating trees in single beds where the roots are in communication. Preliminary target: 20 to 30 percent.
- In squares: Changing ground cover materials and maximizing green surfaces. Preliminary target: 40 to 70 percent.
- In parks: Maximizing the layering of green areas. Preliminary target: 80 to 90 percent.

In a study carried out in Attica during a short, extremely hot period in 2007, the following air temperatures were measured under tree vegetation on suburban streets (with reference measurements on five streets in Athens under mostly light wind conditions):

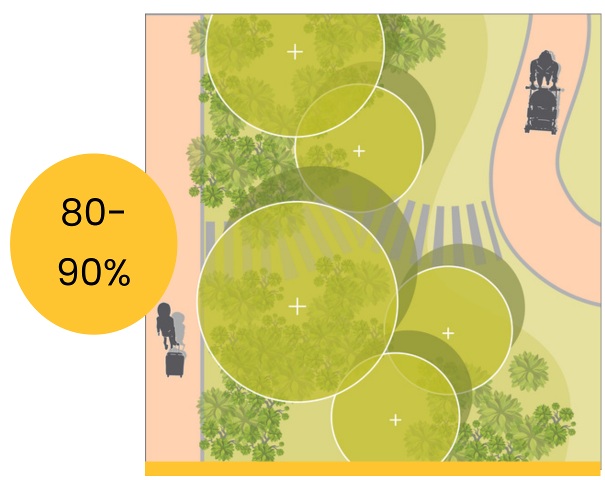
- The average cooling effect of the vegetation at 14:00 local sidereal time (LST) ranged from 0.5° to 1.6°C and at 17:00 (LST) from 0.4° to 2.2°C.
- The highest cooling effect of 2.2° C was achieved on a street with a shaded area with tall trees and minimal traffic.



Streetscape green coverage



Plaza green coverage



Parks green coverage

Urban typologies along the Hadrian aqueduct

As mentioned at the beginning of the chapter on Water Elements (Chapter 1), urban uses and urban fabric structures in Attica are categorized into three main urban typologies:

- Streetscape typologies,
- Plaza typologies,
- Park typologies.

Suitable planting groups are presented for each of these typologies. The choice of planting is relative to space availability and required functionality. These solutions must be designed in parallel with the typologies of sensitive urban design, as mentioned in the previous chapter.

Streetscape typologies

Plaza typologies

Park typologies

Streetscape typologies

In Attica, streetscapes constitute the largest part of the public urban space, both in percentage and in square meterage. Changing the circulation of street traffic to include green elements, while reducing parking spaces and introducing bicycle paths, should be the approach for the future—and will need to be implemented in cooperation with urban planners, circulation engineers, and sociologists.

Streetscapes are public spaces with the greatest competition of uses: cars, storefronts, pedestrians, pipes, sewers, infrastructure, and parking lots. Of them, parking lots are the least used spaces on streetscapes. To be future-compatible, parking spaces and traffic lanes will need to be replaced with fortified public transport systems (in terms of equipment, organization, and staff). This entails expanding the metro and tram system, the introduction of rentable e-bikes, e-scooters, and e-cars (as is the case in all major European cities, in cooperation with private companies), and the redirection of parking into multistory parking buildings (mobility hubs).

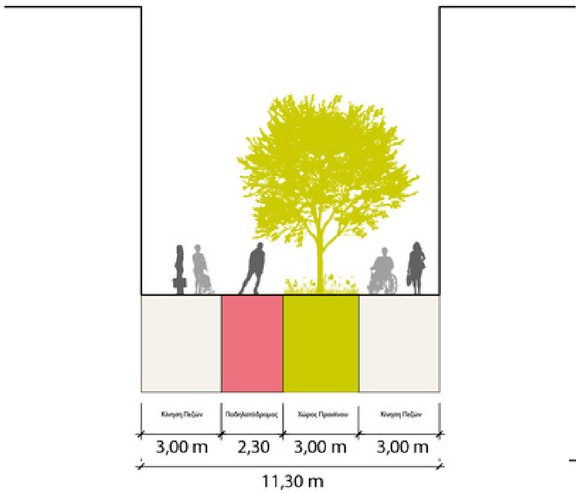
Changes to the streetscapes should permit access for emergency vehicles (with thoroughfares of 3.5 meters and 4 meters squared short-stop locations); pavements suitable for wheelchairs and child carriages, as well as for people who are visually impaired. A major obstacle to streetscape redesign in Attica is the fact that sewer pipes and infrastructure networks are not clearly delineated on the same side of the street, but are often located under the pavement and within tree zones (the planting area) instead of under car lanes, evidencing a true prioritization of car traffic rather than pedestrians.

Also noteworthy is that infrastructure companies in Greece such as water and electricity service providers are not required to reconstruct the streetscape to its original state after conducting system repairs and are instead free to close the hardscapes or cut tree roots as they please, signaling an urgent need for a change in legislation.

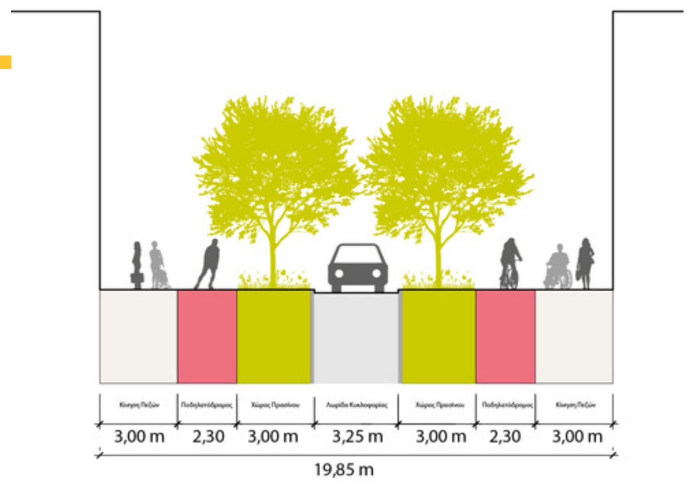
For the redevelopment of streetscapes where the thoroughfare is narrow, attention should be paid to the following issues:

- Selection of small trees with narrow crowns.
- Creation of a continuous crown layer (distance of about 6 meters between trees and 1 meter from the road curb line).
- Planting of more than one species on each side of the pavement, depending on the width of the pavement.
- Narrow formations where possible.
- Creation of common planting areas to encourage communication between the roots.
- Covering roots with green biomass (green mulching), living plants, metal root covers, gravel, or concrete paving systems.
- The green zone can be developed into a bioswale as discussed in the previous chapter, given that there is an overall design of stormwater runoff at the city level.

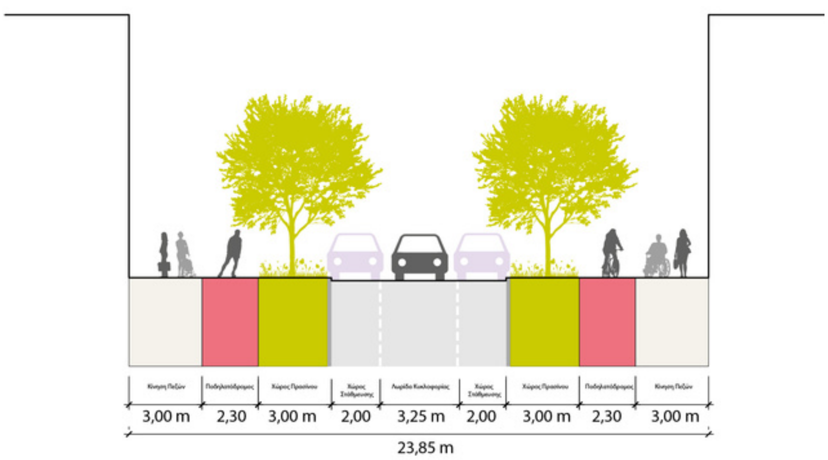
Streetscape typologies



Pedestrian ways



Narrow roads with one lane of traffic, one

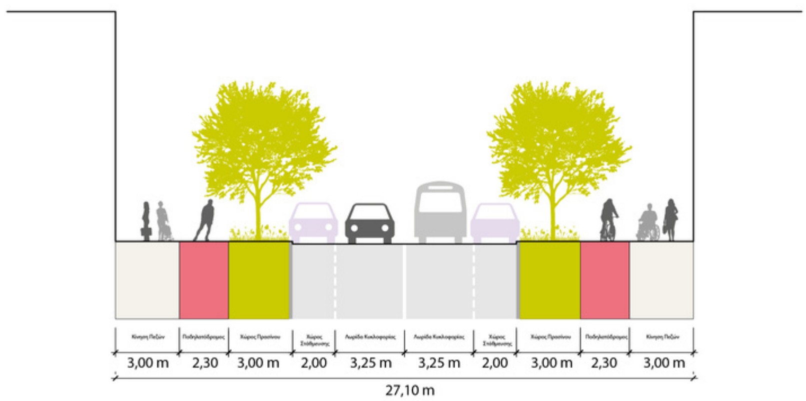


Roads with one traffic lane and two parking lanes, two-way roads (light traffic) or roads with two direction lanes and one parking lane

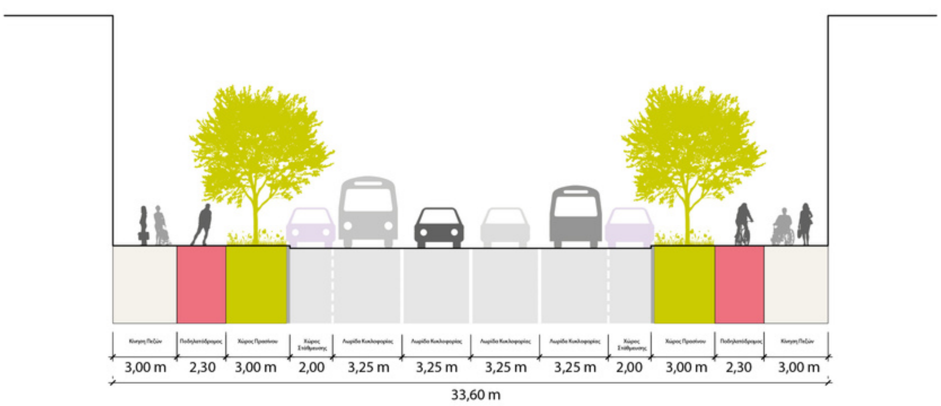
Streetscape typologies

For the redevelopment of streetscapes (where wide enough), the following considerations should be made:

- Selection of medium and large trees (see table in Appendix A).
- Use of shade trees with dense crowns on streets running north to south, as they are exposed to more sunlight during midday hours.
- Creation of a continuous crown layer (distance of about 10 meters between trees and 1.5 meters from the curb).
- Creation of common planting areas to encourage communication between the roots.
- Covering roots with green biomass (green mulching), living plants, metal root covers, gravel, or concrete paving systems.
- The green zone can be developed into a bioswale (as discussed above), given an overall design of stormwater runoff at the city level.



Central commercial axis with one traffic lane and one parking lane, or two traffic lanes. The bus lane is also a possible inclusion.



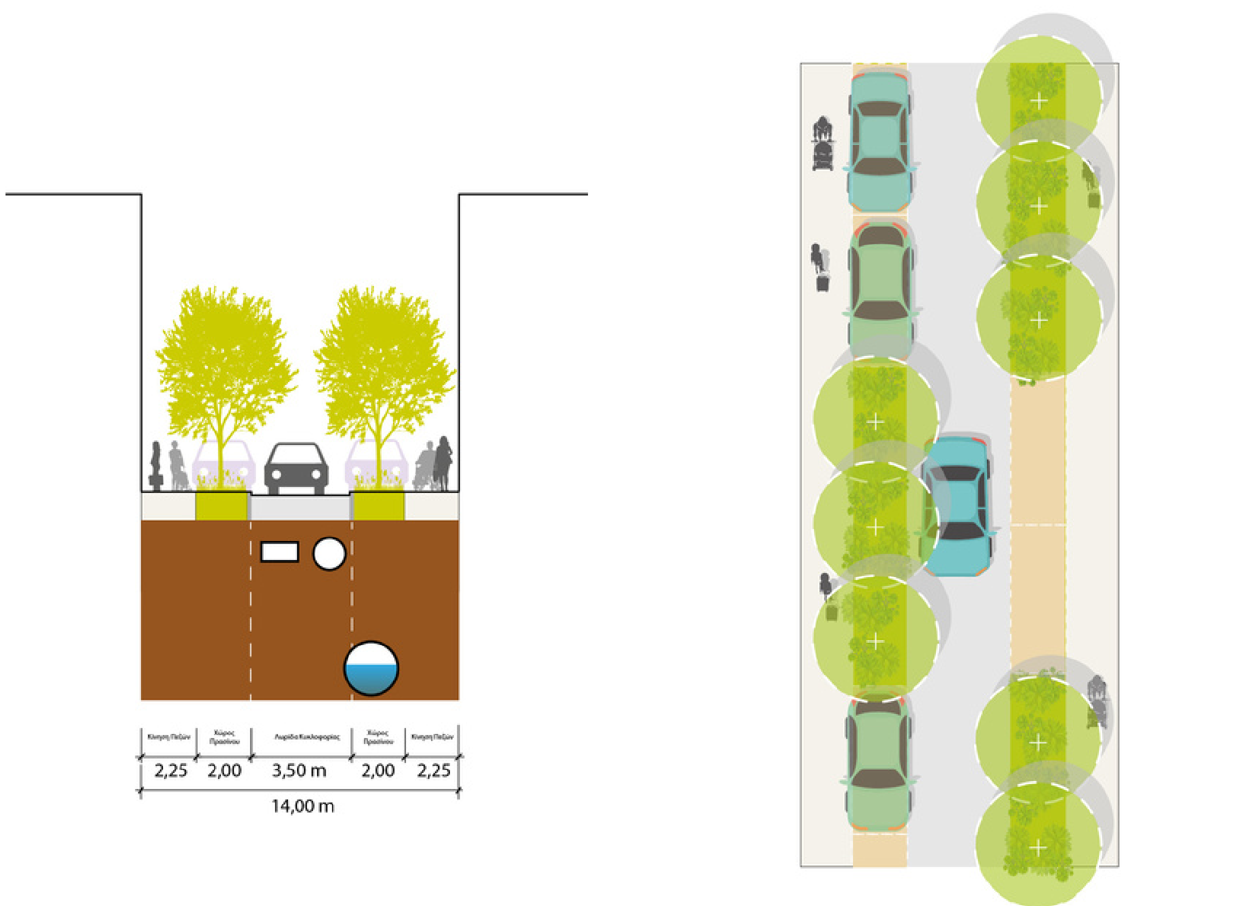
Avenue with two traffic lanes and one parking lane, or three traffic lanes. The bus lane is also a possible inclusion.

Streetscape typologies

In the urban environment of Attica, it is common to find very narrow, one-way streets with both sides of the street used for parking. Given the prevalence of this type of street, it is worthwhile to further analyze the particularities and present three alternative approaches to dealing with such streets.

Single lane street with a parking area on both sides:

- To incorporate more green into the streets and manage stormwater, a selection of parking spaces on both sides of the street should be removed and replaced with green elements.
- In this proposal, two parking spaces on each side are freed alternately to make space for planting trees. In these beds, the trees share the soil and permit communication among the roots.
- Tree roots are covered and protected with green biomass (green mulching) that retains water, protects against soil erosion, and provides thermal protection for the roots.
- Parking lots shall have water-permeable paving.

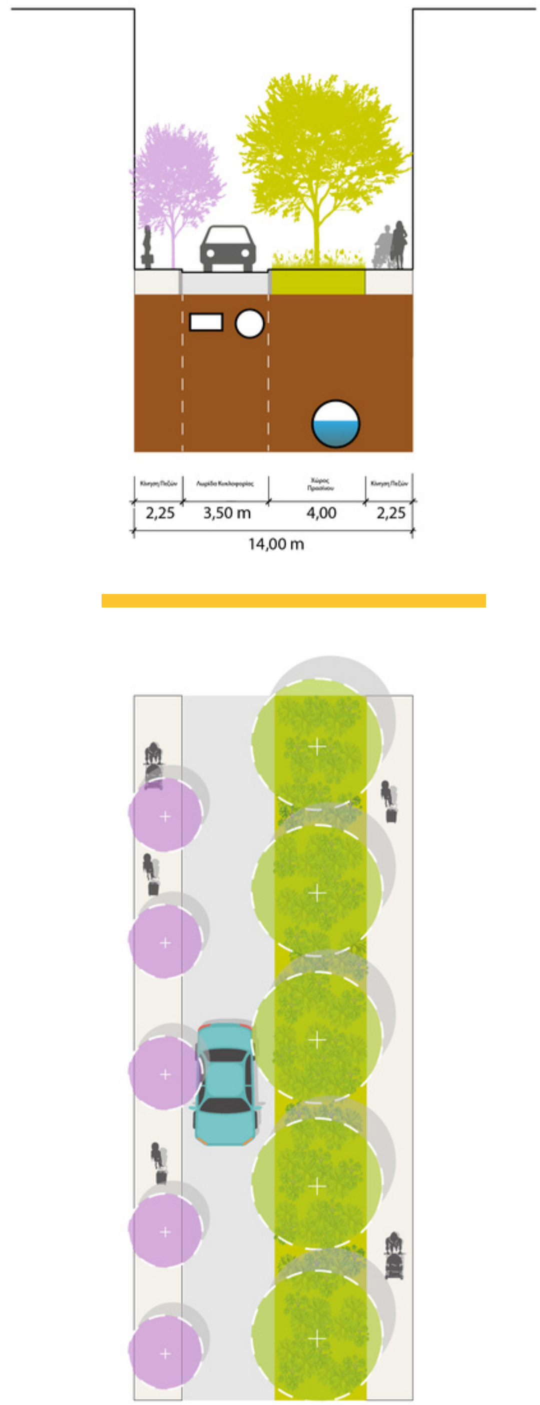


Streetscape redesign with a bioswale system and parking spaces

Streetscape typologies: megabioswales

Megabioswales can be created in streets where parking spaces are removed or space is otherwise freed, and where a stormwater flow study indicates that this location can help reduce flooding.

- In this blue-green zone, plantings with semiaquatic character and water purification properties (with abilities to retain heavy metals and other pollutants) are recommended.
- Trees able to withstand and survive high soil moisture and in polluted environments should also be included.
- Plants with other qualities that are important to the city, such as flowering and other colorful elements, can be planted on the opposite side of the street, helping to incorporate existing trees into the design.
- Tree roots are covered and protected with green biomass (green mulching) that retains water, protects against soil erosion, and provides thermal protection for the roots (greatly increasing evapotranspiration).
- Trees on the left side should have root protection covers, through which water can pass, and where the space for growth is defined and protected. There are many products on the European market with these characteristics.
- In the urban environment, this megabioswale zone can follow the underground route of the Adriatic Aqueduct above ground, and integrate infrastructure projects of the Greek water company (EYDAP). In this way, a modern green and blue infrastructure project can demonstrate and reflect the passage of the underground HA, providing the same ecosystem properties, and bringing together the past, present, and future both metaphorically and literally, through contemporary landscape performance design.
- The elements of stratification and construction of biological filters are described in Chapter 1.

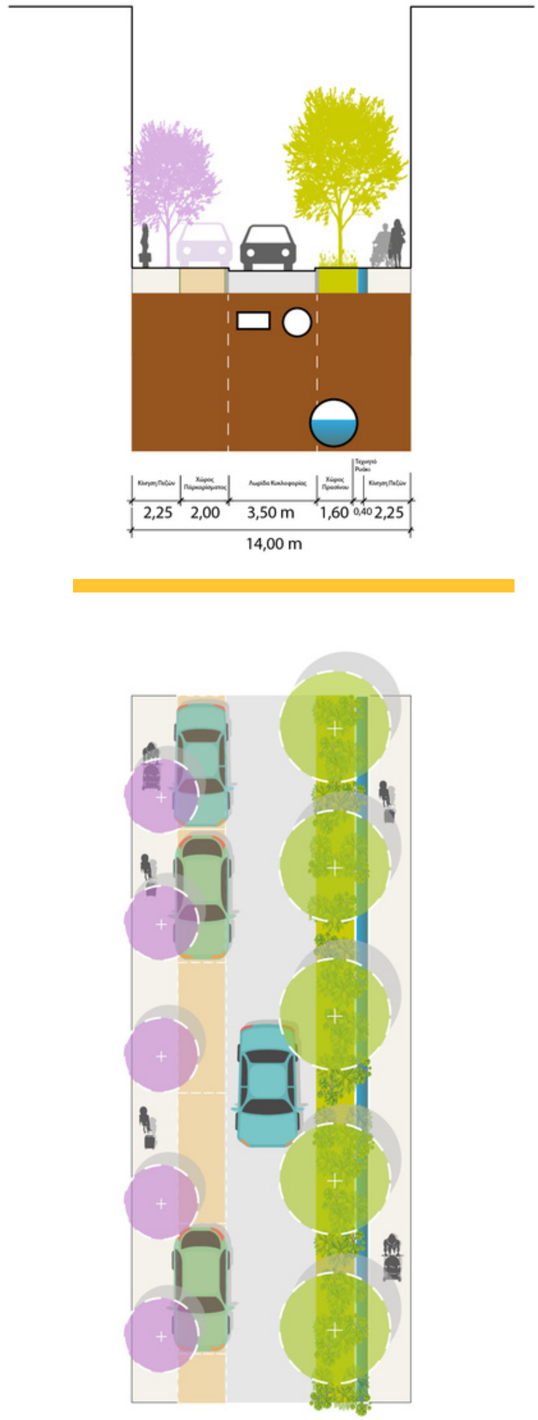


Streetscape redesign with a megabioswale

Streetscape typologies: water line and biological filter zone

In streets where a continuous parking zone must remain on one side, the following measures can be applied:

- Parking should be on water-permeable paving—not asphalt.
- On the opposite side of the street, a water stream can indicate the flow of the HA.
- Ideally, the water line should run in parallel to a biological filter zone so that it can manage water overflow during heavy rain events, i.e., water purification and safe movement of stormwater.
- Here plants with a semiaquatic character and water purification properties, with the potential to retain heavy metals and other pollutants, should be introduced.
- Trees with root systems able to withstand high soil moisture and to survive in polluting environments can be included in this zone.
- Plants with other qualities that are important to the city, such as flowering and other colorful elements, can be planted on the opposite side of the street, incorporating existing trees into the design.
- Tree roots are covered and protected with green biomass (green mulching) that retains water, protects against soil erosion, and provides thermal protection of roots (greatly increasing evapotranspiration).
- Trees on the left side should have root protection covers, through which water can pass, and where the space for growth is defined and protected. There are many products on the European market with these characteristics.
- The elements of stratification and construction of biological filters are described in Chapter 1.



Streetscape redesign with water line, biological filters and parking spaces

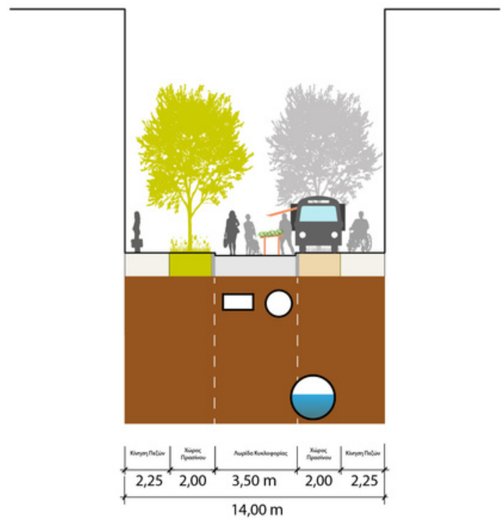
Streetscape typologies: farmers markets

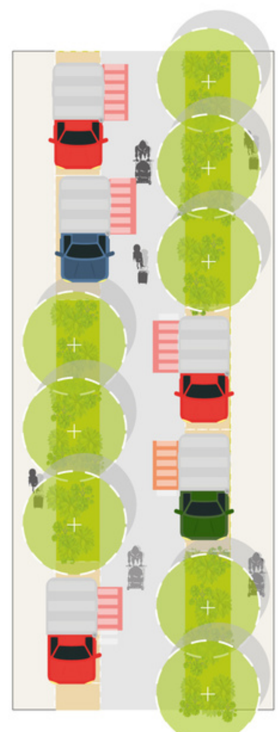
Inclusion of farmers market on a streetscape:

- Weekly farmers markets take place throughout the year on many streets in Attica.
- Published proposals already exist for sustainable farmers market practices in Attica. Incorporating these proposals into the redesign of streets of this type is recommended.
- A proposal to integrate the farmers market into an ecologically designed street with the goal of heat risk reduction could be a redesign of the solution for a single-lane street with parking areas (presented above).

This case can benefit from:

- Integrating more greenery in the streetscape and strengthening stormwater management, with some parking spaces forfeited for plantings on both sides of the street.
- Allocating two parking spaces per side for trees so that can share soil and connect their roots.
- Covering and protecting tree roots with green biomass (green mulching) that retains water, protects against soil erosion, and provides thermal protection of the roots.
- Using water-permeable paving for parking spaces.
- Temporarily converting parking spaces to spaces for the farmers market during its hours of operation.





Streetscape redesign integrating a farmers market with parking spaces and bioswale

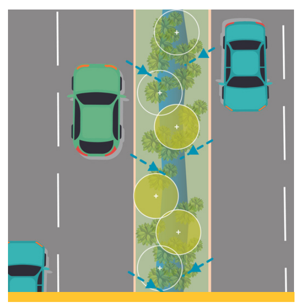
Streetscape typologies: special typologies:

The following special typologies do not offer the same degree of thermal comfort as the solutions described above, but they play a role in the greater change of city surfaces.

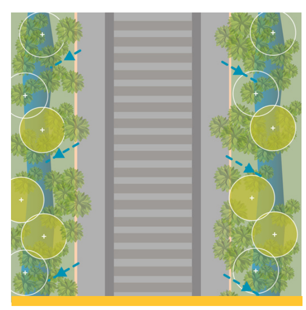
Green middle zones in boulevards:
Green middle zones in boulevards are often found in Attica in avenues like Kifissias or Vouliagmenis. These zones can take on the character of intensive linear super-coniferous forests that filter and manage runoff water from roads. Such a design significantly increases the city's biodiversity and connectivity for animals and promotes the creation of sublayers of vegetation that play a very important role in creating a cooler microclimate. These corridors are very important as they run straight through the city for many kilometers and are otherwise not used.

Green zones at rail/tram line boundaries:
Zones at the edge of train and tram lines, e.g., serving suburban areas, should not be left unused as urban voids, but can instead be converted into intensive, linear supra-coniferous forests that filter and manage the rainwater from the train lines. Such a design significantly increases the biodiversity of the city and its connectivity and promotes the creation of vegetation sublayers that play a very important role in creating a cooler microclimate. These corridors are very important as they run straight through the city for many kilometers and are not usable for other urban applications. In tramway areas, vegetation with low grasses is preferred for full water permeability.

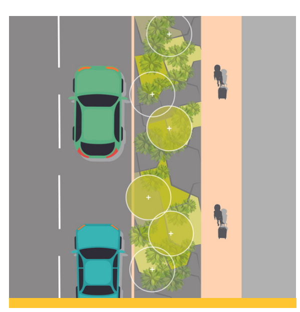
Breaking up the pavement:
Another way to directly manage the city's impermeable surfaces—at low cost—is to reduce traffic and parking lanes in cooperation with traffic planners and to break the asphalt into smaller irregular pieces, and then plant trees and other plants directly in the restored substrate. In this way, overgrown woods can be placed directly on the streetside without the need for a complete redevelopment of the streets and sidewalks. Such a design significantly increases the biodiversity of the city and its connectivity and promotes the creation of sublayers of vegetation that play a very important role in creating a cooler microclimate.



Green middle zones in boulevards



Green zones on the borders of train and tram lines



Breaking the asphalt

Plaza typologies

The square is an urban design typology that we often find in Greece and Southern Europe and less so in other European countries. It is an extensive paved surface, which is open and flexible for various public uses (e.g., fairs, markets, gatherings). At the same time, it plays an important role as an open space for gathering in earthquake emergencies, as it is surrounded by apartment buildings. It often consists of small green spaces and playgrounds. Squares serve as places for social gatherings and socializing and, accordingly, lighting also plays a major role in nighttime use. The proposed solutions are applicable to all squares in Attica.

Guidelines for plazas:

- In squares, there is often a need for a hard surface allowing multiple uses. When redeveloped, the use of a water-permeable surface should be mandatory.
- Depending on the uses of the square, the area of hard, uniform surface should be kept to a minimum.
- Green areas should be maximized.
- See suggested plantings for plaza plants in this chapter and Appendix A.
- Green areas should have maximum biodiversity, depending on the character and area of the plaza. Layering is very important.
- It is suggested that green elements should directly touch or indirectly relate to water features and have a role in water purification, increasing the potential for biodiversity and the survival of semiaquatic or aquatic species, or associated species that need more water.
- Closed-system aquatic elements that do not use potable water should be introduced —using HA water and rainwater.
- Squares are an important node in the biodiversity axes as they provide more space and accessibility to vegetation, water, birds, and small animals. Squares should be designed in conjunction with the green and shaded corridors of the city.
- Squares should offer drinking water fountains for cooling as well as pergolas and shaded areas with plants or artificial elements.
- They also should include elements of seating, play, and water play.
- All water streams employed or collected at the plaza level should be redirected for use in city irrigation or the aquifer.

Redevelopment of a square including green spaces, water-permeable floors, and water elements as well as rainwater storage and reuse for watering

Plaza typologies

Typically, most squares in Attica are surrounded by cafes and active facades, and often there are churches at the center. It is very important that the character of the squares remain public and that there are opportunities for rest, and that the spaces not related to the cafes are usable.

These squares often have a very formal character as religious ceremonies are held there, and there are often large gatherings of people. This typology is found in many church squares along the length of the HA.

Guidelines for such squares:

- Repave a large area with a water-permeable surface.
- Introduce large new trees for shading, and add root protection boxes that allow water to pass through, as shown below.
- Include water features enabling people to cool off by putting their feet in the water.
- The same water feature should also be a play feature for children.
- Maximize canopy cover of the trees through adequate species and substrate selection, plant growing conditions optimization, maintenance, and pruning.
- See the types of plants to use in the squares below and in Appendix A.
- Squares should provide drinking water fountains for cooling, and pergolas and shaded areas with plants or artificial elements.
- All water streams employed or collected at the plaza level should be redirected for use in city irrigation or the aquifer.

Redevelopment of a square with green spaces, water permeable surfaces, and water elements; square rainwater storage and capacity to reuse that rainwater in the square for irrigation; root protection elements in trees with perforated caps; and use of new technologies that create a root protection substrate.

Squares with water game elements

Park typologies

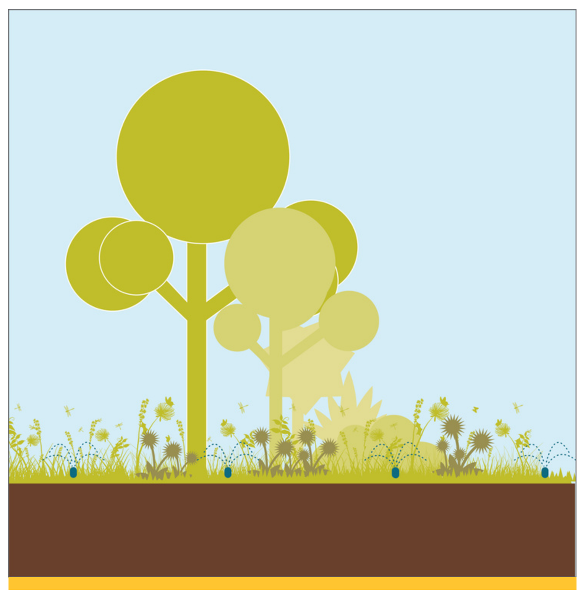
For this technical guide, parks in the urban landscape are defined as places where the green elements predominate. These parks have the role of recreational spaces in nature, while urban uses are kept to a minimum. Paths should be kept to the number needed for accessibility, safety, and connectivity of the park and no more. Path materials should be water permeable: firm gravel, compacted earth, etc. Green areas should provide as much shade and biodiversity as possible.

The discussion here focuses first on large parks, namely those with a surface area of more than one hectare, as found in the Hills of Attica (e.g., Lycabettus, Ilisia, and Turkovounia).

Guidelines for large parks:

- Priority should be given to the use of native plants for parks and hills, as they are natural ecosystems with minimal maintenance work.
- Biodiversity should be promoted at all levels (i.e., species, communities, strata, and zones).
- It is recommended to design a combination of coniferous and broad-leaved species that creates a park more resistant to infestations (forest fires, high temperatures, host species, etc.).
- The retention, protection, and introduction of new mature adult trees is very important to regulate the microclimate in the subsurface.
- Thin out dense plantations of coniferous species to foster proper growth and strong trees and plants, as overcrowding can result in weakness.
- Shrub species that cannot tolerate shade conditions should be placed near paths, clearings, and central park routes with adequate and continuous exposure to sunlight.

Permeable paths and green elements in a park, with a mix of coniferous and broadleaf trees, shrubs and grasses.



Planting stratification in a park, with a mix of coniferous and broadleaf trees, shrubs and grasses.

Park typologies: special park typologies

Green triangles:
Green triangles are scattered across the municipalities of Attica. Typically, they are spatial remnants of traffic junctions that are too small to be squares. Many of the thousands of triangles in the area are planted, but they are both difficult to maintain and maintenance is costly given their dispersion across the city's road network.

Ultradense forest integrated in a green triangle

These green triangles should be infused with a new character and be integrated into the redesign of the street-level stormwater flow at the city level. In this manifestation, green triangles can become rain gardens or even small constructed wetlands, in which case the water-level depth should never exceed 30 cm for the safety of children.

For larger areas, the following guidelines are recommended:

- Any wetland area and two-thirds of a pond area should be flat-bottomed and about 25 cm deep.
- Large stones and rocks should be eliminated to reduce the risk of someone hitting their head after a fall.
- The remaining one-third of the pond should be divided into two flat-bottomed areas of 50 and 75 cm depth, respectively. A 50 cm terrace should occupy about two-thirds of this area (i.e., two-ninths of the pond), with the deepest terrace occupying the final one-ninth of the pond.

Another solution is to convert these unused triangles into fenced super-coniferous forests. The typology will be detailed later in this technical guide.

Constructed wetland or extended bioswale integrated in green triangle

Park typologies: special park typologies

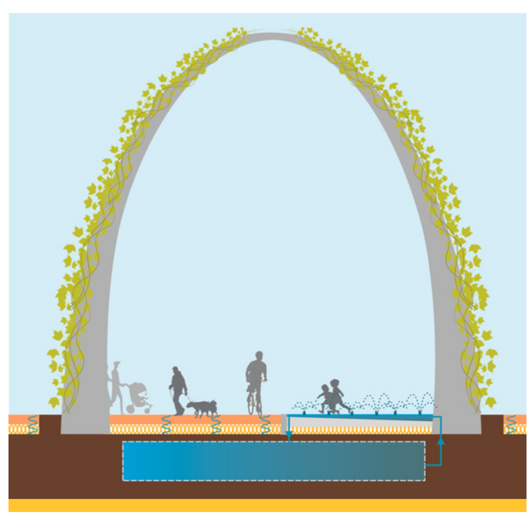
School playgrounds:
School yards and forecourts are public spaces with specific uses that present boundaries that can be planted with high biodiversity to create cooling poles in schools and densely populated city neighborhoods. School yards should be designed with playground materials and incorporate water play elements for cooling fountains. Paving materials should be permeable, with asphalt and concrete surfaces prohibited for sports and play areas and replaced with sand, compacted dirt, or special small and smoothed gravel for play and fall protection. Plantings, shading, and biodiversity should be maximized. These areas should be designed as "pocket parks" that meet the requirements of play, sports, and open space learning for students. The Cool Oases program in Paris, France, is a great reference on this topic.

Shade and extended paving of the Athens Olympic Stadium (OAKA):
According to satellite maps measuring the city's surface temperatures besides the most densely populated parts of Athens, the OAKA area has the highest temperatures and the most elevated UHI of the entire UHI axis. Also, there is a large water drainage basin under the OAKA area, which causes flooding because it is not integrated into the design of the concrete pavement at all. There is only minimal shading provided by the metal elements designed by the architect, Santiago Calatrava Valls.

Therefore, it is recommended that:

- The metal elements of the pedestrian pathway at the OAKA area be given a planted or shaded character so that citizens can use it as an open space throughout the year.
- The vast cast concrete paving could be broken up and changed locally to water-permeable paving.
- A large water feature could be placed on a large section of the paving, designed for play, but with a smooth draw to preserve the usability of the space.
- A study should be done on how the massive, enclosed area around the stadium can be broken up to meet the usable needs of the stadium, but still provide space for greenery and increased biodiversity.

Typical development of permeability zones in schools, from green to gravel or beaten earth, to permeable paving

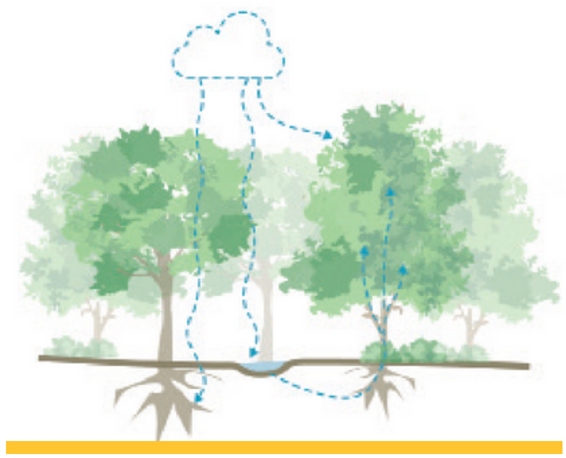


2. Diagram of the proposed development of the OAKA shade and inclusion of water elements in the paving

Park typologies

Within all urban parks and regardless of size—from pocket parks and hyper-dense forests to the hills of Attica, the foothills of Parnitha, and the National Garden—the general principles of healthy park ecosystem properties apply:

- Reinforcement and maintenance of the water cycle.
- Creation and reinforcement of connectivity of green axes for pollinators, small animals, and plants.
- Regulation and maintenance of microclimate and the creation of cooling air currents.
- Presence of thermal reserve in the soil that is released in winter.



Parks and the water cycle

Green axes and pollinator connectivity

Maintenance of microclimate and coolness

Thermal reserve in winter

Park typologies

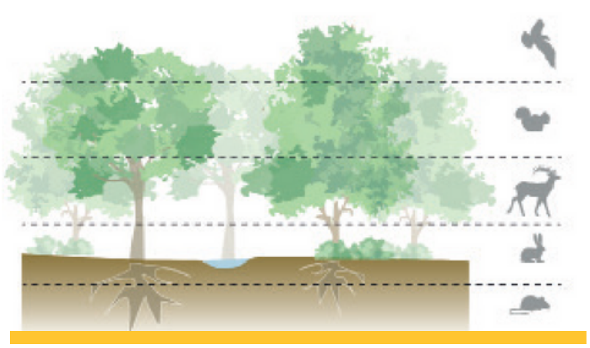
The general principles of the properties of healthy park ecosystems are:

- Creation of a source of food and shelter for animals and plants at different vegetation levels through layering.
- Connectivity, movement, and management of nutrients in land and trees.
- Carbon storage in trees and shrub growth (biomass) and increased oxygen yield, also result in improved air quality.
- The presence of forests is an important source of food for animals and humans. Their design can be based on various technical solutions, which are briefly described below.

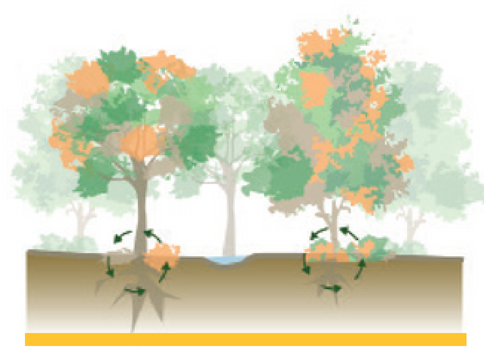
Finally, parks and woodlands can be great tourist attractions and can become a source of income. These technical solutions can be applied differently to the different parks and the more authentic Mediterranean landscape of the Attica hills.

Specific measures proposed for the hills of Attica include:

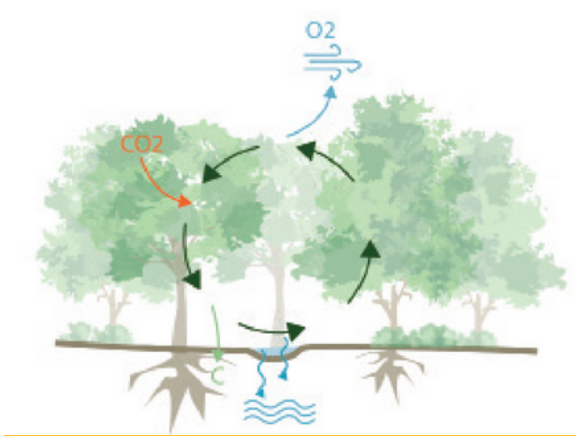
- The restoration of biodiversity.
- The planting of different varieties on each hill, to achieve greater biodiversity in the whole city.



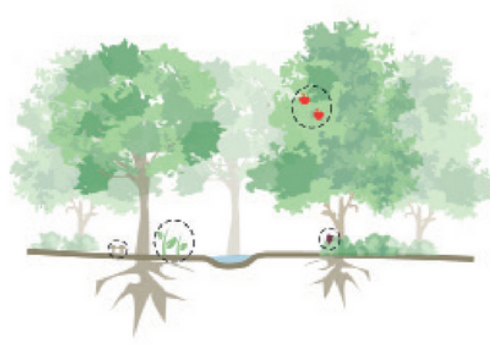
Stratification and source of food and protection for animals



Connectivity and nutrient management



Carbon dioxide storage and oxygen yield



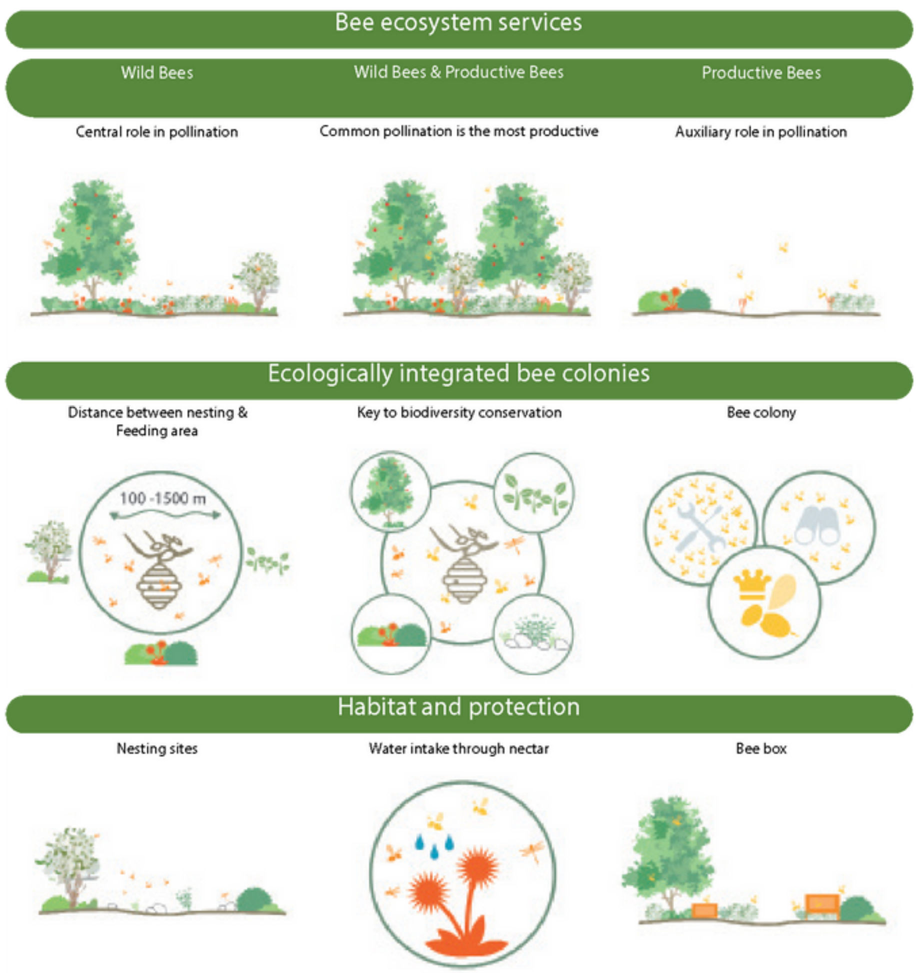
Source of food for animals and humans ologies

Park typologies

There are other important considerations for park ecosystems both in terms of biodiversity and climate resilience. For example, the design of north-facing slope plantings is very important because of the lower temperatures experienced there and the different levels of humidity. In these zones, sensitive endemic plants can survive future heat waves. The orientation of the slopes must be considered in the design from small to large scale.

The presence of pollinators is of immense importance to the functioning of urban ecosystems, as mentioned earlier. In recent years, several studies have found that the health of urban bees is better than that of rural bees. Wild bees play a central role in plant pollination, much greater than production bees.

The charts below provide additional data. These design principles should be considered in new urban redevelopments in the region of Attica, with an emphasis on the HA zone.



Guidelines for the inclusion of pollinators and wild bees in the design of the parks and hills of Attica: Ecological role of wild bees in the ecosystem

Ultradense forests/tiny forests

Ultradense forests, also called tiny forests, are another important green element that has been applied in parks and public spaces in Europe in recent years. These forests are concentrated in very small areas but are dense and, accordingly, carry very high biodiversity ratios. They are usually fenced off and cannot be traversed because of their biodiversity reserve status. There are no size specifications, but as a base reference, up to 600 trees can be planted in an area of a tennis court.

Ultradense forests provide:
- Extra evapotranspiration and cooling in a city.
- Ecosystem restoration and additional related ecosystem services (e.g., jobs, water, air, rain, recreation, environment, etc.).
- Carbon capture (can absorb forty times more carbon than monocultures).
- Twenty times more biodiversity than monocultures.

These forests can be integrated into squares, parks, unutilized road triangles, and other unused areas of the urban landscape.

Ultradense forest / tiny forest

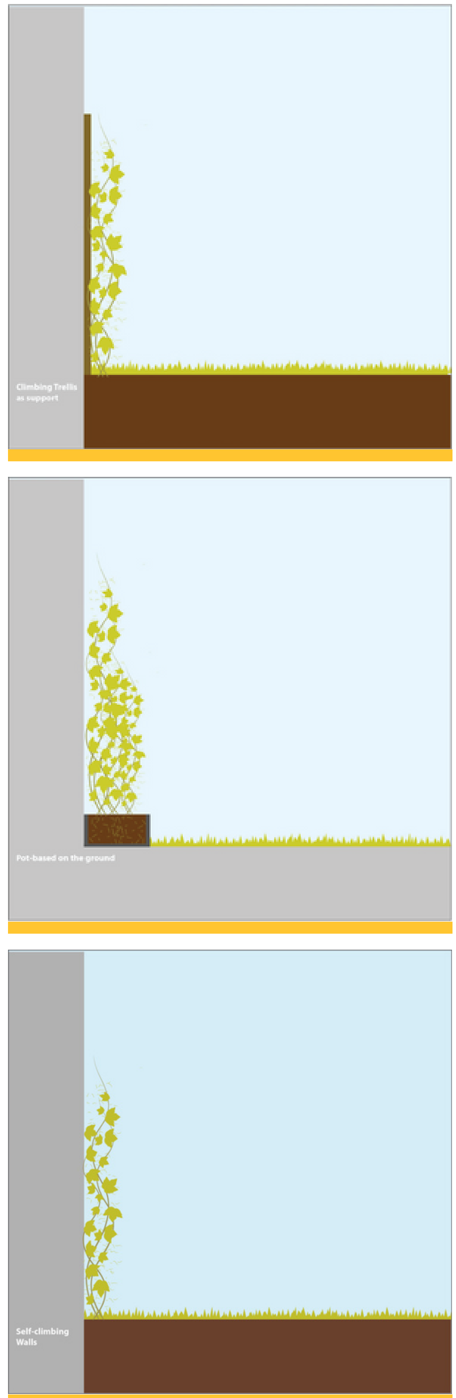
Green walls

Different forms of green walls include:

- Soil bound green walls: Vines cover the wall along climbing aids, such as stiff rods or flexible ropes, or are self-climbing.
- Wall-anchored green walls: Living wall with substrate coverage, or with the substrate body divided into trays or cascades.

Green wall maintenance:

- Just before the start of winter, the watering system must be set to frost-protection mode, and the plants trimmed and cleaned.
- At least once per month during wintertime, the moisture level of the growing medium must be monitored, and the irrigation systems manually activated, if necessary.
- At the end of winter, the irrigation system must be reset, and the plants trimmed and cleaned again.
- During the growing period (April to October), the entire system will need to be inspected at least once per month to ensure correct operation, reset the irrigation system, determine the moisture levels of the growing medium, check on the health of the plants, record plant growth, and confirm the ongoing integrity of the underlying structure. If needed, the watering frequency must be increased or decreased, and any plant health treatments must be undertaken.



Typologies of soil-bounded green walls

Green walls

Areas of application include not only building facades, but also fences, freestanding walls, or other vertical structures.

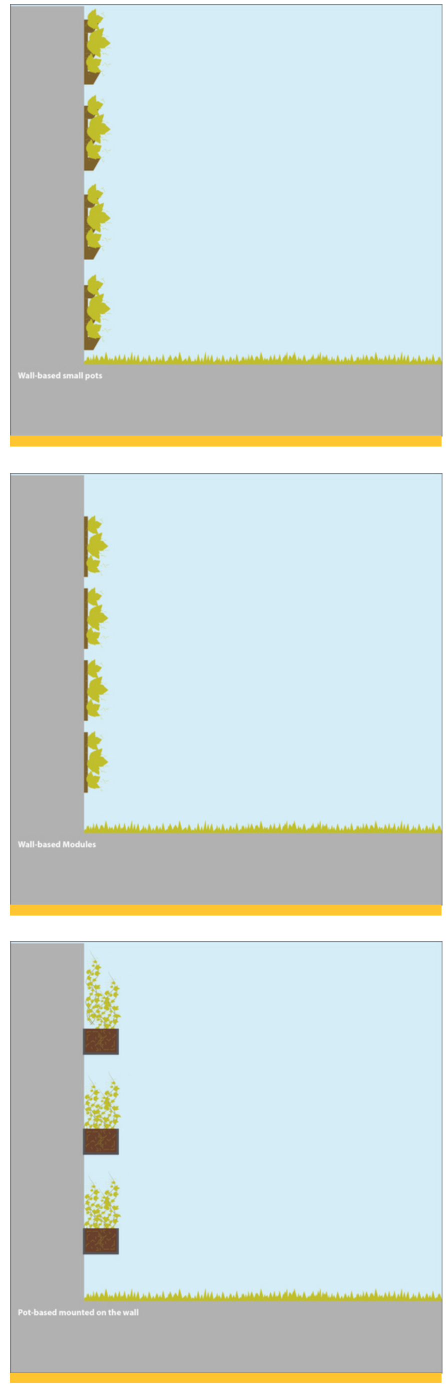
Main benefits:

- Reduction of the UHI effect.
- Water retention and evaporation.
- Air quality.
- Sound insulation.
- Biodiversity.
- Aesthetics.
- Energy efficiency.

Things to consider in design include

- Installation.
- Operation and maintenance costs.

Green wall detail



Typologies of wall-anchored green walls

Green roofs

Typologies of green roofs:

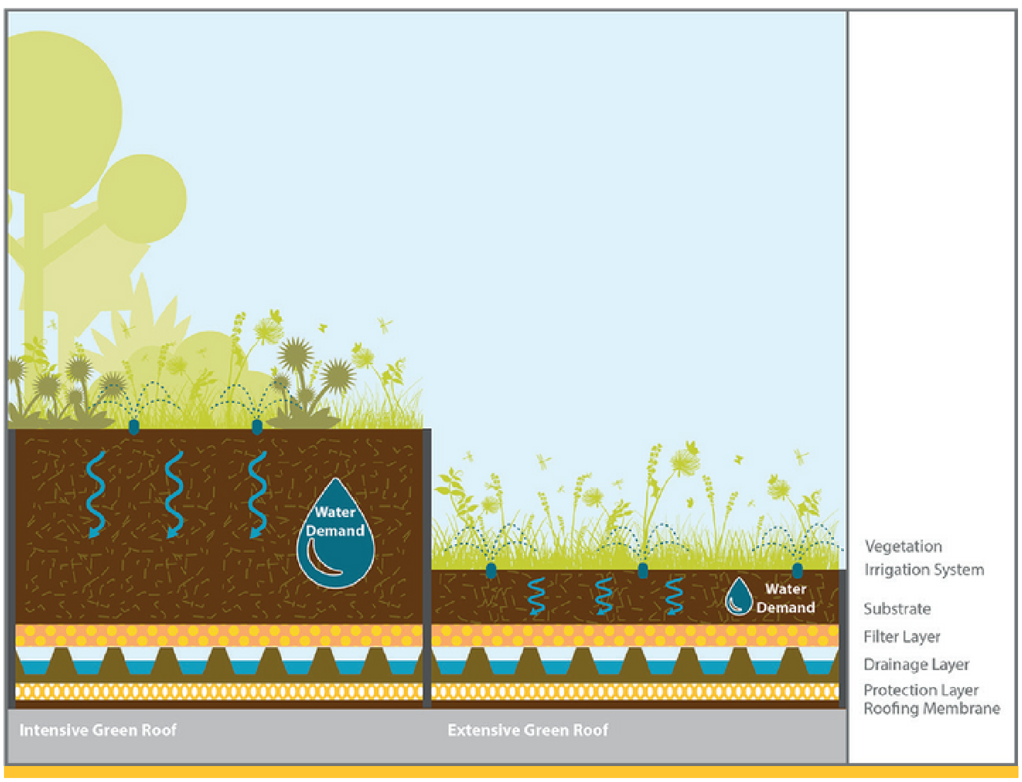
- Intensive green roof: Greater substrate depth—over 20 cm, which gives far greater scope to design and enables cultivation of more elaborate gardens on concrete structures
- Extensive green roof: Shallower depth—under 20 cm, designed for low-maintenance, lightweight systems with no general access.
- Combination of green roofs with solar panels.
- Combination of green roof with water retention roof.
- White roof.

Main benefits:

- Reduction of the UHI effect.
- Thermal reserve for hot and cold seasons.
- Water retention and evapotranspiration.
- Improved air quality.
- Sound insulation.
- Biodiversity, aesthetics.
- Combination with photovoltaics.
- Intensive green roofs.
- Urban gardening.
- Recreational space.

Guidelines for green roofs on private and public buildings, pavilions (where they still exist), bus stops, bus roofs, and areas with canopies are:

- Different systems (intensive/extensive green roofs, water retention).
- Combination of green roofs with solar panels.
- White roofs, and a complete ban on gray roofs and other colored roofs (even light gray pebbles can heat up to 60°C).
- Maintenance of green roofs should be included in the project budget.
- See the many examples of different applications.



Typologies of green roof

Green pergolas and green balconies

Green pergola typology:
- A simple structure to support plants and provide shade in open spaces
- Use in parks, squares, bus stops, or even road crossings.

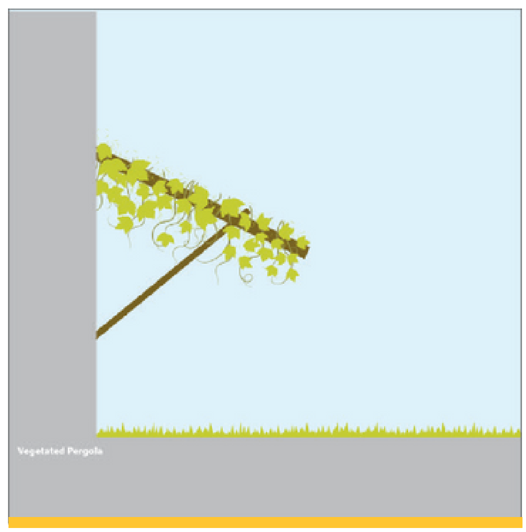
Main benefits:
- Reduction of the UHI effect
- Reduction of radiation reaching the ground
- Evapotranspiration
- 24-hour effect (e.g., water surfaces only during the day, at night they may emit heat)
- Improved air quality
- Biodiversity
- Aesthetics

Things to consider in design:
- Maintenance requirements.

Green balcony typology:
Balconies are often key features of the typical Attica building. If all these balconies were greened at the expense and responsibility of the residents or building owners, in cooperation with the municipality, a major inroad would be achieved against unfavorable UHI levels. We suggest that such a strategy would be necessary for mitigation of the heat levels experienced in the Attica.

There are many innovative solutions enabling the simultaneous and intensive use of balconies. For example, small home composters can be set up on balconies as sources of sustainable fertilizer.

Green pergola



Vegetated shading structure

Green pergola in Lisbon combined with trees and colorful plantings, with a variety of seating and tables

Guidelines for green elements

Urban green design for maximum cooling
Different forms of green and blue design elements need to be integrated strategically to create the desired cooling effects in targeted redevelopment areas; only then can they result in thermal relief benefits and enhance public health and well-being. More specifically, these elements include: urban forests and their edges, parks, street trees, private gardens, edges of green corridors, green roofs, green walls, green pergolas, and green balconies. The following section describes the overall considerations and strategies for the types of planting and landscape character of these green elements for the primary purpose of heat risk reduction and their co-benefits for the city.

Biodiversity solutions in streetscapes: Root protection, planting preparation, and creation of habitat for birds and small animals

Key considerations include:

- The cooling effects of evapotranspiration from green elements and how water elements affect urban plant crown conditions.
- Cooling at the boundary of the urban canopy layer is mainly achieved by increased surface roughness of green spaces, which improves heat absorption efficiency. In other words, grasses and groundcover elements should be integrated as they create pockets of coolness in the heterogeneous green surfaces of the city.
- Water elements have the potential to cool urban areas during the day; however, to avoid heat release at night, the presence of green elements is also required.
- Trees provide the greatest relief from heat stress during the hottest hours of the day. Shaded surfaces, for example, can be 11° to 25°C cooler than the maximum temperatures of unshaded materials. Evaporative cooling, alone or in combination with shading, can reduce peak temperatures by 1° to 5° C.
- The extent and spread of cooling in the surrounding urban space depends on the size and design of green spaces.

Basic principles for plant selection:
Tree, shrub, and grass species requiring low, medium, and high irrigation regimes and different substrates have been identified and classified. These should be applied in the new public space projects in Athens by following the extreme heat scenario projected for Athens by 2050 (which estimates twenty additional days of heat per summer).

The urban environment is often inhospitable for the establishment of vegetation and green infrastructure. The microclimate in the Greater Athens area is hot and dry, the supply of direct solar radiation is quite limited, and air pollution is usually excessive. Stormwater runoff (from hard surfaces) flows and drains directly into the drainage system, dramatically reducing the volume of water delivered back to the soil. Under these harsh conditions, the selection of appropriate plant species is vital. The list given in Appendix A has taken these factors into account.

Shading and cooling systems

Trees and vegetation:

- Priority should be given to broad-leaved species that offer shade during the summer season.
- Canopy size and leaf area index characteristics increase plant cooling mechanisms.
- Evaporation is the most effective means of reducing ambient air temperature in the sense that it increases solar reflectivity and emissivity. Its cooling effect is stronger during the day because that is also the time when plants breathe. However, shade plays a much greater role than evaporation in reducing temperature.
- The Attica oak species, such as Quercus pubescens, is an example of a broad-leaved tree that can be used in Attica.
- Mature, large trees should be preserved as they will create microclimate conditions for the subfloor.
- Endemic species should be used where possible, but other species adapted to the Mediterranean climate can be chosen, depending on soil, water, and lighting conditions.
- Depending on the size of the canopy, plants can intercept 70 percent to 90 percent of incoming solar radiation.

Biodiversity strategies in streetscapes:
Deadwood, stones, and a wide variety of plants

- An attempt must be made to use shade trees for roads with a north-south orientation, as they are exposed to more solar radiation during the midday hours. This makes the streets more pleasant for residents.
- Trees and vegetation can also reduce stormwater runoff and protect against erosion.
- At the same time, green roofs and green walls play an important role. Where possible, green roofs could also include trees.
- Species with a preference for sunny conditions usually create an uneven canopy if planted near buildings.
- Choose a tree based on the availability of space to avoid excessive pruning.
- Nonphototrophic smaller species can be preferred for street planting without access to sunlight. In this case, the appropriate substrates need to be provided. Be aware, that many non-photosynthesising plant species are also not green but often whitish.
- Beware of species with an abundance of crown branches or with an uneven shape that are not pruned, as they are prone to urban winds and can create accidents and disasters (i.e., the Populus genus).

Planted (and cool) sidewalks:

Grass-covered ground can be up to 24°C cooler than concrete pavement. In addition, grass reduces the temperature by up to 3°C. However, the smaller the area it occupies, the less effectively it cools: a strip one meter wide, for example, has a local cooling effect of just 0.6°C.

Choose the appropriate endemic species, depending on the availability of space, water, and exposure to the sun.

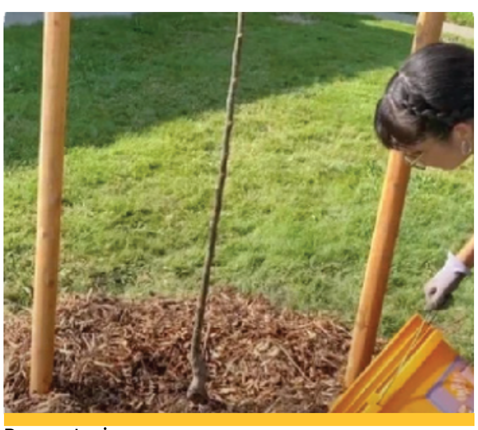
Heat stress and water stress

High temperatures and lack of sufficient water create negative conditions for vegetation in cities.

- The resistance of plants to the extreme adverse conditions of reduced humidity and high temperatures depends on their root system, the water system in the trunk and branches, and the size and architecture (shape) of the leaves.
- The proper growth and functioning of a plant require the existence of a normal water balance. Water lost through transpiration must be replaced by taking up sufficient water from the soil.
- Prolonged periods of high temperature and drought disrupt the water balance in plants, as the intensity of transpiration increases, and water uptake decreases. The wilting created in these cases causes lesions and can spread from the leaves to the rest of the plant, resulting in its drying.

Plants, depending on the species, have a series of mechanisms to cope with these adverse conditions:

- Reduction of biological activity during drought, such as by dropping their foliage (e.g., spurge, more formally known as the Euphorbia genus of plants), reducing the surface area of the leaves, or dropping the shoots.



Re-watering

- Maintenance of a high-water potential in their cells by reducing transpiration. This is achieved with morphological characteristics that certain plants have, such as the protection and covering of the stomata and protection by a layer of fine hairs during difficult hours, etc.
- Powerful water extraction from the ground. This is achieved by increasing the underground root system relative to the above-ground section of the plant, and increasing tissue ducts and vessels that carry water into the wood.
- The adaptive capacity of acclimatization through osmotic balancing, polyhydric organisms, twisting of the lamina to protect against solar rays, and the modification of plant structures and functions.
- Finally, new research shows that after a summer of heat stress, the trees enter the deciduous state much earlier in the fall.

Here are several good practices that administrators should consider:

- Correct selection of plants, adapted to water stress conditions, e.g., sclerophyll broad-leaved species in vulnerable locations.
- Planting typologies (i.e., plantings in narrow formations, creating a favorable microclimate); see Appendix A.
- Use of resistant seedlings developed for adverse climatic conditions by nurseries.
- Use of endemic plants and of local origin that have adapted to the climatic conditions.
- Permanent monitoring of meteorological phenomena and the water balance of selected indicator plants in the urban fabric.
- Additional irrigation and water supply during periods when water stress is detected (e.g., Adopt a Tree initiative).

Water demand and heat resilience

Effect of heat stress on a tree

Appendix A provides a detailed plant palette, with plants sorted from the most to the least resistant to high temperatures. The following section presents three irrigation needs typologies (low, medium, and high irrigation) and recommends a selection of suitable trees for each major urban space typology (streets, squares, and parks).

Wide Streets:

- Medium and large trees should be selected.
- Shade trees with a dense canopy should be used on north-south roads, as they are exposed to more solar radiation during midday hours.
- A continuous canopy layer (with a distance of about 10 meters between trees and 1.5 meters from the sidewalk) is recommended.
- Plants in a continuous planting bed and bushes at the lowest level are both suggested.
- Consider the appropriate height and shade resistance of plant options.
- Taller trees should be used on eastern sidewalks to provide additional shade to nearby buildings.

Low irrigation needs:

- Medium to large trees: Pinus pinea, Albizia julibrizin, Sophora japonica.
- Shrubs: Rosmarinus officinalis, Teucrium fruticans, spartium junceum.

Medium irrigation needs:

- Medium to large trees: Acer campestre, Acer negundo, Brachychiton populneus.
- Shrubs: Buxus sempervirens, Pittosporum tobira, Rhamnus alaternus.

High irrigation needs:

- Trees: Tilia tomentosa, Platanus orientalis.
- Shrubs: Viburnum odoratissimum, Myrtus communis.

Narrow streets:

- Small trees with a narrow crown.
- A continuous ridge (with a distance of about 6 meters between the trees and 1 m from the sidewalk) is recommended.
- Depending on the length of the sidewalk, try to plant more than one species on each side.
- Appendix A lists species suitable for pavements, according to their water needs.

Low irrigation needs:

Small trees: Cercis siliquastrum, Olea europaea, Albizia julibrizin, Celtis australis.

Medium irrigation needs:

Small trees: Morus platanifolia, Ligustrum vulgare, Citrus aurantium.

High irrigation needs:

Small trees: Catalpa bignonioides, Acer campestre.

Resilience to atmospheric pollution

Different types of plants show different resistance to air pollution, but also performance in air purification. The ecosystem properties of plants are a critical design element as the combination of high temperatures and air pollution multiplies health impacts and mortality rates in cities.

Broad-leaved species produce more oxygen (due to higher photosynthetic activity) and reduce air pollution.

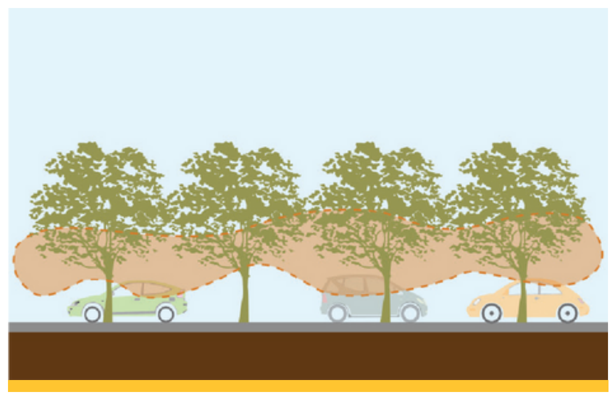
More specifically:

- The primary pollutants in the urban environment consist of sulfur dioxide (SO_2) and nitrogen oxides (NO_x), while the secondary pollutants in the atmosphere are ozone (O_3).
- Oxides dissolve with atmospheric water and are deposited on leaves or soil as acid rain. Ozone has direct effects on leaf tissues and disrupts plant physiology, especially the process of photosynthesis.
- Several species are resistant to air pollution and adapt, such as Acer negundo, Catalpa bignonioides, Acer campestre, and Ligustrum vulgare; for more species, see Appendix A.
- Some species, as barriers, are better at reducing noise pollution (such as Acer pseudoplatanus) than others.
- Dust and particulate matter can be retained by downy leaves (Populus species).
- In general, it is recommended to use broad-spectrum species.

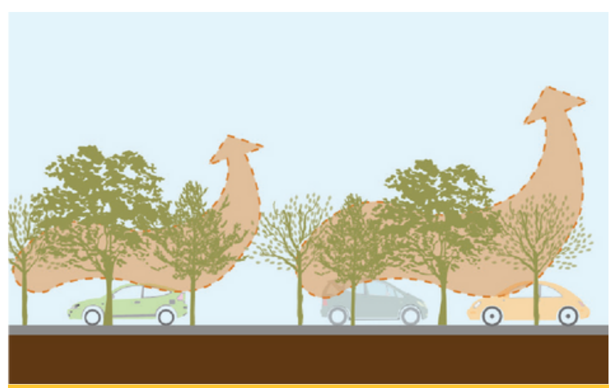
Air pollution and green roofs:
By reducing demand for air conditioning, green roofs can reduce associated air pollution and greenhouse gas (GHG) emissions from conventional energy sources. Vegetation can also remove pollutants and greenhouse gases from the air through dry deposition and carbon sequestration and storage, respectively.

Other benefits include:

- **Reduced energy use:** They remove heat from the air through evapotranspiration. Green roofs also act as insulators for buildings, reducing the energy needed to provide cooling and heating.
- **Improved quality of life:** They provide aesthetic value and habitat for plants and animal species.
- **Improved stormwater management and water quality:** They can reduce and slow down runoff and filter pollutants from rain.



Recent street air quality studies show that a common tree size locks in pollution.



Using different tree sizes and species along roads is a better strategy for air quality.

Space demands

Green cover and shading from tree canopies are essential to reduce ambient air temperatures on streets and in adjacent buildings.

Different types of trees require different amounts of space. The streets and sidewalks in Athens and the other municipalities are narrow, and the buildings are tall. Criteria related to available space are of significant importance in the selection of plants as well as their maintenance. For example, it is important to prune trees in a way that allows adults to pass under them and that does not create problems for awnings, sheds, articulated buses, and trolleybuses.

More specifically:

- The mature height and shape of the plants must be considered for each typology (street, square, park).
- Plants with a shallow root system should be avoided on roads with small tree beds to avoid raising the pavement, as can occur with the silver poplar (Populus alba).
- Trees that cause allergies or drop fruit, and those of the same genus should be avoided. Male plants can be replaced with female plants, after consultation with botanists, to reduce pollen and allergies.
- Wherever possible, a mosaic of trees, shrubs, and grasses should be created. Vegetation that does not tolerate shade, should be avoided in lower layers.
- Trees must be planted at least 1 meter from the street-side edge of the sidewalk.
- The minimum distance for street trees depends on the size of the crown, but usually is not less than 5 meters. A different strategy is to overplant, as done in China, for example, where small trees are planted in flower beds at 2 meter intervals in order to immediately provide shade.
- After a few years, when the trees start to compete with each other, the extra trees are cut down.
- For large trees (over 20 meters), the average distance is 12 meters; for medium and small trees, 8 meters.
- Species with an open crown should be selected and planted in groups in continuous pits.
- Species with uneven crowns that need regular pruning should be avoided near buildings and power lines (e.g., Pinus halepensis).
- Shrubs and ornamental flowers listed in Appendix A are recommended, especially in squares for ground cover. Fruit-bearing shrub species are recommended to attract birds and wildlife (e.g., Pyracantho), a feature of animal-aided design.
- Shrubs near intersections should be less than 1 meter tall, or else pruned

Tree crowns near buildings and businesses promote energy conservation. Such shading can reduce utility bills for air conditioning in residential and commercial buildings by 15 percent to 50.

- Smaller plants should be chosen when there are overhead power lines or lines that impede the extension of the crown and branches.
- Species that create a combination of shapes, colors, and aromas are preferable.

Populus, Indian tulip tree

Populus alba (dust and particle retention)

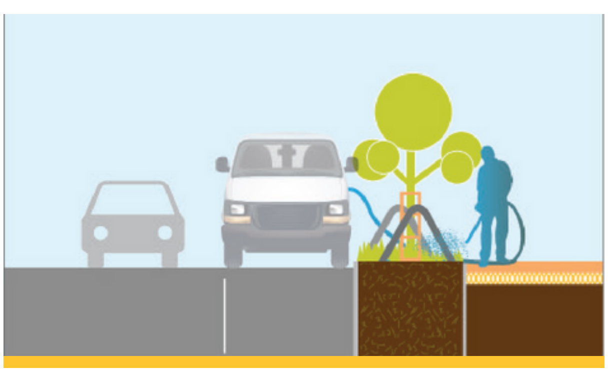
Availability and characteristics of young trees

To increase green coverage and shading in the city, special solutions are proposed for the new planting of young trees to protect against heat and improve the microclimate.

- Species that are available and produced in local nurseries must be selected.
- Genotypes must be selected from the neighboring region of Attica.
- Cultivation and preparation of seedlings can create more resilient plants. Directions are provided by the Mediterranean Mosaic program (see bibliography in Appendix B).
- Be aware of the balanced growth of plants and seedlings with an appropriate distribution between the root/shoot ratio (i.e., the root system should be big enough to be able to extract nutrients and water. Literature states an average optimum root/shoot weight ratio of 1:5 to 1:6 or to plan about the same volume for roots as the planned size of the canopy. Different trees and optimized soil management can potentially reduce the size of the planting pit - contact local arborists or horticulturists for details).
- Attention must be paid when planting edible fruit plants, as they can create organic waste and may be unfit for consumption due to air pollution.

Planting and care details include:

- Use appropriate growth containers with internal ribs to avoid the spiral movement of the roots (volume of between 250 cubic centimeters and 400 cc; depth of between 14 cm and 18 cm).
- Select suitable substrates for optimal oxygenation of the root system (i.e., materials with open pore structures like zeolite, perlite, compost - also other soil loosening techniques can introduce oxygen to the root area).
- Choose among slow-release fertilizers, delivery of soluble fertilizing elements through the irrigation system, or application of compost and organic matter to the soil instead of synthetic fertilizer.
- Reduce the amount of fertilizer at the end of production to strengthen the plant.
- After germination, grow the seedlings outdoors, i.e., in natural conditions outside of greenhouses to become robust.
- Decrease substrate moisture by 50 percent to 60 percent at the end of the production process, to ensure hardening before replanting in the urban environment.
- Avoid tree pruning for the first three years. Specifically in Athens, public utilities often cross planting areas with their vehicles. The metal elements shown below can protect tree roots from parked cars and from excavation for repairs or reinstallations.



Municipal water truck tending to newly planted trees in their first year

Guidelines for root protection: metal elements

Grasses in urban design

The use of grasses in planting beds in the city can play a role in increasing the green cover of the surface of the city and play a major role in improving the microclimate of the city and managing UHI.

Grasses can be planted on small plots, where it would be difficult to introduce trees or other types of plants. Also, the introduction of grasses makes it possible to cut through the sealed areas (continuous concrete and asphalt), so that the plant cover increases and there is a better absorption of rainwater (see earlier example for broken asphalt). Finally, grasses have much lower maintenance costs and provide an interesting new aesthetic trend, which is spreading from America to Europe.

More specifically:

- The cumulative effect of removing small hard surfaces and replacing them with green elements has a positive effect on the heat storage capacity of a neighborhood.
- Some grasses are well adapted, not only surviving but thriving in conditions of water limitation and heat stress.
- They can grow happily in shallow soils of low fertility and require little to no maintenance.
- Some grasses can become invasive, meaning they spread quickly, dominate ecological zones, and are difficult to eradicate.
- Even native species can become weeds when they have certain characteristics, i.e., they produce many seeds that can be dispersed easily.
- Invasion propensity can be assessed before planting and low-risk strategies adopted.

Lessons from abroad:
Australia's native species have evolved over hundreds of thousands of years in an environment dominated by shallow, barren soils, regular droughts, and extreme summer temperatures. Grasses have developed highly efficient coping mechanisms such as prolonged dormancy and underground growth sites that allow them to survive over long periods of drought and quickly recover from interruptions. Some species that have been cultivated and evaluated for many years include: Themeda triandra, Poa labillardieri, Rytidosperma pallidum, and Austrostipa scabra. They are visually appealing, especially in mass plantings.

Other species that have the appearance of grass but are not grass (e.g., Lomandra) also are suitable as they are extremely hardy and retain green leaves all year round. They are also nonseed bearing, which limits their spread and reduces the risk of them becoming invasive. Other smaller species worth considering are, e.g., Multiflora, Bracteata, and Filiformis.

These features have been recognized by urban planners in Australian cities, where mass plantings of various types of grass are common. Due to high demand, nurseries in Australia have specialized in propagating and distributing seeds of a wide range of native grass species. Numerous native Greek species also meet the above criteria.

A report published by the Athens branch of the Mediterranean Horticultural Society examined native grasses and their tendency to become invasive in the Pelion region of Greece. See the list of species that are favored and those to be avoided in gardens (https://www.mediterraneangardensociety.org/96-grasses.html).

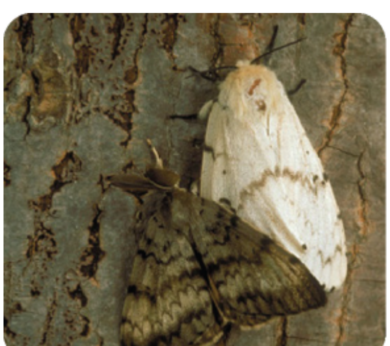
Pest management

Climate change brings many challenges to plant pest management. High temperatures enable pests to multiply faster and over longer periods. In addition, when plants are dormant due to heat stress, they cannot defend themselves against attacks.

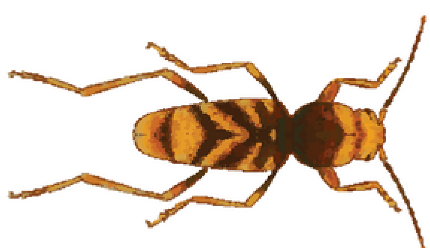
In recent years, the Attica region has struggled with a mass infestation of Thaumetopoea pityocampa in pine trees (Chalepi pine). The pine caterpillar is a leaf-eating species that builds several nests in the branches of trees. Climate change has increased their presence, which is developing into an epidemic. More waves of bark-eating insects are expected: e.g., Pityokteines spinidens, which mainly attacks the Greek fir. The bark beetle spreads in the Parnitha area, especially during periods of high temperatures and drought. Another prevalent pest, the plaster insect (Limantria dispar), multiplies extensively when the temperature is high in the winter. Larvae feed on the foliage of host plants, especially broad-leaved species. They attack crops, forest trees, and ornamental shrubs, such as oak and rosewood species.

Suggested protection measures against the above attacks:

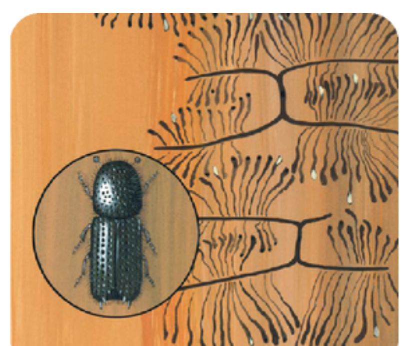
- Avoid planting vulnerable species (e.g., Aleppo pine) in narrow formations. Especially in parks, trees should not be placed near each other.
- Plant with a mixed palette, with coniferous and broad-leaved species. This can improve the ecological balance of insects and reduce infestations of species.
- Ensure the availability of water for the affected species in dry periods to strengthen the plants' resistance to pests.
- Improve plant health by providing the necessary space, soil health, pruning, and irrigation.
- Apply integrated plant protection and biological methods (i.e., an abundance of beneficial competitive insects) for each pest, such as Bacillus thuringiensis, based on the appropriate life cycle of each species.
- Carefully remove and clean infected parts of the plant.
- Avoid chemical agents, such as diflubenzuron for the pine caterpillar. If absolutely necessary, use them individually instead of combining multiple agents.



Bugwood



Tiger longhorn beetle



Bugwood

Pest management

The insect xylotrechus chinensis has recently been introduced from Asia to Greece and has been observed to attack and kill mulberry varieties (Morus species). Due to its rapid spread in countries such as Greece and Spain, it has been included in the danger list of the European and Mediterranean Plant Protection Organization (EPPO). According to records of the municipality of Athens, about 30 percent of urban trees have already been infested by the insect. Preliminary studies show that infestations mainly involve mature trees, where larval activity cuts off the transport of sap and nutrients to the bark and woody part of the host. The extensive use of mulberries in tree stands further exacerbates the problem and increases the hazards of branches falling on passersby.

Preventative measures:

- Accurately record the areas, location, and affected plants, so that targeted measures can be taken.
- Avoid planting mulberries in a southwest orientation, where the chances of infestation are greater.
- Plant them in combination with other species, especially in tree lines (e.g., Celtis australis, Broussonetia papyrifera, Sophora japonica).
- For immediate treatment of acute cases, remove the affected individual plants, or apply special sprays or injections of insecticides into the trunk of the trees to prevent egg-laying and to kill the larvae.
- Determine the type of insecticide (e.g., abamectin) as well as the exact date of application based on the degree of infestation and spread, as assessed by plant pathology specialists.

Entomology sprays

Xylotrechus chinensis

Use of insect pheromones against insect infestation

Maintenance and management: best practices

Plants in networks:
The creation of a mosaic of layers, trees, shrubs, and grasses bear a host of advantages for climate change adaptation. This involves integrating companion plants and a diversity of vegetation layers (i.e., multilayer integration).

Advantages of multiple levels of planting:

- Reduces soil compaction.
- Decreases plant exposure to reflected heat.
- Ensures increased shading.
- Increases diversity at all levels: species, community, strata, levels.
- Protects the soil and roots, specifically through the lower level of plant cover provided by shrubs and grasses (e.g., Hedera helix, Rosa sp., Cotoneaster dammeri).
- Reduces noise pollution, especially near busy roads.

Green corridors between urban forest parks reduce UHI effects through their connectivity:

- Green corridors are a highly effective practice to reduce UHI.
- The maintenance and provision of mature adult trees are very important to ensure a microclimate for the low planting layer.
- Green spaces should be at intervals of no more than 1 km to increase connectivity.
- Plantings of competing plants must be avoided. Instead, combine species with high and low nutrient and water requirements.
- Green axes are vital for landscape connectivity and biodiversity.
- Efficiently reduce UHI by locating hotspots based on factors such as heat distribution and wind trajectories, and greening them with pocket parks.
- Parks and larger green areas create a cooling effect beyond their boundaries.
- Square and circular green spaces have a greater cooling effect than long, narrow ones.
- Tree rows without ground-cover vegetation have a smaller cooling effect than parks.
- In narrow formations, a greater density of tree canopies can further reduce temperatures.

Dune park with a forest

Pocket park Podomonte Elba

Ground preparation

Soil preparation and planting methods:
A quick, efficient way for water to permeate soil becomes increasingly important as the temperature rises. Soil compaction is an obstacle to that permeability, requiring attention to soil preparation.

The best possible planting conditions must be provided to strengthen the resilience of green spaces. Good soil preparation practices before planting are essential to the success of urban greening and include:

- Green ground cover, no tillage, and conservation methods are several good practices.
- Good soil preparation and careful planting to avoid transplant shock.
- Stripping, accumulation, conservation, and reuse of existing topsoil in urban and periurban developments.
- In urban areas, the soil is usually compacted, often lacks nutrients, bears high levels of acidity or alkalinity, and may be contaminated by industrial or other human activities. Therefore, nutrients need to be both available and added, such as compost or organic matter of local origin, before planting.
- It is important to analyze soil characteristics before selecting plants and adjust any parameters (e.g., soil pH) to what is optimal for plant growth.
- The soil surrounding tree trunks should be open or covered with lower vegetation. Avoid the use of concrete around tree trunks as it inhibits water infiltration and nutrient cycles.

Terra Preta:

- Terra Preta methods were developed by farming communities in the Amazon region between 450 BC and AD 950. They are responsible for the enormous productivity of the Amazon forest.
- Terra Preta is characterized by the presence of low-temperature charcoal residues in high concentrations, large amounts of microscopic ceramic fragments, organic matter, such as plant remains, animal droppings, fish, and animal bones, and other materials, as well as nutrients including nitrogen, phosphorus, calcium, zinc, and manganese.
- Fertile soils have high levels of microbial activity and other beneficial properties.

Compost

Hard and dense soils

Agro forestry

Agroforestry systems provide:

- Additional evapotranspiration and cooling.
- Restoration of ecosystems and additional benefits of related ecosystem services (water, air, rain, recreation, environment, jobs, etc.).
- In the short to medium term, they generate income for users who harvest the edible yield, wood, and other biomass.
- A land use regime, where trees and shrubs are planted between agricultural crops and/or livestock in a dynamic, ecological, and natural system.

Multilayered agroforestry has great potential for climate change mitigation:

- The carbon sequestration rate is ten to forty times higher than any other improved annual crop production practice.
- The practice sequesters carbon in woody biomass and soil; can reduce fuel consumption for agriculture by 80 percent; and helps to maintain long-term agricultural yields.

The following cross-section shows how permanent crops such as trees and shrubs are layered within a linear forest. In the cross-section, left to right represents the north to south orientation.

Standard Section of Permaculture forest that can be integrated in a park

Green infrastructure management

Proper operation and maintenance of green infrastructure solutions are essential for their success and long-term viability. Green spaces are often designed with a budget for their planning and construction, but disregard management and maintenance, which are essential for living organisms such as trees.

Municipalities can directly support or facilitate other stakeholders to comanage green spaces and infrastructure including:

- Residents.
- Water supply and wastewater companies.
- School administrations.
- Non-profit organizations.
- Religious groups.
- Power utilities.
- Facility management companies.
- Business improvement districts.

Measures to encourage collaborative management include:

- Create a sense of ownership of the jointly implemented solutions among residents and end users (e.g., through the co-design processes).
- Link to existing stakeholder priorities and interests (e.g., green school projects).
- Formalize maintenance responsibilities in agreements (e.g., with neighbor- hood committees, local associations, companies, etc.).
- Establish new professional roles with responsibilities to maintain urban greening (e.g., community gardeners offering workshops and sessions for residents).
- Engage residents and promote resident leadership for the management of green infrastructures.

Bioswales: Planting

- Grass lawns planted with mowed turf provide a neat appearance but have been found to be less effective at slowing down stormwater runoff than ditches with taller plants.
- Ornamental grasses, shrubs, perennials, or a combination of these can be planted in a biological pit. To protect the soils in the areas that are not covered by turf, add a layer of stone. Larger stones can also be used to break up concentrated water flows and reduce velocity.
- Xeriscape is a landscaping method developed specifically for arid and semiarid climates. It uses water conservation techniques including drought-tolerant plants, mulch, and efficient irrigation. Due to water conservation and consequent low evapotranspiration, the plants used in Xeriscape are more drought tolerant but have a lower cooling effect.
- Wet bins work similarly to stormwater wetlands.

Graywater filter

Public participation event

Bioswale detail in parking area

Green infrastructure management

Composting:
Biomass residues from landscaping can be co-composted with kitchen waste. The composting process generates heat, which can be optimized and employed through design (i.e., compost heater, or biomeiler).

Composting is possible in a number of ways, each with different advantages and disadvantages:

Centralized and decentralized collection and processing:
- Centralized composting: Where the municipality or a central agency is responsible for collection and composting, biowaste from pruning can be added and economies of scale gained. The removal of plastics and other impurities is important and larger open spaces are needed for larger amounts from centralized collection. Mulch biomass and slow composting can be applied directly in parks around trees and shrubs.
- Decentralized composting: This can also feature heat recovery. Small-scale, decentralized collection, with active citizen participation, often improves the purity of collected material.

Composting with and without earthworms:
- Earthworms ensure hygiene and volume reduction.
- Composting without earthworms enables hot rot phases (over 60°C) for hygiene. However, the creation of suitable conditions requires more precision, namely, the correct carbon to nitrogen ratio, ideally 35:1 (organic kitchen waste has a ratio of about 42:1, brown leaves ~70:1, fresh green clippings less than 30:1, human waste ~8:1, sawdust ~600:1). These are combined for an ideal compost mix.
- Rule of thumb: Ten parts fresh kitchen scraps and about three parts chopped twigs and dry leaves.
- With proper thermal management, temperatures above 60°C are achieved after a few days (use a temperature sensor) and animal waste such as bones, feces, etc. can then be added.
- The heat can be harnessed either through integration into a well-insulated outer casing of the composter or by placing tube coils directly inside the composter, which is filled with water as a heat exchanger. This system is called 'biomeiler'.
- This heat can be used directly (e.g., in biogas plants to maintain the correct temperature during winter).
- Biogas production works with the exclusion of air during the fermentation process.
- The resulting gas can be used directly for cooking.
- Humidity, ventilation, leachate collection: Air supply must be guaranteed, and moisture content must be about 50 percent to 60 percent (organic kitchen waste has a high moisture content).
- The added biomass must be dry (about 30 percent moisture content); compost that is too wet can produce unwanted gases. The extracted air can be cleaned with biochar or a biofilter; wet biomass including plants must be shredded.
- Diluted leachates make a very good liquid fertilizer. However, long-term storage is not recommended.

Composting

Green infrastructure management

Biomass utilization pathways:

This chapter deals with biomass utilization pathways from pruned green infrastructure in cities, as they are an important and valuable resources.

- Conversion of woody biomass into chemicals, bioplastics, clothing, packaging, paper, etc.
- Some processes are described in detail, for example, in the Austrian BioCycles study, the BIOTRANSFORM or Forest Value projects.
- After extraction or conversion, energy and nutrients can be recovered from residues.
- Collaborations with experts on utilization pathways are beneficial.
- Start by identifying stakeholders, appropriate infrastructure, collection, storage, and application pathways.

Ground cover:

Shredded biomass can also be used directly as materials around trees or shrubs (without touching the bark).

- Best applied in deep layers of greater than 20 cm to increase moisture, soil biodiversity, soil organic carbon, water storage capacity, and adaptation to climate change.
- Thin layers of decaying ground cover can extract soil nitrogen content.
- Decaying mass applies and stores carbon in the soil for a long time.

Ground cover

Best practices

Co-development of a public tender and holistic project support for nature-based solutions in Milan, Italy:

- Open tender to support and subsidize the construction of green buildings (called Bosco Verticale) addressed to public and private bodies).
- Cofinancing of ten pilot projects (for a 35 percent non-reimbursable share of the total cost), feasibility study of roof statics and funded technical assistance (up to €7,000 in value) for the co-design and co-implementation of the nature-based solutions (NBS).
- Agreement to follow a co-configuration process with the participation of at least the people who live and/or work in the building to develop a maintenance plan for the next ten years and to support monitoring activities.

Sustainable drainage systems (SuDS), Bovisio Masciago, Italy:

- Approximately 1 km of road was reconstructed with SuDS to manage urban runoff. SuDS techniques include bioretention systems, seepage ditches, and dry retention basins.
- Commissioned by BrianzAcque (a public water company) and funded by the Lombardy Region and ATO Monza e Brianza (water service funding authority).
- Consultations in eleven public agencies.

Green-blue large-scale infrastructure, Izmir, Turkey:

- Elements: Green corridors, reforestation, recreational areas, and carbon sinks.
- Water solutions: SuDS, flood prevention, and green pavements.
- Other solutions: Single green infrastructure solutions (biochar and pollinators). Vertical and horizontal green infrastructure solutions and urban agriculture.
- Impact: 3° to 5°C lower temperatures in summer.
- Absorption: 50 tons of CO_2 per year.
- Public financing from the municipality: loans, guarantees, equity.
- Specialized staff training: not required.

Farfalle in Tour: Citizen science project in Turin, Italy:

- Transforms urban green spaces into spaces that attract butterflies and other pollinators.
- Uses native plants.
- Connects spaces located in different parts of the city, with residents of neighboring areas encouraged to plant private gardens and balconies with plants that attract butterflies, thus creating networks of streets for butterflies.
- Increases social integration, especially with the participation of mental health centers.

Impact assessment

Impact assessment
The ARSINOE project deals with the impact assessment of the heat island phenomenon in Attica. Based on this technical guide, the project will propose NBS innovations and define the application of climate modeling, specifically with respect to:

- Water availability (water savings and water needs).
- Annual CO2 sequestration with greening (comparison

of current greening vs. intensified greening).

- Potential local temperature levels and heat mitigation potential are grouped into meter groups.
- Additional maintenance needs relative to benefits.
- Biomass utilization pathways and potential additional revenue streams.
- Biodiversity (ecology, ecosystems, and habitats).

This technical guide also informs the EU-funded NEXTGENWATER project. The Athens Urban Tree Nursery is part of Goudi Park, an area undergoing regeneration to become the capital's main metropolitan park. The nursery includes 4 acres of vegetation, supplies plant material to all city parks and green spaces in Athens, and uses potable water from the national water supply and wastewater company for irrigation. The NEXTGENWATER project supports the city's search for alternative water sources and the exploration of circular economy solutions to achieve environmental, social, and economic benefits for the city.

The installation of a modular wastewater extraction plant for urban green irrigation at the point of demand would have a direct benefit to the sustainability of the new metropolitan park. In addition, organic compost-based crop products will be reused as fertilizer on-site, as part of a portfolio of autonomous, decentralized circular water, energy, and material solutions for cities in water-scarce regions. Finally, thermal energy recovery systems will be explored to minimize the environmental footprint of the pilot program.

MATERIALS

MATERIALS

Role of materials for heat risk reduction

New urban development projects in the Hadrian Aqueduct zone and, in general, in the Greater Athens area should follow the example of most European cities that have developed specific guidelines for the form, size, quality, color, and permeability of public hardscapes, as well as public equipment. Public equipment includes benches, other types of seating, bus stops, kiosks, pavilions, public toilets, lighting elements, and public Wi-Fi poles, litter bins, public fountains, fountains, planted pergolas, shading elements, wind or rain protection structures, and signage elements for parks.

The choice of materials for these urban furniture elements is complex. Designers must consider the availability of products on the market, the project budget, the expertise of the manufacturers, and the general building code of Greece, especially in matters related to seismic and fire protection.

They must also consider aspects of heat risk management, as the color and reflectivity value may or may not make certain materials and elements usable in the summer months. Different materials also dissipate heat differently. Finally, to design sustainable solutions for the city, these urban elements should be made from locally sourced sustainable materials and meet the requirements of the design of the circular city.

This chapter presents the following considerations related to materials:

- The role of color and reflectivity of materials on Microclimate.
- The importance of the water permeability of paved areas.
- Guidance on the criteria for the selection of urban furniture elements and their integration into the design.
- An indicative list of options for urban furniture elements.

Role of color in heat risk reduction

Human reactions to colors are both physical, mental, and emotional.

The correct application of colors in urban spaces helps people easily find their way around a city. Telephone booths, bus stops, electronic equipment, and other structures are recognizable based on their colors. Colors play a vital role in shaping people's perceptions. Furthermore, color has a dominant effect on the solar reflective behavior of surfaces, in addition to other effects such as surface roughness and reflection.

Color is inherent to urban planning and architecture: there is no surface without color, which can have a protective function for the surface layers of the carrier, and always affects aesthetic perceptions.

In the study of microclimate and thermal effects on humans, color is of particular importance. To achieve the optimal effect of reflecting sunlight, any coloring of buildings and floors should be as close to white as possible. Black asphalt absorbs a high percentage of incident solar energy, which is degraded into heat and emitted over time. However, light-colored pavers, especially white marble pavers, have such high reflectivity that they end up having a blinding effect, creating a hazard for pedestrians and drivers. When using reflective and white materials, it is important to consider the reflections and how the materials around us react in order to understand the thermodynamics of the design. Sunlight in Greece is very strong and therefore the pavers must use a color palette from cream to very light gray, or from aioli cream to terracotta.

n general, we can consider several characteristics that outdoor floors should have for heat mitigation:

- The range of colors should be chosen according to the colors present in the surrounding area, so that they do not differ too much from them.
- Use green elements (e.g., planted surfaces, soil, trees) to reduce the heat island effect.
- Use reflective materials and colors that guarantee greater solar reflection and, consequently, less heat accumulation.
- Use materials with high solar reflectance index (SRI) values. *SRI is a formula that factors in thermal emissivity, which is the efficiency of a material's ability to shed heat that has built up).
- There is a robust and mature market for so-called cool colors that absorb a particular band of the visible spectrum (thus giving it a color), but are highly reflecting in the near-infrared (reflecting heat). This allows for highly reflective blues, greens, reds, and even blacks. White is not the only option, although it is overall the most reflective. This is particularly important for pavement. State of the art products are about 30 percent reflective in the visible spectrum (a medium grey), but achieve higher overall reflectivity in near-infrared spectroscopy (NIR). Some cool pavement colors darken while increasing in reflectivity.

Therefore, in addition to the design of large green spaces, it is possible to intervene in the road surface, choosing highly reflective road surfaces, made with natural and permeable materials with solar reflection properties.

Effect of color for microclimate

This section covers additional considerations regarding color and reflectivity.

What is albedo?
Solar radiation includes visible light (typically, 43 percent of solar energy), near-infrared light (52 percent), and ultraviolet light (5 percent).

Albedo, or solar reflectance, is the ratio of reflected solar radiation to the total amount falling on that surface, i.e., the incident solar radiation. Albedo values range from 0 (perfect absorbers) to 1 (perfect reflectors). Solar reflectance (SR) is the ratio between the solar energy reflected from a surface and the total incident solar energy.

Outdoor surfaces absorb and store some of the solar radiation that falls on them, resulting in local overheating of them as part of the wider UHI phenomenon. Solar reflectance is, together with thermal emission, a key parameter for characterizing the thermal response of the surface receiving solar radiation. Their combination is the SRI: The higher it is, the less the surface irradiated by the sun heats up. The use of light-colored floors allows the surfaces to be kept cooler, increasing the percentage of reflected solar energy, especially in the field where thermal radiation is concentrated.

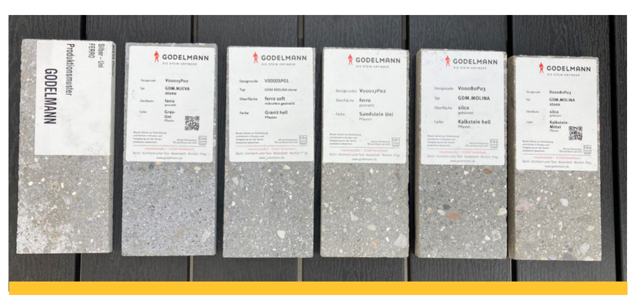
The effect of overheating pavement is more pronounced in areas with hot summers and several hours of sunshine, at the expense of urban pedestrian comfort. Further, the effect on cold pavements is proportional to the areas covered: the larger the area of cold surfaces, the larger the areas where citizens can benefit from reduced urban heat.

Trade-offs:
First, lighter pavements reduce ambient air temperature, which is a positive. However, there is also evidence that the reflected solar energy can increase the solar heat gain of individuals. Paradoxically, a cooler air temperature might still lead to thermally overloaded people, meaning that temperature is the most essential aspect. A person crossing a cool paved street is receiving a low dosage and is likely getting a net cooling benefit from the ambient air temperature reduction. A road worker, a tourist in a pedestrian area, or a child in a playground (i.e., someone present in this space) might receive a much higher dosage of solar energy and experience a negative cooling impact.

Urban tree shading systems can reduce the trade-offs of reflective pavements. Urban vegetation that shades surfaces reduces the incoming solar radiation.

Reflection, absorption, and transmission are the mechanisms by which urban greenery intercepts and disperses solar radiation. Recent literature reports that suburbs without trees are 2° to 3°C warmer than suburbs with mature trees. Finally, only the combined strategy of cool surface cover and shading trees reliably provides additional benefits.

Colors with SRI >35



Colors with SRI >35

Permeable paving

Permeability is the physical property that represents the ability of a body to be permeated by a fluid. This definition can also be applied to self-locking floors to counter rainwater. A permeable floor is one that allows the drainage of rainwater to the deeper layers of the soil.

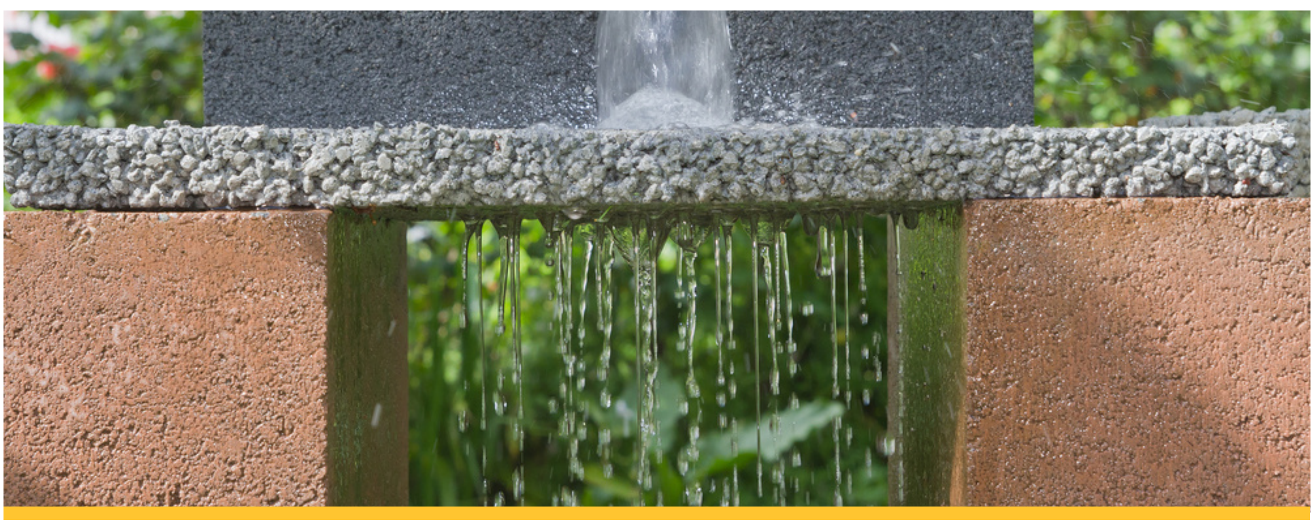
- Currently, impermeable cement mortar is the typical default choice in Greece—but it removes the natural water cycle and contributes to the UHI.
- The water permeability of the pavements changes over the years and its absorbency decreases, so we must keep the sealed surfaces as small as possible and maximize green surfaces.
- Gravel paths should not form the sole or main axis of movement because the gravel does not allow the movement of carriages or wheelchairs, and makes the path inaccessible for some population groups.
- Gravel materials can come from reusing old concrete surfaces after they have been crushed.

Drainable paving:
Draining flooring is a self-supporting concrete floor designed to facilitate drainage of precipitation and percolation of water into the subsoil through joints filled with permeable material (sand or gravel).

Filtering paving:
A filtering surface is a self-supporting concrete floor consisting of a mixture designed to facilitate the drainage of precipitation and the infiltration of water into the subsoil.

Types of water-permeable surfaces include:

- Meadows.
- Dirt roads with grass.
- Grassy concrete grates.
- Plastic grates.
- Cubes and solids with wide or narrow joints.
- Porous solids.
- Drainage concrete.



Permeable paving

Permeable paving

The advantages of permeable floors include:

- Reduction of the waterproof surface of a space.
- Reduction of the volume of runoff water.
- Conservation of groundwater, as it is fed in a more natural, sufficient, and stable way.
- Reduction of surface runoff phenomena with benefits for road safety during severe weather events.
- Durability compared to other types of surfaces.
- There are reports that air gaps make roadways quieter and help reduce sound reverberation.

Permeable paving

Permeable floors must not allow moisture to pass through to the foundations of buildings and basements of apartment buildings. The greenery should not come in contact with the building, but there should be a 25 cm to 30 cm gravel zone for water drainage. Further, the paving must always have a minimum 2.5% slope outward from the building, at all building entrances.

Permeable paving

The disadvantages of permeable floors:
There is the possibility of "overbuilding" spaces for infiltration when filling materials block due to the accumulation of suspended solids carried by the runoff water. In other words, permeable paving will not remain effectively permeable forever.

Recommended application:

- In areas of residential expansion, where it is not economically feasible to reconstruct white water pipes as additional infrastructure elements.
- In areas where there is a maximum limit on the discharge of rainwater into the public sewer network.

Not recommended for application:

- Where there is excessive sediment deposition on the surface (construction sites or yards of construction companies).
- In areas adjacent to steep slopes that are a source of sediments.
- In petrol stations, truck parking areas, chemical industry yards, and in general in all areas where hazardous materials are handled that may be dispersed into the environment, or where concentrated amounts of pollutants may leak.
- In areas where the water table remains seasonally very high and therefore can saturate the soil near the surface and within the pavement section.

Cool pavings

Cool pavings include several established and emerging technologies that communities are exploring as part of their efforts to reduce the UHI effect. These paving materials reflect more solar energy, enhance water evaporation, or are otherwise modified to stay cooler than conventional pavements.

Conventional paving materials can reach peak temperatures of 48º to 67ºC in the summer, transferring excess heat to the overlying air and heating rainwater as it runs off the pavement into local water resources. Due to the large area that pavements cover in urban areas (typically nearly 30 percent to 45 percent of the land cover), they are an important factor in heat island mitigation.

Cool sidewalks can be created with existing paving technologies (such as asphalt and concrete) as well as with newer approaches such as using overlays or covering with grass.

In addition to reducing heat islands, the benefits of cool pavements include:

- Rainwater infiltration into the road surface and soil, reducing runoff and filtering pollutants.
- Lower tire noise.
- Better night visibility.
- Improved local comfort.

Communities looking to use cool pavements as part of a UHI mitigation program may find it difficult to estimate net costs or benefits based on temperature reduction alone. Green as an overall value can provide multiple benefits, such as improved stormwater management and water quality. This should be factored into the evaluation of a paving approach.

A study in Paris, France, found that wetting pavements reduces daytime temperatures by up to -1.5ºC. Pavements can be wetted with 6 mm of water for 10 minutes in the morning, preferably between 8:00 a.m. and 10:00 a.m., guaranteeing maximum evaporative cooling for twenty-four hours during a heat wave. This wetting can be applied using aqueduct water, rainwater, or treated wastewater.

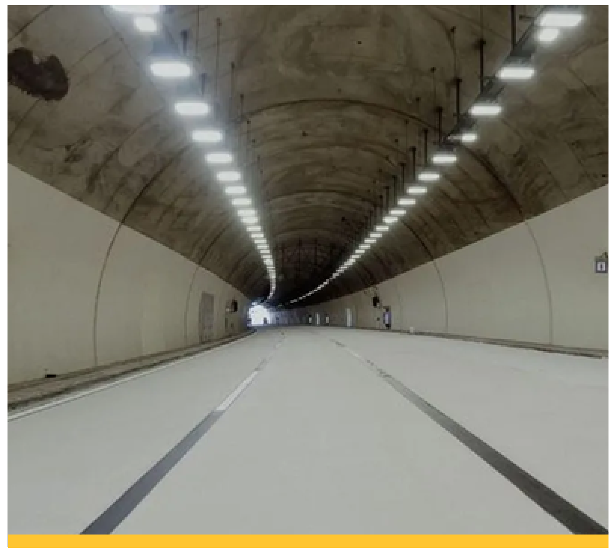
Shaded pedestrian ways

Asphalt

Asphalt pavements absorb and store more heat than natural surfaces. Thus, high temperatures are emitted from conventional asphalt pavement, which then releases heat into the atmosphere and contributes to the UHI effect. Building materials, especially those with dark surfaces (e.g., asphalt pavement), are dense and able to absorb and store solar radiation. Asphalt is the strongest heat collector, amplified from typically significant direct heating.

Cool pavements refer to any new pavement material or design technology intended to reduce heat transfer. Pavement design depends on the ratio of components used and the air void ratio must be suitable for its purpose. Most asphalt pavements are densely graded with a low reflectance value. As a result, surface temperatures of conventional asphalt pavements can reach 48° to 67°C with maximum solar intensity. Porous pavements, due to their high permeability, allow water to pass through the pavement and evaporate.

Moreover, lower tire noise is only applicable to permeable paving. Reflective pavement can substantially increase overall lumens and reduce the need for outdoor lighting by up to 30 percent. However, there are issues with aesthetics, including oil deposits and tire marks.



White-tinted asphalt in Olympia Odos Highway, Greece

Greek case study for white asphalt:

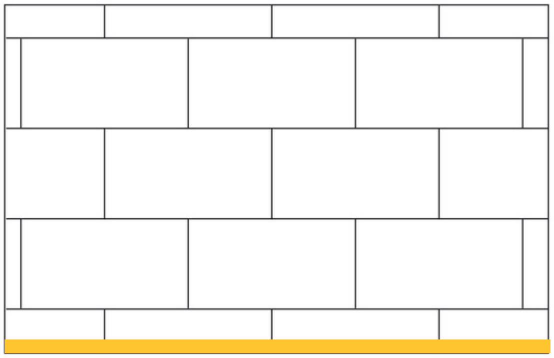
The light lining of the Theseas tunnel provides a relevant Greek best practice. With the completion of the Olympia Road works, the road now has completely white asphalt, and this makes the tunnel brighter. The asphalt uses a solar reflectance of 0.35-0.37, a light gray.

In the tunnel, reflective equipment was installed every 10 meters along the pavement on both sides of the tunnel, while a black frame with a dashed white line applied inside was combined to maintain the contrast of the lines on the new light-colored road surface. The purpose of this light coloring is to exploit the positive consequences of the reflective characteristics of light-colored pavements compared to dark-colored ones, while always keeping the functional characteristics of the rolling surface high. At the same time, the application of a special surface coating to the road surface of a tunnel has the effect of slightly coloring the existing asphalt and therefore reducing the necessary brightness of the tunnel with a positive environmental impact on its operation.

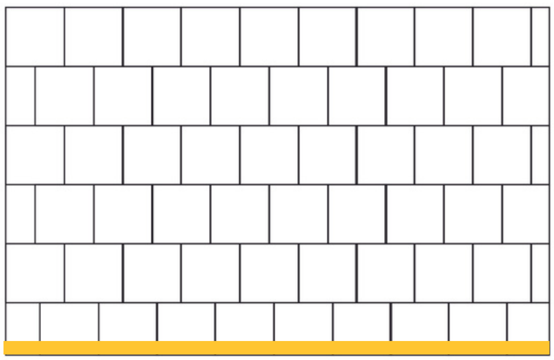
Municipalities have experimented with cool pavement treatments. The CoolSeal coating method is used extensively in Los Angeles and Phoenix, USA. In central Athens, it was used in 2018 on two streets and it never "bonded" with the asphalt.

This practice has been tested in European countries such as Germany, France, and Austria. In fact, it has been applied in tunnels that are more than one kilometer long, with results that are positive both for the environment and for driving.

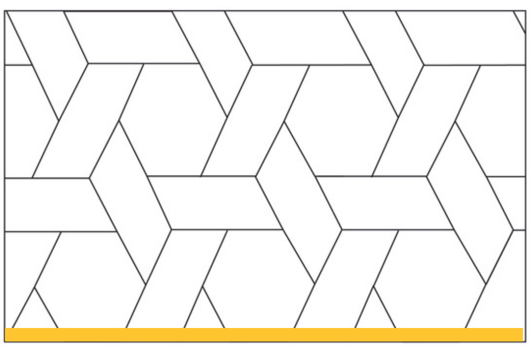
Paving typologies



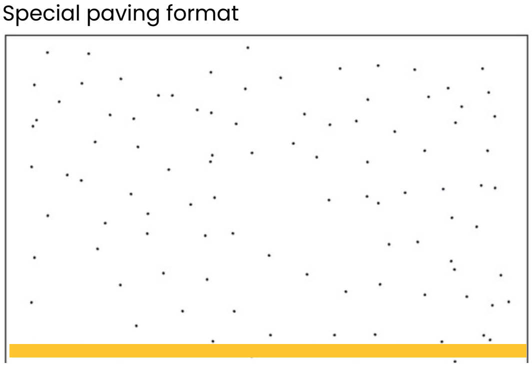
Large paving format



Small paving format



Special paving format



Long paving format

The paving of the newly developing urban spaces in the HA zone, and in Attica in general, must be selected based on a design system of prioritizing paths and squares. Depending on the importance of the space in the general structure of the city and the urban planning concept, closed surfaces must be organized based on their uses and prioritization. The categories are usually the following:

- Central axis of movement: mainly a path(walkway, promenade).
- Secondary axis of movement: secondary path.
- Third axis of movement: path of exploration, and discovery.
- Central square.
- Secondary concentration point.
- Tiled water and water play features.
- Activity areas.
- A sitting area and space for gatherings of small groups of people.

These general categories can have different types of paving with different color tones, materials, and structures. See potential solutions in the diagrams on the right.

Recommendations include:

- Paving of large size on the central movement axis, the central squares, and the water elements.
- Paving of small size in the secondary and tertiary axis of movement, in the secondary concentration point, and in the water elements.
- Oblong paving in the central squares or in the secondary gathering point.
- Special paving on the third movement axis, in the gathering area.
- Gravel or compacted surface solutions in gathering areas or activity areas.
- Surface solutions made of sand or EPDM in activity areas and playgrounds.

Gravel, sand, rammed earth, and EPDM are produced in various colors, and the above rules for color selection must be followed. EPDM can have many non-natural color shades.

Urban elements

The elements of urban amenities should be designed to improve the quality of life of the inhabitants and the pleasant experience and rest in open space. Alongside the need for adequately equipped public spaces, new studies show the importance of offering greater psychological well-being through city care and street equipment with seating, canopies, and plantings. Aesthetics, functionality, and sustainability of materials should be primary goals in an urban equipment project, and the street equipment itself becomes the connecting element of the various areas that make up the city. Attica remains one of the most active and lively areas in Europe, where we see street level and building facades remain active and vibrant with different public or semipublic uses, which is rare in other European cities.

Vandalism:
Urban equipment elements must in principle be protected from vandalism. Strategies include:

- Use of robust materials and forms in the elements of urban equipment.
- Ensuring prompt repair and regular maintenance of landscape and lighting to promote proper care.
- Design of active public spaces to prevent acts of vandalism.
- Managing access including through operating hours.
- Increased focus on entrances and exits, lighting, and fencing to ensure a safe space.
- Expression of ownership of private property and delineating it from public spaces through fencing, signage, and overall good design.

Special typologies:
Specific typologies for urban equipment elements include seating elements, bus stops, lighting elements, public Wi-Fi poles, waste bins, public fountains, fountains, paddocks, pergolas, shading elements, wind or rain protection structures, and signs in parks.

The choice of the materials of these elements, their form, and color affect their function, especially in terms of thermal performance, vandalism, and maintenance.

Urban equipment items include several types. Each type has very different characteristics related to the intended use. For any open space project, it is important that the design vocabulary of the urban equipment elements must be common and be from the same product line, color palette, and material palette. A common design in the Attica region as well as in each municipality would be ideal.

In this case, the abstract, simple, and utilitarian aesthetics of the selected elements are of great importance, making it easier to integrate these elements into all the existing projects that the different designers will design and implement in the future. Classic or traditional forms should be avoided as their forms are very specific to the style of the historical period and are more expensive.

Urban elements

For ecological and sustainable urban furniture, the choice of the right materials is fundamental. The selection of materials affects not only the final aesthetic, but also comfort, value, and durability over time. To maintain the highest possible value of the selected materials, follow the principles of circular economy. The circularity of structures includes the ability to repair and refurbish them, and to recycle materials after the end of life. This will also ensure quality and preserve resources. The most common materials on the market and their characteristics are listed below.

Wood:

- Wood is the material that best represents the concept of ecological sustainability. It stores atmospheric carbon as a solid over the long term and provides ecosystem services and a habitat during its growth period. Wood certified by the Forest Stewardship Council (FSC) or the Programme for the Endorsement of Forest Certification (PEFC) comes from sustainably managed forests and plantations.
- Depending on the type of wood, cost, and weight, the furniture varies both in terms of resistance to loads and weather conditions. In warm, dry, or moderately humid areas, light wooden furniture can be used, perhaps with collapsible structures that can be stored easily during the winter. For more humid areas, furniture made of moisture and mold-resistant types or treated wood is recommended, e.g., using the accoya technique on softwood (https://www.accoya.com).
- Pine, oak, beech, fir, and chestnut wood is cultivated in Europe, each with different characteristics and colors to suit different choose from according to needs. They can be left raw for a more natural look and treated with natural oils and resins that extend their life and resistance to mold, sun, and moisture.
- The cultivation of bamboo, a highly ecological and durable wood, is also beginning to spread in Europe.

Aluminum:

- An ecological material par excellence, it can be recycled again and again.
- Aluminum is lightweight and durable, unaffected by rust or mold, and can withstand any kind of temperature.
- These features make it ideal for use on all types of outdoor furniture.
- However, being a metal, it can get very cold in winter and very hot in summer.

Steel:

- Steel is harder and more durable than aluminum but also much heavier.
- Like all metals, it can become very hot or very cold depending on the outside temperature.
- It is suitable for tables and furniture accessories that remain firmly on the ground even under strong gusts of wind. It is not affected by mold and does not spoil easily.
- Despite the treatments, it requires occasional maintenance to prevent rust.
- Its protection from rain and moisture increases its durability.

Urban elements

Wrought iron:
- Heavy, thanks to anti-rust treatments, it withstands weather conditions well.
- This material is ideal for benches, chairs, and tables in classic and romantic style or for decorative garden structures.

Plastic:
- Plastic is a low-cost material, but has a very short lifespan.
- Especially if placed outdoors, it tends to damage easily, hardens and eventually breaks, particularly when exposed to strong sunlight.
- Although well recyclable, it is a material to avoid for outdoor furniture and construction.

Resin:
- Synthetic resins may be beautiful, but require constant treatment and are easily damaged.
- This is not an ecological or long-lasting material. For example, woven resins have an average lifespan of five to ten years and, once damaged, cannot be repaired.

Seating and pergolas

Seating:
- Seating should be produced from sustainable, locally produced materials in the same color palette as the entire range of urban furniture materials.
- The seat surface should be made of wood or high-pressure laminate (HPL) to make the seat usable throughout the year.
- The seat frame can be made of natural stone, concrete, wood, or metal, depending on the location and the design concept of the space.
- Different kinds of seats are necessary: with a back, without a back, or wide seats to lie down.

Types of shading systems in open spaces:
- Trellis
- Garden umbrellas
- Outdoor awnings
- Garden gazebos
- Solar screens
- Canopies
- Brise-soleil
- Sail tents

Sun shades are needed in plazas, outdoor dining areas, rest areas, playgrounds, bus stops, and possibly at major street intersections. The frame and shading can be made from many different materials. See Chapter 2 for more on green pergolas.

Bench with back

Platform bench

Pergola

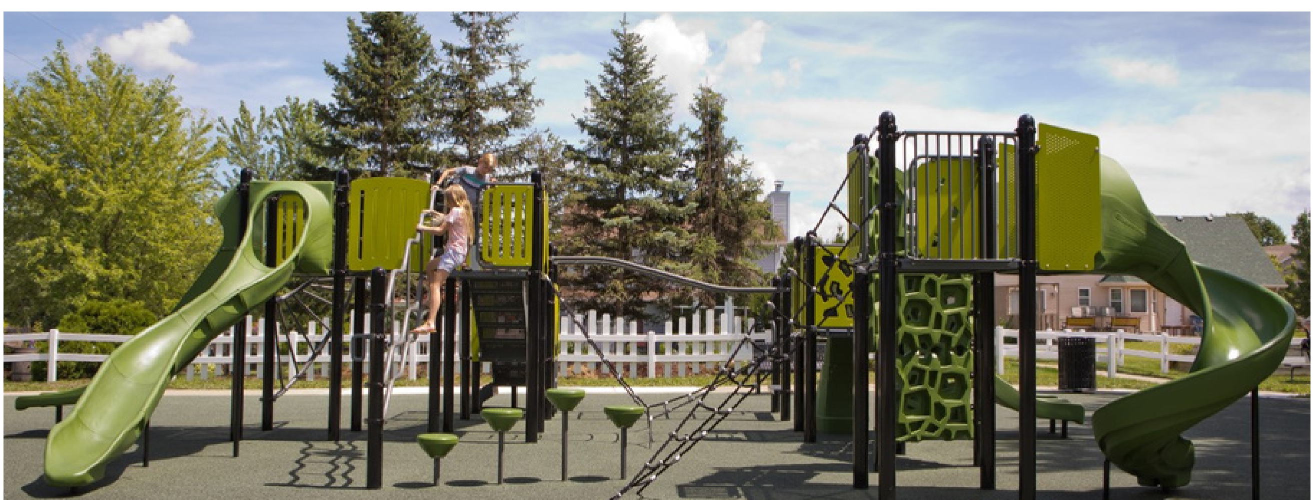
Lighting, WIFI poles, and play elements

Lighting elements:
Since the sunlight in Greece is very strong, the population is used to over lighting, which gives a sense of security. As a result, indoor public spaces and outdoor public spaces tend to be illuminated with very high intensity. This habit is not sustainable in terms of energy and cost, and results in light pollution. It is therefore important to make more efficient use of lighting elements.

- New lighting elements in the city should have photovoltaic and automated systems.
- Lighting can be provided at three levels: floodlights, light poles, and low light poles.
- With rising temperatures, open spaces in Greece will in the future be increasingly used in the late afternoon and at night. Examples of this can be found in the United Arab Emirates.
- Special lighting elements should be used sparingly and only where necessary. It is advisable to combine them with playgrounds. An example is the theme of a playground light with different colors and interactive features.
- Even more specific and well thought out themes are the combination of a light playground with a water playground (as done in the newly implemented square in the Hellinikon park). Another solution is a light playground for bicycles.
- A light study is important for new public spaces.
- Light as a theme can create thematic walking paths in the city, where specific routes can reveal and give new life to elements of the city via light-generated artworks (such as areas under bridges, pedestrian bridges, or non-active facades of buildings).

Playgrounds:
Attica has a low ratio of playgrounds per inhabitant, but there are play and exercise areas for teenagers and young adults (skateparks, parkour areas, carousels, adult swings, etc.). For this issue, comprehensive planning and zoning of areas for new playgrounds is needed for different age groups (under three, three to six, seven to ten, eleven to fourteen). Playground materials should avoid plastic and metal. Instead, extensive use of wood is recommended.

Music and sound playgrounds are also important, as is the design of toys for children and young people with special needs. Shading and water features should be included in new playground design (see Chapter 1, Water Playgrounds).



Drinking fountains and public urinals

Drinking water fountains:

Drinking fountains are necessary to make green routes in public spaces sustainable.

The Athens municipality recently installed three fountains (supplied by EYDAP), and it is important to expand this practice. The ability to cool off with a little water while moving around the city on hot days is very important for public health and well-being. Recommendations include:

- Place drinking water fountains every 500 meters in new urban developments, parks, and squares.
- Select a standard fountain for use in public places.
- Create options to reuse bottles and cups for water refills.
- Partner with cafes to offer free water refills.
- Treat wash water (from cleaning these bottles and cups) via green walls (i.e., graywater treatment) and reuse it in street cleaning or irrigating adjacent green areas.
- Employ collaborative governance and financing strategies to create more green spaces in urban areas, while offering sustainable business models and waste reduction.

Drinking fountain suggestion

Innovative green public urinals: LooPi®:

The unisex plant-based urinal called LooPi® has been tested by hundreds of people in Vienna, Austria. It is optimized for up to 150 uses per day and meets public toilet standards against vandalism. Green elements include:

- The toilet flushes regularly and dilutes urine with water automatically.
- The urine-water mixture is an excellent fertilizer that can create a green oasis.
- Excess nutrients are bound in a biochar filter, which can be reapplied to green spaces.
- Existing public toilets can be retrofitted with this technology.

Green urinal LooPi®

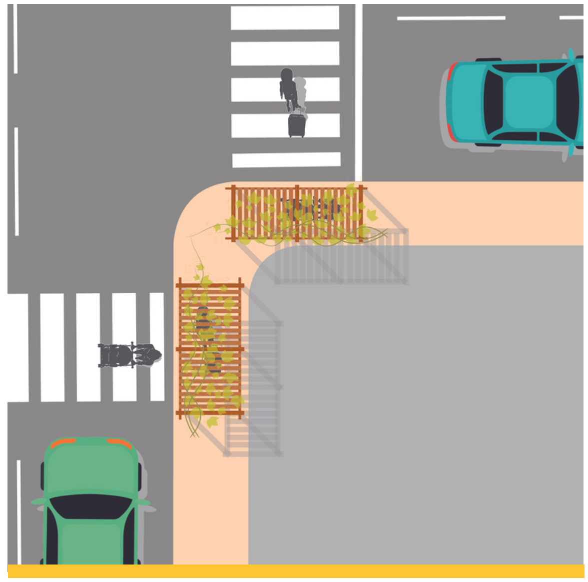
- The green system applied here is a very good example of NBS and elegantly showcases the applied nutrient and water cycles.
- Users can experience how natural cycles work.

Strategic shading structures for the city

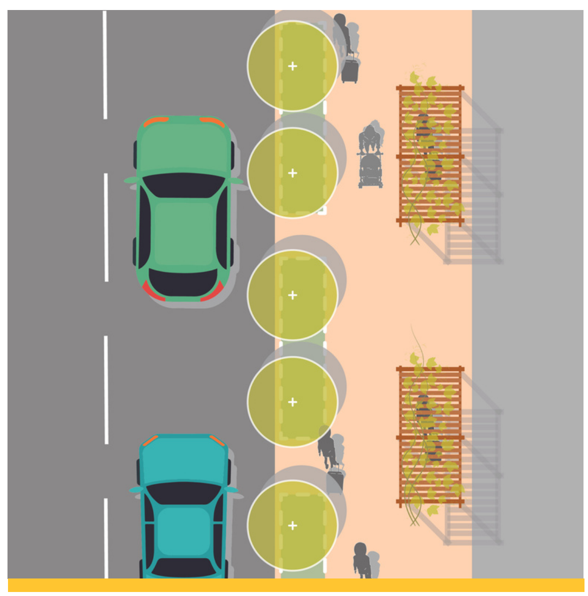
Shaded and cool pathways in the city are especially important to keep the city running during heat waves and to protect people while outdoors during the hottest days of the year. These pathways can include many of the cooling elements discussed so far, such as cooling fountains, shade from trees, buildings, and pergolas, as well as arcades, awnings, and canopies.

Shade stations at intersections:
On hot days, pedestrians need to be able to move quickly through sun-exposed areas of the city to avoid health impacts. The most difficult areas to find shade are street intersections, usually due to the interruption of the building structure offering shade and the wait at street crossings. These areas often become the most uncomfortable for pedestrian traffic. It is recommended that cooling fountains be introduced at these points.

Shading stations:
Shade stations should be introduced on long straight routes in the city facing west, south, or southwest to protect pedestrians. The number of shade stations needed depends on the length of the blocks and the route, with at least two per block recommended on each side of the street. It is recommended that cooling fountains be introduced in these areas.



Shade stations at intersections for pedestrians and cyclists

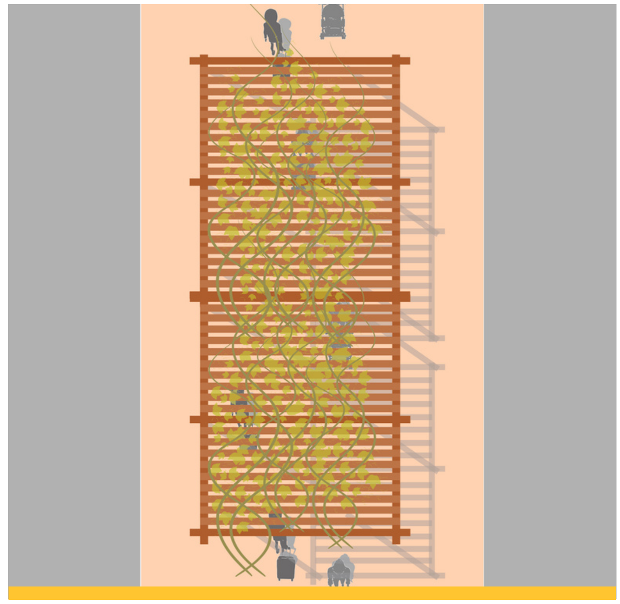


Shade stations on long tracks, two per block.

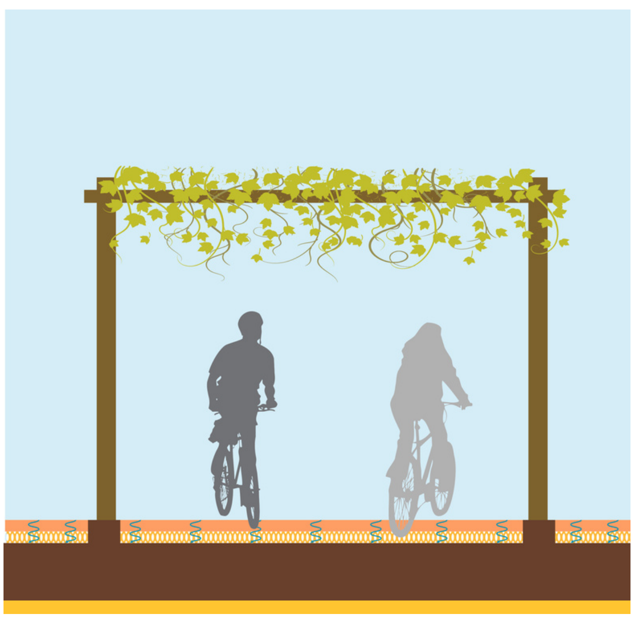
Strategic shading structures for the city

Shaded pedestrian streets:
City sidewalks should be assessed for the provision of shade, taking their width and orientation into account. An elongated trellis can be installed along the sidewalk to enable cooling and shaded movement through the city. These cooled routes should be listed on Google Maps and recommended for pedestrians in the city. This information should also be included in the EXTREMA Global app, which tracks heat risk.

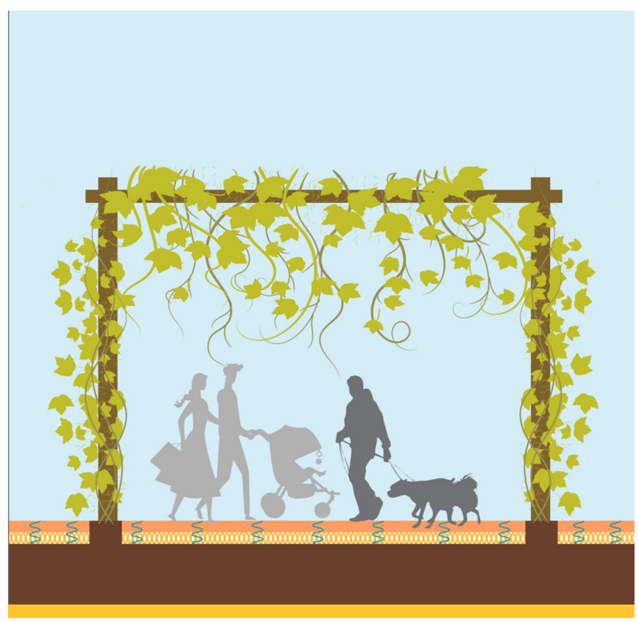
Shaded cycle paths:
Exposed sections of bike lanes oriented to the west, south, or southwest should be covered with trellises to protect cyclists. Intersections are very critical points for cyclists as well.



Fully shaded walkways with trellises



Fully shaded bikeways with green pergola



Fully shaded walkways with green pergola

MUNICIPALITY POLICIES

MUNICIPALITY POLICIES

Suggested heat risk reduction policies: measures for resolution

The previous three chapters presented a wide range of possible solutions to regulate microclimates and mitigate UHI effects through blue and green spaces in urban environments, as well as choices of materials and colors. This chapter looks at those opportunities through the lens of strategy development within the public realm, focusing on municipal (or metropolitan) policies and issues to resolve for heat risk reduction.

Tailored for the City of Athens and the other municipalities in the Athens Metropolitan Area

The following proposed policy measures summarize the Heat Risk Reduction Guidelines put forward to support the adaptation and resilience of Athens (and the metropolitan area) to climate change. These measures are addressed to the municipal mayors, policymakers, and decision-makers, as well as the Councils of Athens, the municipalities along the Hadrian Aqueduct, and in effect all the municipalities of the Athens metropolitan area. They are necessary measures for the survival and well-being of the cities' residents and the metropolitan economy, and can be adopted in their entirety or incrementally. The focus is on public spaces, trees, water, and surfaces used to best lower extreme heat.

Policies for heat risk reduction for municipalities

1	Designated land uses for green spaces (and/or public spaces such as plazas) shall remain intact and respected in their entirety and to their borders, and they shall not be considered in any way as potential expansion areas of public or private buildings in any respect or at any time.
2	Obligatory requirements for green coverage of the surface of the city shall be set at 20 percent to 30 percent for streets;40 percent to 70 percent for plazas; and 80 percent to 90 percent for parks. Tree canopies shall be maximized to increase shading in squares, sidewalks, and streets.
3	Increase shading for sidewalks, plazas, public transportation stops, bike paths, and other public spaces with trees as a priority (due to evaporative cooling, trees provide more dew) or other appropriate shading elements.
4	Obligatory estimation of an additional 20 percent of the budget beyond the design and installation of new green spaces, green corridors, wetlands, etc. for the necessary maintenance and long-term support of these new blue-green infrastructure solutions (i.e., nature-based solutions).
5	Measures implemented to prevent and manage pest infestations that are increasing due to climate change.
6	Strategic selection and planting of trees and other species of flora based on their resilience to high temperatures, drought, and water scarcity. Priority selection shall be based on: (a) high performance in terms of shading and temperature reduction, (b) function as carbon dioxide storage sites, i.e., their contribution to the mitigation of greenhouse gas (GHG) emissions, (c) reduction of air pollution, (d) slowing down of stormwater runoff, stormwater conveyance, filtration, infiltration, and groundwater recharge, and (e) enhancement and support of biodiversity.

Policies for heat risk reduction for municipalities

7	Adequate green spaces within fifteen-minute access for all city residents: creating a "fifteen-minute city."
8	Integration of existing and new green spaces into networks, connected by green corridors to enhance accessibility for all citizens, biological connectivity, and urban biodiversity.
9	Introduction of ultradense forests (tiny forests) in public spaces (e.g., existing triangles of road intersections) for temperature reduction and other ecosystem services. Ultradense forests shall not be accessible to citizens.
10	Soil preparation and planting methods that protect topsoil layers by retaining nutrients for trees, protecting tree roots, providing resistance to soil compaction, and providing space for stratified planting.
11	Specifications for planting trees in tree alleys: provisions to promote oxygen transport to the roots and avoid soil compaction, as well as creating a suitable planting pit to allow for irrigation from three to five years, covered by tree grates. In addition, protection of tree roots with mesh or metal frames to avoid being damaged during public utility works and interventions, etc.
12	Continuous planting beds should be the rule when designing tree alleys; planting beds between trees shall extend to a minimum of 4 square meters per tree. Where possible, existing planting beds should be connected or there should be a 30 percent to 40 percent increase of space given to tree planting beds where they cannot be joined. This way, the trees have more space for their roots and aeration, can retain more water and nutrients, and better cope with periods of temperature stress.

Policies for heat risk reduction for municipalities

13	Prioritization of the use, integration, and combination of green and water elements to solve climate challenges in urban public services: i.e., blue-green infrastructure and nature-based solutions. Integration of nature elements into the city's operations in a functional and not exclusively ornamental way—performative landscape concepts (for example, wetlands to address local flooding).
14	Integration of existing and new green spaces into networks, connected by green corridors to enhance accessibility for all citizens, biological connectivity, and urban biodiversity.
15	Incorporation of interactive water elements (jets, grooves, "mirrors," misting, etc.) in public areas of the city: plazas, sidewalks, parks, and wherever else possible.
16	Inclusion of public drinking fountains within a fifteen-minute walk from any point in the city.
17	Reduction of the number of cars and parking spaces in the city at a specific rate per decade, based on the building and residential density of each neighborhood. The resulting space/areas shall be designated as green space.
18	Increased urban biodiversity of flora and fauna (pollinators, birds, and other wildlife species) that play a major role in the resilience of the city's natural life and help manage pest infestation.

Policies for heat risk reduction for municipalities

19	Maximization of water-permeable pavements and pavers that allow rainwater to infiltrate to deeper soil layers, providing water filtration capabilities and enriching the aquifer.
20	Elimination of materials such as steel, iron, plastic, aluminum, and low-quality rubber elements (which quickly decompose when exposed to the Attica sun), as well as avoidance of dark colors, especially gray, charcoal, black, dark green, dark blue, and dark terracotta colors in new playgrounds, and replacing them in existing playgrounds.
21	Discontinuance of the use of paints with a solar reflectance (SR) value greater than 0.29 and SRI>35 on paved areas, tamped soil, or gravel surfaces. Similar guidelines shall be followed for roof-tops and facades of public and private buildings in the city.
22	Support and facilitate individual and neighborhood initiatives to enhance urban green elements, such as gardening, community flower beds, permissions for potted plants on sidewalks, community vegetable gardens, and intensive green roofs. Promotion of the City of Athens' award-winning "Adopt a Tree" initiative (crowdsourcing irrigation support for young trees), etc.
23	Use of alternative water sources such as rainwater (collected in tanks), water from the Hadrian or other aqueducts, and water from sewer mining, etc. for the irrigation of urban green elements, but also for the irrigation of pavements, squares, bus stops, and other public spaces for cooling purposes.
24	Capacity building among municipal staff and specialized training for the design, operation, maintenance, and monitoring of the proposed new blue-green infrastructure and nature-based solutions.

Policies for heat risk reduction for municipalities

The aim of this climate-adapted redesign guideline for the public spaces of the Athens metropolitan area is to activate the urban public space. Urban space is finite, very valuable, and needs to address constantly increasing and often conflicting uses (bikeways, car traffic, infrastructure pipelines, pedestrian walkways, biodiversity connectivity, outdoor commercial space, etc.). The continuous increase of such pressures, together with new challenges that public spaces need to address (such as the frequency of extreme weather phenomena due to climate change), intensifies the importance of these spaces and escalates their real estate value. Consequently, these policies upgrade and activate spaces with a multi-benefit and multi-hazard approach.

Prioritization of the socioeconomically deprived and marginalized neighborhoods of the Greater Athens area is essential for the design and implementation of the above measures, as these neighborhoods and communities are the most vulnerable to all types of risks. They are especially vulnerable to high temperatures due to the lack of green, high-quality housing and other public infrastructure investment. Providing equal and democratic access to green public spaces for mental and physical health, recreation, and socialization contributes significantly to the strengthening of the social cohesion of the city. And it is this social cohesion that contributes highly to becoming resilient amid the increasing and different crises facing our urban centers.

Finally, through these measures, the aesthetics and identity of the city will be renewed and redeveloped to herald a city that responds, adapts, and promotes future-oriented solutions for our new climate era.

APPENDIX A: PLANTING PALATTE

APPENDIX A
Planting palatte

The following plant palette has been created to facilitate the selection of plants based on watering needs and the best match of plant character to urban typology (i.e., street, square, park). The ranking has been arranged from most hardy to least heat tolerant. The list shows the most important plants and is not exhaustive. This appendix should be read in conjunction with Chapter 2.

A summary of the categorization follows:

Low irrigation needs:
Recommendations and instructions for plazas:

- Create multiple clusters of trees in close formations to create microclimates.
- The periphery of the square should be planted with plants resistant to strong winds, with a deep root system (e.g.: Celtis australis).
- Try to achieve more than 80 percent soil cover.

Trees: Pinus pinea, Cercis siliquastrum, Quercus ilex, Albizia julibrizin, Celtis australis, Ceratoniasiliqua

Shrubs: Laurus nobilis, Pistacia lentiscus, Rosmarinus officinalis, Juniperus communis

Typical section of a low-irrigation ultradense forest/ tiny forest

Planting palatte

Medium irrigation needs:

Recommendations and instructions for squares:

- Plants grouped in clusters provide continuous shade while allowing wind circulation for additional cooling.
- Each cluster can have a combination of trees and shrubs.
- Shrubs under the foliage of trees should be adapted to semishade conditions.
- Try to achieve greater than 70 percent ground cover.

Trees:
Sophorajaponica, Quercus pubescens, Prunus mahaleb, Broussonetia papyrifera, Ligustrum vulgare

Shrubs:
Pittosporum tobira, Cotinus coggygria, Rhamnus alaternus, Buxus sempervirens, Medicago arborea

Typical cross-section of medium-irrigation ultradense forest/ tiny forest

Planting palatte

Recommendations for high irrigation needs:

Instructions for squares:
-Combine large trees with uniform adjacent crowns and low shrubs.
- Use herbaceous vegetation as ground cover for the entire surface.
-The provision of open green space within the site is encouraged.
-Ornamental plant beds are proposed near paths for aesthetic reasons.

Trees:
Tilia tomentosa, Acer platanoides, Catalpa bignonioides, Acer platanoides, Platanus orientalis

Shrubs:
Nerium oleander, Viburnum odoratissi- mum, Viburnum tinus, Weigela florida, Vitex agnus castus

Typical cross-section of high-irrigation ultradense forest/ tiny forest

Planting palatte

APPENDIX A

A.2 TREES

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APPENDIX A

A.2 TREES

Trees

Photo	Latin Name	Common Name GR	Type	Size	Soil Type		Light	Shape	Origin	Suggested Use	Notes	Irrigation Need	Code
	Pinus halepensis	Πεύκη Χαλέπιος Aleppo pine	Evergreen		Sandy and clayey soils. It can grow on poor soils and sloping soils.			Non-uniform	Endemic	Park	The trunk has a useful resin, easily infested by Thaume-topoea pityocampa. Needs pruning.	Low, very drought tolerant	T1
	Pinus pinea	Κουκουναριά Stone pine	Evergreen		Adapted to all soils, not for clay			Spherical	Endemic	Street, plaza, park		Low	T2
	Broussonetia papyrifera	Βρουσονέτια Παπυροφόρος- Paper mulberry	Deciduous		Fertile soil conditions			Non-uniform	Non-endemic	Plaza	very hardy species, planted for ornamental purposes, some-times becoming naturalised and invasive	Middle, can cope with drought	T3
	Cercis siliquastrum	Κουτσουπιά Judas tree	Deciduous		Dry, well-drained, rocky conditions			Ovoid, more than one branch	Endemic	Street, plaza		Low	T4
	Quercus ilex	Αριά Holm oak	Evergreen		Prefers nutrient-rich soils			Spherical	Endemic	Plaza, park		Low, tolerant to high temperatures	T5
	Acer negundo	Σφενδάμι νεγκούτο Box elder	Deciduous		Clay and sandy soils			Broadly columnar	Non-endemic	Street, plaza	air pollution (SO2) resistant, fast growing tree, provides shade conditions, tolerant species commonly used in landscaping and industrial areas, branches break easily, small phototropic reaction	Medium, tolerant to high temperatures	T6
	Acer campestre	Σφενδάμι πεδινό Field Maple	Deciduous		Light (sandy), medium (loamy) and heavy (clayey) soils and can grow in heavy clay soils. Neutral PH.			Widespread	Endemic	Street, plaza, park	Fast growing tree, tolerant to atmospheric pollution, tolerates strong winds, low phototropic reaction	Medium	T7
	Celtis australis	Μελικοκκιά Nettle tree	Deciduous		Sandy and medium soils, rocky slopes, very low requirements			Round domed, spherical	Endemic	Street, plaza, park	Deep root system, wind resist-ant, edible berry-like fruits, low maintenance without pruning	Low, resistant to high temperatures	T8

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HADRIAN AQUEDUCT COOLING DISTRICT: HEAT RISK REDUCTION GUIDELINES

Planting palatte

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APPENDIX A

A.2 TREES

APPENDIX A

A.2 TREES

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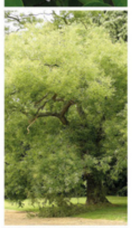
Trees

Photo	Lating Name	Common Name GR	Type	Size	Soil Type		Light	Shape	Origin	Suggested Use	Notes	Irrigation Need	Code
	Tilia tomentosa	Φλαμουριά Silver lime	Deciduous	🌳🌳🌳	Light (sandy), medium (loamy) and heavy (clayey) soils, prefers well-drained soils, neutral PH to slightly acidic		☀☀☀	Marginally vaulted	Endemic	Streets, plaza	The flowers are very common for tea, usually coming from the bottom of the stem.	💧💧💧 High, tolerant to high temperatures	T9
	Catalpa bignonioides	Κατάλπη Ιαπωνική Indian bean tree	Deciduous	🌳	Light (sandy), medium (loamy) and heavy (clayey) soils and can grow in heavy clay soils. Neutral PH.		☀☀☀	Ευρέως θολωτό	Non-endemic	Streets, plaza	Resistant to atmospheric pollution, a fast-growing tree with an extensive root system, the crushed foliage has an unpleasant odour.	💧💧💧 High, tolerant to high temperatures	T10
	Sophora japonica	Σοφόρα Ιαπωνική Japanese pagoda tree	Deciduous	🌳🌳	It can grow in poor soils. Neutral PH.		☀☀☀	Σφαιρικό	Non-endemic	Streets, plaza	Fast-growing tree, tolerant of air pollution, can fix nitrogen. Used in Chinese medicine. This species has a symbiotic relationship with certain soil bacteria, which form nodes in the roots and fix atmospheric nitrogen.	💧💧 Medium, tolerant of drought and high temperatures	T11
	Olea europaea	Ελιά Olive tree	Evergreen	🌳	They can grow in nutri-ent-poor soils. Moderately acidic, neutral pH.		☀☀☀	Σε σχήμα κυπέλλου	Endemic	Streets, plaza and park	It does not tolerate low temperatures. The fruit is particularly used for its oil.	💧 Low, drought tolerant	T12
	Quercus pubescens	Χνοώδης Βελανιδιά Downy oak	Deciduous	🌳🌳	It prefers soils rich in lime. Clayey and loamy soils. Can grow in heavy clay soils. Neutral pH.		☀☀	Ευρέως εξαπλώμενο	Endemic	Plaza and park	Tolerates strong winds, but not marine exposure, does not tolerate root disturbances.	💧💧 Medium	T13
	Ligustrum vulgare	Λιγούστρο κοινό Coomon privet	Semi-evergreen	🌳	Any ground		☀☀ / ☀☀☀	Ανομοιόμορφο, θολωτό	Endemic	Streets, plaza	Fast-growing, usually fence plant, needs pruning, is pollu-tion resistant	💧💧 Medium, drought resistant	T14
	Arbutus unedo	Κουμαριά Strawberry tree	Evergreen	🌳	Tolerant to calcareous, light and medium soils.		☀☀	Ανομοιόμορφη, ευρεία εξάπλωση, κοντός κορμός	Endemic	Plaza and park	Ornamental species, resistant to atmospheric pollution, mul-tiple stems from the crown.	💧💧 Medium	T15

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Planting palatte

APPENDIX A

A.2 TREES

Photo	Latin Name	Common Name GR	Type	Size	Soil Type		Light	Size	Origin	Suggested Use	Notes	Irrigation Need	Code
	Citrus aurantium	Νεραντζιά Bitter orange	Evergreen	🌳	Medium to heavy clay soils, slightly acidic pH		☀☀☀	Elliptical	Non-endemic	Street	Very bitter fruits, prefer a moderately heavy clay with plenty of compost and sand added. It does not like the disturbance of roots.	💧💧 Medium	T16
	Morus platanifolia	Μουριά Πλατύφυλλη Mullbery	Deciduous	🌳	Prefers fertile soils		☀☀☀	Spherical	Non-endemic	Street	Heartless, male selection species, easily attacked by the insect Xylotrechus chinensis.	💧💧 Medium to high, can withstand drought and air pollution	T17
	Albizia julibrizin	Ακακία Κωνστα-ντινουπόλεως Persian silk tree/mimosa	Deciduous	🌳	It can grow in nutrient-poor soils. It can fix nitrogen. Grows in very alkaline and saline soils.		☀☀☀		Non-endemic	Street, plaza	Small phototropic reaction	💧 Low, drought resistant	T18
	Brachychiton populneus	Βραχυχιτώνας ετερίφυλλος Bottle tree	Evergreen	🌳🌳	Can grow in most soils, neutral pH		☀☀☀		Non-endemic	Street	Extensive root system and shallow roots, fast growth, needs pruning, resistant to atmospheric pollution	💧💧 Medium, tolerates drought	T19
	Melia azedarach	Αγριοπασχαλιά Chinaberry tree	Deciduous	🌳🌳	Can grow in most soils, neutral pH		☀☀☀		Non-endemic	Street, plaza	Resistant to air pollution	💧 Low, drought resistant	T20
	Platanus orientalis	Πλάτανος Ανατολικός Oriental Plane	Deciduous	🌳🌳🌳	Deep fertile soils		☀☀☀		Endemic	Street, plaza and park	Resistant to air pollution	💧💧💧 High, drought resistant	T21
	Acer platanoides	Σφενδάμι Πλατανοειδές Norway Maple	Deciduous	🌳🌳🌳	Can grow in very alkaline soils		☀☀		Endemic	Street, plaza	Resistant to air pollution	💧💧💧 High, drought resistant	T22
	Populus alba	Λεύκη λευκή White Poplar	Deciduous	🌳🌳🌳	Light (sandy), medium (loamy) and heavy (clayey) soils and can grow in heavy clay soils		☀☀☀		Endemic	Street, plaza	Shallow root system, fast growth	💧💧💧 High, drought resistant	T23
	Prunus mahaleb	Αγριοκερασιά Mahaleb Cherry	Deciduous	🌳	It can grow in poor soils. Neutral PH.		☀☀		Endemic	Plaza and park	Root shafts	💧💧 Medium to high, drought resistant	T24

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Planting palatte

APPENDIX A

A.2 TREES

APPENDIX A
A.2 TREES

Trees

Photo	Latin Name	Common Name GR	Type	Size	Soil Type		Light	Shape	Origin	Suggested Use	Notes	Irrigation Need	Code
	Ceratonia siliqua	Χαρουπιά Carob	Evergreen		Sandy soils, grows in poor soils, can fix nitrogen				Endemic	Plaza and Park		Low, drought resistant	T25

A.3 SHRUBS

A.3 SHRUBS

Shrubs

Photo	Latin Name	Common Name GR	Type	Size	Soil Type		Light	Shape	Origin	Suggested Use	Notes	Irrigation Need	Code
	Buxus sempervirens	Πυξάρι Common box	Evergreen	Small bush, up to 2 m.	Moderately fertile soils, neutral pH.		Semi-shady conditions, can grow in shade	All shapes depending on the pruning	Endemic	Street, Plaza	Slow growing, suitable for short fences, attracts wildlife	Medium, vulnerable to high temperatures	S1
	Pittosporum tobira	Αγγελική Australian laurel	Evergreen	Bush, up to 5 m.	Sandy and medium soils		Semi-shade conditions		Non-endemic	Street, Plaza	Commonly used for fencing, withstands marine exposure, resistant to low temperatures	Medium to low, tolerates drought	S2
	Photinia glabra	Φωτίνια Ιαπωνική Japanese photinia	Evergreen	Bush, up to 5 m.	Light (sandy), medium (loamy) and heavy (clayey) soils. Neutral PH, can grow in heavy alkaline soils. Prefers fertile soils		Half-shading	Hedges	Non-endemic		Not resistant to winds and low temperatures, susceptible to fire, needs regular pruning	Medium to low, can tolerate drought	S3
	Laurus nobilis	Δάφνη Grecian Laurel	Evergreen	Small tree or shrub	Light (sandy), medium (loamy) and heavy (clayey) soils. PH neutral		Semi-shaded and sunny conditions	Non-uniform	Endemic	Plaza and Park	Slow growing, should not be planted under paved surfaces, Leaves used as spices.	Medium to low, can tolerate drought	S4

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A.3 SHRUBS

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A.3 SHRUBS

Shrubs														
Photo	Latin Name	Common Name GR	Type	Size	Soil Type		Light	Size	Origin	Suggested Use	Notes	Irrigation Need	Code
	Vitex agnus castus	Λυγαριά Chasteberry	Deciduous	Bush, up to 3m.	Prefers clay soils, can grow in nutrient-poor soils		Sunny conditions, can not grow in the shade	Multiple strains	Endemic	Plaza and parks	Aromatic plant	High	S12
	Viburnum odoratissimum	Βιβούρνο εύοσμο Sweet Viburnum	Evergreen	Bush, up to 4m.	Prefers deep rich loamy soils, intolerant of poor soils		Semi-shaded conditions		Non-endemic	Street, squares, parks, especially for fences	The flowers are sweetly scented	High	S13
	Viburnum tinus	Βιβούρνο κοινό Laurustinus	Evergreen	Bush, up to 4m.	Prefers deep rich clay soils, not hardy in poor soils.		Semi-shaded conditions		Endemic	Street, squares, parks, especially for fences	Can tolerate heavy pruning	High	S14
	Teucrium fruticans	Τεύκριο Tree germander	Evergreen	Bush, up to 1.5m.	Sandy and clayey soils, neutral or alkaline.		Sunny conditions		Non-endemic			Medium, drought resistant	S15
	Rosmarinus officinalis	Δενδρολίβανο Rosemary	Evergreen	Bush, up to 1.5m.	Suitable for rocky and limestone soils, can grow in very alkaline soils.		Sunny conditions		Endemic	Streets, plaze	Leaves used in cooking for flavoring	Medium to low, resistant to drought	S16
	Cotinus coggygria	Χρυσόξυλο Smoke tree	Deciduous	Bush, up to 4m.	Tolerates well in poor soils, grows on limestone.		Partly shaded, sunny conditions	Spherical	Non-endemic			Medium to low, can tolerate drought	S17
	Lagestroemia indica	Λαγκεστρέμια δενδρώδης Crape myrtle	Deciduous	Bush, up to 4m.	Light (sandy), medium (loamy) and heavy (clayey) soils. Prefers clayey. PH 5-7,5.		Sunny conditions		Non-endemic	Streets, plaze	Nesting bush for birds	Resistant to high temperatures and drought	S18
	Weigela florida	Μηλίτσα Bristol ruby	Deciduous	Bush, up to 2m.	Acidic, alkaline, neutral PH, can tolerate clay soil		Semi-shaded conditions		Non-endemic	Streets, plaze		Medium to high	S19
	Cotoneaster dammeri	Κυδωνίαστρο Bearberry cotoneaster	Evergreen	Bush, up to 0.5m.	Prefers limestone soil		Shaded conditions		Non-endemic	Streets, plaze	Excellent for groundcover	Low to medium, drought resistant	S20

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A.3 SHRUBS

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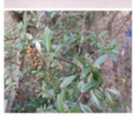
A.3 SHRUBS

Shrubs

Photo	Latin Name	Common Name GR	Type	Size	Soil Type		Light	Shape	Origin	Suggested Use	Notes	Irrigation Need	Code
	Myrtus communis	Μυρτιά κοινή Myrtle	Evergreen	Bush, up to 4m.	Moderately fertile soil, prefers dry soil		Sunny conditions, can not grow in the shade		Endemic	Hedges	Edible fruits, antibiotic actions, many uses of plant parts, aromatic flowers	Medium	S5
	Medicago arborea	Μηδική δενδρώδης Moon Trefoil	Evergreen	Bush, up to 2m.	Grows in poor dry soils, can fix nitrogen		Always sunny, cannot grow in the shade		Non-endemic	Plaza and park	Resistant to air pollution (SO2), Fast growing tree, provides shade conditions, tolerant species commonly used in redevelopment and industrial areas, branches break easily, small phototropic reaction	Medium	S6
	Nerium oleander	Πικροδάφνη Rose bay	Evergreen	Bush, up to 4m.	Clay soils, can grow in heavy clay soils		Sunny conditions, does not tolerate shade	Spherical	Endemic	Street, plaza and park	Fast growing, Poisonous plant tolerant to air pollution, tolerant to strong winds, low phototropic reaction	High, causes drought	S7
	Pistacia lentiscus	Σχίνος Mastic tree	Evergreen	Bush, up to 4m.	Can grow in very alkaline soils		Sunny conditions, shade resistant, resistant to high temperatures		Endemic	Squares, parks, especially for fencing	Deep root system, wind resistant, edible berry-like fruits, low maintenance without pruning	Medium to low, resistant to drought	S8
	Rhamnus alaternus	Ράμνος Italian Buckthorn	Evergreen	Bush, up to 5m.	Can grow in a variety of soils		Semi-shaded conditions, shady conditions		Endemic	Street, square	Fast growing, resistant to sea winds, should not be planted in northern exposure	Medium	S9
	Berberis thumbergii	Βερβερίδα Red barberry	Deciduous	Bush, up to 1,5m.	Can grow in a variety of soils		Sunny conditions		Non-endemic	Plaza and park	Very hardy species, has thorns	Medium	S10
	Pyracantha coccinea	Πυράκανθος Firethorn	Evergreen	Bush, up to 4m.	Prefers calcareous soils, can grow in heavy clay soils		All the conditions		Endemic	Plaza and park	It has thorns, grows fast, protects the root system for wet conditions, attracts wildlife	High	S11

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Planting palatte

APPENDIX A

A.4 GRASSES

APPENDIX A

A.4 GRASSES

Grasses

Photo	Latin Name	Common Name GR	Type	Size	Soil Type		Light	Shape	Origin	Suggested Use	Notes	Irrigation Need	Code
	Prunus lusitanica	Πορτογαλική δάφνη Portugal laurel	Evergreen bush	Bush, usually 7.5m high and 4.5m wide	Moderately fertile, moist, well-drained soils, but also thrives in poor, shallow, calcareous soils.			Round	Non-endemic	Best choice for edging or windbreak	very resistant species, which are planted for beautification, and become invasive	Moderate - tolerant of heat, sun, wind and drought	G2
	Sesleria autumnalis	Autumn Moor Grass			Well-drained soil		sun and partial shade	Inhomogeneous	Endemic	Plaza, park and green roofs	High pH tolerance, cold hardiness and drought tolerance make it suitable for green roofs\ Adaptability makes it a smart choice for urban landscapes	Moderate to high	G3
	Codiaeum variegatum	Κροτώνας Garden croton	Evergreen	3m.	Sandy or clay soils		full sun	Round	Non-endemic	Plaza		Medium	G4
	Sambucus nigra	Κουφοξυλιά Edelberry	Evergreen	6m.	Clay soils		sunny and semi-shady conditions	Inhomogeneous	Endemic	Plaza and park		Moderate to high	G5
	Bouteloua gracilis	Blue Grama	Green	0,50m.	Well-drained soils		sunny conditions		Non-endemic	Plaza, park and green roofs	Use on green roofs	Moderate to low, drought tolerant	G6
	Oenothera lindheimeri	Λευκή γκαούρα Lindheimer's beeblossom	Evergreen	0,50m.	Any soil texture is possible, slightly acidic soils pH =6-7 are preferred. Low tolerance to salinity		full sun to partial sun	Inhomogeneous	Non-endemic	Park		Moderate to high	G7
	Philodendron bipinnatifidum	Φιλόδενδρο Tree Philodendron	Green, fallen leaves	Rapid development	Any soil texture is possible, slightly acidic soils pH =6-7 are preferred. Low tolerance to salinity.		partial shading	Inhomogeneous	Non-endemic	Plaza and park	Large, deeply divided, drooping leaves- evergreen, perennial flowers- susceptible to freeze damage- tolerates occasional wet soil.	Moderate, requires moderately drained soils	G8

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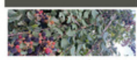
APPENDIX A

A.3 SHRUBS

APPENDIX A

A.3 SHRUBS

Shrubs

Photo	Latin Name	Common Name GR	Type	Size	Soil Type		Light	Shape	Origin	Suggested Use	Notes	Irrigation Need	Code
	Rubus fruticosus	Βατόμουρα							Non-endemic				S21
	Eriobotrya japonica	Μουσμουλιά Loquat	Evergreen	Shrub small tree	Mildly acidic, neutral and basic (mildly alkaline)		Semi-shaded conditions		Non-endemic	Plaza and park	Edible fruits	Moderate to high	S22
	Rhamnus cathartica	Ράμνος European buckthorn	Deciduous	Bush, up to 5m	Alkaline soils		Semi-shaded conditions		Endemic	Plaza and park		Low, drought tolerant	S23
	Spartium junceum	Σπάρτο Spanish broom	Deciduous	Bush, up to 3m	Can grow in nutrient poor soil.		Sunny, cannot grow in the shade		Endemic	Streets, plaza and park	It is used in the restoration of waste and abandoned lands, it tolerates atmospheric pollution	Moderate to low, can tolerate drought	S24
	Juniperus communis	Άρκευθος κοινή Common juniper	Evergreen	Bush, up to 7m	Can grow in nutrient poor soil.		Partial shade, sunny conditions		Endemic	Park	Edible fruits	Low, drought tolerant	S25

A.4 GRASSES

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Grasses

Photo	Latin Name	Common Name GR	Type	Size	Soil Type		Light	Shape	Origin	Suggested Use	Notes	Irrigation Need	Code
	Hesperaloe parviflora	Κόκκινη γιούκα Hummingbird yucca	Evergreen - alternative to Agave without spine	Grows in clumps 0.91–1.83 m (3–6 ft) tall and wide. The red or yellow tubular flowers are borne on branched flower stalks (inflorescenc-es) up to 1.5 m tall from late spring to mid-summer.				Non-homoge-neous, mostly oval	Non-endemic	Plaza and park	Has become popular in xer-iscape landscape design for public and private gardens	Low, plant attributes include drought tolerance, heat tolerance, low maintenance, flowers that attract hummingbirds	G1

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Photo	Latin Name	Common Name GR	Type	Size	Soil Type		Light	Shape	Origin	Suggested Use	Notes	Irrigation Need	Code
	Talinum calycinum	Fameflower	Hardy perennial plant	up to 0.40m height	Well-drained, moist soil rich in organic matter, but adapts to most soil types, preferably not too heavy in texture.		Full sun to light shade	Inhomogeneous	Non-endemic	Green roofs	Used for its impressive flowering. It has attractive, succulent foliage and quickly sends up slender corms adorned with pink or magenta flowers with a yellow center, which open each afternoon. It does not face serious insect and disease problems. The plant goes dormant in winter.	low, drought resistant	G9
	Geranium	Γεράνι Pelargoniums		0.10 - 0.50 m. height	Any terrain		Full sunshine	Uneven, uncontrolled		Park		High	G10
	Bougainvillea cvs.	Μπουκαμβίλια Bougainvillae	Evergreen, bushy climbing plant	1 - 20 m. height	Sandy, clayey, rocky - pH=4.5 -7		Full sun and partial shade	Uneven, uncontrolled	Non-endemic	Park	Once settled, they tend to be carefree. All cultivars are susceptible to frost damage.	Low- high drought tolerance	G11
	Schizachyrium scoparium	Μπλουεστέμ Blues Little Bluestem	Evergreen	0.30 - 0.50 m. height	Well drained soils, low fertility soils, dry conditions		Full sun	Inhomogeneous	Endemic	Park	Adapts well to the edge of rain gardens or bioswales.	Medium to low	G12
	Ipomopsis rubra	Standing cypress	Biennial herbaceous wildflower	60-150 cm height and 45-60 cm. width	Dry to moderately moist and well-drained soils		Full sun, but tolerates light shade	Inhomogeneous	Non-endemic	Best for borders or edges	Attracts hummingbirds and other beneficial pollinators - generally disease and pest free.	Low- drought tolerant once established	G13
	Lavendula angustifolia	Λεβάντα στενόφυλλος Lavender	Perennial shrub-like plant	30 - 50cm	dry, well-drained, sandy or gravelly soils		Full sun	Inhomogeneous	Non-endemic	Plaza and park		Moderate to high	G14
	Achillea millefolium	Αφριαμιθιά Yarrow	Evergreen	20 - 50cm	sandy clay soil, slightly alkaline, well-drained soils		Full sun or partial shade	Any	Endemic	Edges or vertical divisions and in bushy borders		Medium	G15
	Stipa gigantea	Γίγαντας χόρτο Golden oats	Evergreen, perennial grass	up to 2m height and 1m. width	medium to light moderately fertile soils, well-drained soils		Full sun	Inhomogeneous	Non-endemic	Used for flower bed borders, gravel gardens	Generally pest and disease free - low maintenance	Medium	G16

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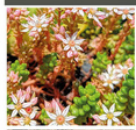	Sedum spp. (Sedum reflexum; S. album; S. sexangulare, S. spurium and S. kamtschaticum)	Σέντομ Reflexed stonecrop	Evergreen	10 cm height	well-drained, shallow soil		Full sun	prostrate, uneven		Green roofs	S. reflexum is occasionally used as a salad leaf or herb in Europe.	Low, drought tolerant once established	G17
	Eriogonum umbellatum	Sulphur flower	Perennial herbaceous herb	Small shrub up to 2 meters.	there are no special requirements		Full sun and partial shade	Uneven	Non-endemic	Park		Medium to high	G18
	Salvia fruticosa	Φασκομηλιά Greek sage	Perennial herbaceous herb	60cm height	well-drained soil		Full sun	Uneven	Endemic	Plaza and Park		Low, very drought tolerant	G19
	Eragrostis spectabilis	Purpule love grass	Perennial herbaceous herb	3-5cm	sandy or gravelly soils		Full sun	Weed	Non-endemic	Plaza	Salt tolerant enough to thrive on roadsides that receive salt in the winter	Low, drought tolerant	G20
	Juncus tenuis	Slender rush	Perennial herbaceous herb	15-60cm height	sandy or clay soils		Full sun and partial shade	Bushy		Parks, road boundaries	Because of its high tolerance to compacted soils, it can compete with other roadside plant species.	Medium to low	G21
	Carex sp.. (C. acuta; C. Helleriana)	Κάρηξ True sedges	Perennial herbaceous herb	60cm height	well-drained soils		Full sun	Uneven	Endemic	Pavement covering		Medium to low	G22
	Deschampsia cespitosa	Φουντωτά hair-grass Tuften hair grass	Evergreen	1m	well-drained soils		Partial shade	Uneven	Non-endemic	Excellent ground cover for partially shaded areas	Responds well to cutting, grows quickly	High	G23
	Delosperma cooperi	Μεσηβριάνθεμο Trailing Iceplant	Perennial herbaceous plant	10-15cm	all soil types, but suffers from water stagnation - well-drained and rocky soils		Full sun	Climbing plant	Non-endemic	Low need for maintenance, it is suitable for urban environments and areas with high temperatures	Propagation can be done by taking a non-flowering cutting, stripping off some lower leaves.	Low, thrives in very dry and hot environments	G24
	Molinia caerulea	Μολίνια Purple moor-grass	Perennial herbaceous plant	up to 1.5 m. high and 40 cm. wide with many closely connected stems	acidic soil pH = 3.5-5		Partial shade	Wild grass (cluster-forming)	Endemic	Park	Due to the dense foliage it is very resistant to fires.	Low	G25

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Green walls

Plants for green walls:
To be able to grow on a vertical surface, the plants must be:

- Satisfied with reduced substrate volume.
- Compact or at least small in size.

The following plant categories are suggested:

- Epiphytic plants, which are naturally adapted to a vertical cultivation surface.
- Sicilian or fissured plants, which are also naturally adapted to a vertical cultivation surface).
- Perennial plants, which do not need to be replaced every year.

Keep in mind:

- Orientation of the green wall.
- Exposure to the sun (i.e., full sun, shade, half shade).
- The climate in the area, as plants with little substrate are more exposed to cold and wind.

The range of plants suitable for green walls is wide. For the outdoors, however, it is important to avoid exposed locations, as they are problematic due to cold winds in the winter and strong sunlight in the summer months.

Choose a combination of species from some flowering plants, ferns, mosses, small grasses, species for soil with a minimal root system (such as helxine, Dichondra repens, Leptinella, Satureja douglasii, sagine, saxifrage, scleranthus), but also low plants with decorative foliage (such as flagella and woody cuttings). Aromatic species can also be planted.

Range of applicable species:
Achillea millefolium, Altenathera sp, Anigozanthos, Kan- garoo Paw Plant, Asparagus Densiflorus, Asparagus meyeri, Buddleiadavidii nana, Carex comans bronze, Carex divulsa, Carex morrowii variegata, Cenecio vira vira, Cotoneaster queen of carpet, Erigeron karvinskianus, Euonymousjaponicus micro- phyllus, Euonymusjaponicus (aureo marginatus), Festuca glauca, Festuca mairei, Hedera helix, Helichrysum petiolare, helichrysum stoe- chas, Lavandula dentate, Molinia caerulea, Nepeta racemosa 'Walkers Low', Origanum laeuigatum (marjoram), Pennisetum setaceumfireworks, Perovskia atriplicifo- lia, Polypodium vulgare, Rosmarinus officinalis prostrates, Santolina chamaecyparissus, Senecio mandraliscae, Stipa tenuifolia, Tradescantia brevifolia, Tradescantia sillamontana, Veronica (Hebe) speciose, Eremophila glabra, Loropetalum fire dance, Ficus pumila repens, Stachys byzantina, Pittosporum heterophyllum, Lantana sellowiana, Teucrium chamaedrys, Pelargonium odoratissimum,
Rosmarinus officinalis prostratus, Santolina chamaecyparissus, Libani sp., Thymus prostratus, Mentha piperita, geranium, dimorphotheca, elitisia, chrysanthemum, cuphea, euphorbia, lampranthos, bouzi (on its own, not in combination), Alternathera dentata, creeping verbena, Helichrysum petiolare, Ajuga reptans, Centranthus, Acorus, Carex, Campanula, Fragaria.

Green roofs

Plants for green roofs:

Categorization:

- Extensive type: Total surface coverage with greenery (i.e., ground cover plants or turf), with a construction depth of 10 to 15 cm. Low herbaceous vegetation whose root system does not require a great depth of substrate for their growth and does not damage the roof infrastructure.
- Semi-intensive to intensive type: The options broaden and include grasses, shrubs, and trees, but also include built places with water, pergolas, sitting areas, etc.

Benefits:

- Extends the life of the building's waterproofing by up to forty years, protecting it from exposure to extreme temperature differences.
- Strengthens thermal insulation, saving energy (up to 2 liters of oil/square meter).
- Limits the rapid runoff of rainwater during rain events. The result is that 10 percent to 50 percent of the water returns to its natural cycle instead of draining into the sewers.
- Filters and improves city air, holding suspended particles and dust and making the microclimate in cities healthier.
- Absorbs noise and solar radiation instead of reflecting it, and in this way mitigating the UHI.
- Offers recreation space for the residents of the building.
- Uses recyclable and recycled materials for construction.

Construction

Its implementation is not particularly complicated or expensive, with the cost starting from €100/m2). A civil engineer must verify the static strength and how watertight the building is. If these aspects are deemed sufficient, the next step is to undertake a comprehensive study.

Growing plants

The plants (i.e., lawn, bushes, or even trees) are installed on a special drainage system, with anti-root protection in a special, particularly light soil substrate to ensure the building is not burdened with excessive loads. An automatic irrigation system can also be installed.

Selection of plants:

Plants are selected based on the climate conditions, irrigation and fertilization requirements, and ecological sustainability.

The planting options in Greece are oriented toward the Greek Mediterranean species (rosemary, lavender, myrtle, Apollo laurel, lilac, lantana, pomegranate, oleander, etc.).

A selection of plants suitable for the Mediterranean climate is a mixture of herb-grass-herbs (sedum), dry perennial habitats and ornamental grasses such as:

Aromatic xyrophytes (such as Artemisia absinthium, Helichrysum italicum, and Helichrysum orientale), Delosperma, Achillea ageratifolia, Armeria pseudarmeria 'Ornament', Armeria canescens, Helictotrichon sempervirens, Allium, rudbeckia, Stipa spc., Sempervivum, and common Sedum species: Sedum acre, S. rupestre, and S. Album.

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APPENDIX C:
IMAGE SOURCES

Image Sources

INTRODUCTION

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CHAPTER 1: WATER ELEMENTS

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APPENDIX A: PLANTING MATERIAL

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