**Chapter**

# Nature-Based Solutions for Climate Change Adaptation in Scholar and Social Buildings: Concepts and Pilot Solutions for Portugal and Spain

*Teresa Batista, Salustiano Torre, José Fermoso, Nuno Morais, Ramona Avila, Carlos Pinto Gomes, Rui Alexandre Castanho and José Cabezas Fernández*

**Abstract**

Climate change has been recognized as one of the most serious environmental, social, and economic challenges facing the world today. Contextually, the Intermunicipal Plan for Climate Change Adaptation in Alentejo Central (PIAAC-AC) has already identified the tendencies and future scenarios of climate change in Alentejo Central until the end of the twenty-first century, namely the increase in the number of days with very high temperatures, the number of tropical nights and heat waves, and the general decrease in annual rainfall. In this scenario, the concerns with school communities and users of social services increase. The project "LIFE-myBUILDINGisGREEN"—"application of nature-based solutions for local adaptation of educational and social buildings to Climate Change," developed in partnership with CIMAC (Portugal), CARTIF Technology Center (Spain), Diputación de Badajoz and CSIC—Consejo Superior de Investigaciones Cientificas (Real Jardin Botanico— Spain—Project Leader), and the Porto City Council (Portugal), focuses on the construction sector, in particular on education and social services buildings in cities in Europe. It aims to implement the prototypes (building adaptation) of nature-based solutions (NBS) on walls, roofs, playgrounds, and exterior surfaces on three pilot buildings. The overall objective is to contribute to improve resilience in these buildings using autochthone vegetation.

**Keywords:** climate change adaptation, nature-based solutions, green roofs, green walls, educational buildings

## 1. Introduction

Climate change has been recognized as one of the most serious environmental, social, and economic challenges facing the world today. Several studies in Portugal and Spain recognize the tendencies for climate change at regional level [1–6].

In Alentejo Central, the Intermunicipal Plan for Climate Change Adaptation (PIAAC-AC) [1] has already identified the tendencies and future scenarios of climate change in Alentejo Central until the end of the XXI century, namely the increase in the number of days with very high temperatures, the number of tropical nights and heat waves, and the general decrease in annual rainfall. In this scenario, the concerns with school communities and users of social action services increase.

The project "LIFE-myBUILDINGisGREEN"—"application of nature-based solutions for local adaptation of educational and social buildings to climate change," developed by CIMAC in partnership with the CARTIF Technology Center (Spain), Diputación de Badajoz, the CSIC—Consejo Superior de Investigaciones Cientificas (Real Jardin Botanico—Spain), and the Porto City Council, focuses on the construction sector, in particular on education and social services buildings in all cities and towns in Europe. It aims the implementation of 3 prototypes (building adaptation) of nature-based solutions (NBS) on walls, roofs, exterior surfaces, and car parking of 3 pilot buildings, one located in Évora—Alentejo Central—South of Portugal, one in the city of Porto in the north of Portugal and one in Solana de los Barros in the Badajoz Province—southwest of Spain. The overall objective is to contribute to improve the resilience in these buildings using NBS and autochthone vegetation. This paper presents the LIFE-MyBuildingisGreen project, its objectives, and expected results [7].

Climate change is now recognized as one of the most serious environmental, social, and economic challenges facing the world. The IPCC's Fifth Report (2014) [8] identifies that many of the global risks of climate change are concentrated in urban areas. In addition, implementing measures that enhance resilience and enable sustainable development can accelerate processes of adaptation to climate change [9].

Europe's educational and social service buildings will face multiple challenges in the coming decades, and climate change will add pressure to it. The project focuses on the building sector, specifically on the public buildings dedicated to education and social services existing in all cities and towns in Europe. The impacts of climate change (heat waves and changes in annual and seasonal precipitation patterns) are affecting the health and well-being of children and elderly people who are the main users of these types of buildings [10–12].

The overall objective of the project is to contribute to increasing the resilience of these buildings by implementing in them NBS as prototypes of climate adaptation and improved well-being. Additionally, other specific objectives are:

1. Improve knowledge base on the development, assessment, and monitoring of vulnerability to climate change of buildings through developing and testing a common, ready-to-use method in the southern, western, central, and northern European regions.

2. Analyze and verify the impact of NBS as adaptation measures to climate change in three pilot buildings.

3. Promote sustainable ecosystem-based adaptation measures and increase the capacity to apply such knowledge in practice through dissemination and demonstration workshops.

4. Promote the governance of regional authorities, directors and building managers, and the building industry to integrate NBS as part of measures to promote

sustainable adaptation in buildings through the development, creation, and dissemination of governance tools and territorial agreements.

5. Contribute to the development and implementation of a common policy at the UE level on adaptation and climate change by transferring best practices and knowledge base to target groups and stakeholders.

The main actions of the project are:

- Selection of 3 pilot buildings by weighting the technical criteria that characterize each building. Analysis of European databases with information relevant to the implementation of NBS in public buildings of education and social services.

- Evaluation and analysis of the baseline of each building to determine the initial state of the building and to use it as a reference to assess the impact of the NBS using the indicators proposed within the Project.

- Installation and implementation of 3 prototypes based on nature in facades and partition walls, roofs, and exterior surfaces of each selected pilot building. In addition, it will be complemented by the implementation of sustainable measures of induced natural ventilation, seasonal shading (natural and artificial), and the choice of native Mediterranean and Atlantic species.

- Monitoring of the impact of the works carried out with the aim of verifying and evaluating the importance of these measures as alternative solutions to climate adaptation for regional authorities at the local level.

- Creation of actions and tools of governance that make possible the signing of government agreements, the development of inter-municipal programs, and the integration of the NBS into regulations and multi-year action plans of political, technical, and institutional scope.

- Demonstrating the feasibility and transferability of NBS as measures for sustainable adaptation to stakeholders in policy, building, climate change, building, and urban planning at local, national, and European levels. Creation of capacities to improve knowledge about the NBS to the responsible authorities and users, directors, and managers of education and social services centers and the building sector.

- Communication and dissemination of the results and good practices of the Project through the website, bulletin board, newsletters, brochures, press articles, and networking at regional, national, and European levels and dissemination activities online with all interest groups and stakeholders.

In the case of Portugal and specifically in Alentejo and Oporto (areas of action of the Project in Portugal), the residential park in 2011 was around 111,826 accommodations. There are more than 120 public buildings of responsibility and municipal management that serve around 238,000 people. Of these, 49 correspond to public elementary schools and the others refer to administrative, institutional, cultural, and sports buildings, scattered throughout Alentejo and Oporto. These buildings house more than 3000 employees. In Portugal, it is the state that assumes the ownership of the buildings of education and social services, but the management and maintenance are carried out in a shared way between the state and the municipalities. The vulnerability to climate change of these buildings, located in regions and municipalities of Spain and Portugal, is a consequence of the high temperatures that are reached inside them between the months of May to October and the constructive characteristics of these buildings [13].

Part of the heating problem of these buildings can be attributed to the construction typology and the materials used. In Spain and Portugal, many of the education and social services centers were built prior to the basic thermal conditions' regulation (Royal Decree 2429/79, of July 6, which approves the Basic Building Standard NBE- CT-79, on Thermal Conditions in buildings). This document provided the basic design criteria that allowed damping of the thermal wave through the enclosures. It was from that moment when thermal insulation incorporated into double-leaf walls began to be used, achieving a notable improvement in the thermal performance of the facades with respect to the mass walls used in previous years. This regulation was replaced by the current Technical Building Code, in 2006, in which special attention has been given to reducing energy demand with the incorporation of high-performance solutions in the enclosures.

As a result, we find insufficiently thermally insulated buildings, and with little sun protection in window openings, which in hot climates such as those in Spain or Portugal, produces overheating effects in last spring, summer, and early autumn periods [14].

In addition, regulatory and labor regulations establish that the temperature inside these buildings should not be less than 10°C or higher than 27° since it allows risk due to thermal stress and causes health problems for the workers. The company or public authority responsible must take the necessary preventive measures and the work and teaching activity should be paralyzed if the thermal risk is maintained.

In this regard, it is worth mentioning that there is currently a significant climate problem and social impact in the regions of Southern Europe, specifically in Spain and Portugal.

This problem is related to the high temperatures inside education and social services centers that users suffer regularly between May and October, with the decrease in environmental comfort in these buildings and with the worsening conditions of health and well-being of the users. So much so that the aforementioned climate problem is addressed by the digital and written press of countries such as Spain, Portugal, Italy, and France that echo on the front pages of this pressing situation in educational and social centers.

The solution to this problem cannot go through the application of a Climate Control Program that allows the installation of artificial cooling by means of air conditioners in these public centers, since neither the responsible public authorities nor the European guidelines advise it, because they contribute to global warming, due to its high consumption of electrical energy and emission of $CO_2$ into the atmosphere [15]. In addition, air conditioners have contributed to increasing the percentage of citizens with respiratory problems such as laryngitis or pharyngitis and have exacerbated the chronic processes of the population at risk. To date, the solutions that the administrations responsible for these centers are taking are the regularization of the students teaching hours, allowing parents to take their children ahead of time as a result of the maximum peaks of indoor temperature coinciding with the hours Central of the day. This situation is causing disorganization of schedules that makes it more difficult to reconcile work and family life [11].

In the sense of the framework of a local adaptation strategy against the effects of climate change in these buildings, it must generate governance tools between the different regional and local administrations with responsibilities in the field of education and social welfare, which allows these centers to innovate and rehabilitate by implementing nature-based solutions that allow to respond to periods of potential overheating and minimize unwanted heat gains during the day and night. The application of these NBS tools in public education and social services centers will enable responsible local administrations to fulfill the objective of the Covenant of Mayors for climate and energy, as well as offer natural, and sustainable response related to the environmental comfort and temperature inside these buildings.

## 2. Climate tendencies and prospective scenarios in study areas

### 2.1 Climatic situation of the territory

Alentejo's central climate is typical Mediterranean. It is a mesothermal climate type with rainy winter and hot, dry summer. However, the geographical position of the Alentejo Central and the layout of the main relief masses of southern Portugal give its (Mediterranean) climate a certain continental character [1].

In general, Alentejo Central has an air temperature regime, with average annual temperature values around 16°C, with a relatively high annual temperature range in the national context, which is accentuated inland. Winter is cool, with average temperatures slightly below 10°C and average minimum temperatures around 5°C, with January being the coldest month.

The summer in the Alentejo Central is hot or very hot, with the heat conditions inland, as well as in the most sheltered and/or less ventilated places. In this context, average temperatures in the warmer months (July and August) range from 23 to 25°C, with average maximum temperature values exceeding 30°C.

The most significant trends observed from 1971 until 2015 were an increase in the mean annual temperature, with a greater incidence in spring and summer maximums, with a greater frequency of tropical nights. In addition, there has been a reduction in precipitation in summer and autumn and an increase, in this last season, in precipitation events concentrated in short periods.

In general, the climate of Badajoz can be described as the Mediterranean with slight Atlantic-continental nuances. Temperatures are very high in summer and mild in winter, with a substantial incidence of sunlight and long hours of sunshine, with the maximum values in the westernmost part, near Portugal. An essential thermal amplitude stands out, evidencing the marked seasonality typical of the Mediterranean climate. Precipitation is the primary source of humidity for the region. Although the general precipitation balance is negative from all points of view since it is scarce in most of the territory, there is also significant evaporation due to the high temperatures, making these rains even more insufficient [16].

As far as rainfall behavior throughout the year is concerned, in Badajoz, there is an evident dry season, summer. There is rainfall in the rest of the year, although with greater abundance toward the end of autumn and beginning of winter, with less critical rains in the rest of autumn and during spring.

In recent decades in the territory of Badajoz, there has been a tendency to increase the minimum temperature while spring precipitation decreases and autumn precipitation increases. An increase in the number of hot days is occurring, as is a decrease in the number of cold days.

The city of Porto is part of the NW of the Iberian Peninsula, in the coastal strip of the Atlantic Ocean, suffering the influence of the sea currents that dominate the North Atlantic, which find in this area of the Iberian Peninsula the first contact with a continental area. Despite belonging to the Atlantic climatic subtype, the climate in Porto has particular characteristics as a result of the influence and attributes, and positioning of an important barometric apparatus—the Anticyclone of the Azores.

In the last 40 years, there has been a steady pace characterized by a moderately cool winter in the areas closest to the sea and cold or very cold in the most sheltered areas of the interior and at the highest altitudes, a moderately warm summer often influenced by the winds of NW and the morning advection fogs along the coast, and hot or very hot in areas far from the Atlantic moderating action or higher altitude [6]. Precipitation is more frequent and intense in the winter months but can occur throughout the year. Winters in O'Porto have tended to be moderately cool along the coast and cold to very cold inland. While the summers have been moderately warm by the sea, they become hot inland. Precipitation tends to be concentrated toward the end of autumn and the beginning of winter.

### 2.2 Climate scenarios

Climate scenarios are made through the collection and treatment of future climate information (projections) using different models and for different global climate scenarios, serving as support to identify possible changes in future climate.

As a result of the global problem of climate change, both in Portugal and Spain, studies have been developed to analyze the scenarios that could occur in the future [1–5]. In the different scenarios, the most extreme weather conditions will be reinforced, generating critical variations in the meteorological variables. Temperatures will suffer a general increase in the annual average in the areas studied. Very hot days will increase in summer, autumn, and spring. Rainfall will suffer a decrease, accompanied by shifts in its distribution between the different seasons, with an increase in autumn.

Due to these scenarios and the actual conditions of the educational buildings referred in the introduction, the partnership of the project "MybuildingisGreen" [7] decided to study and implement in each one of the selected buildings the solutions as explained in the next section for the Évora pilot building.

## 3. Nature-based solutions (NBS): prototypes and pilot solutions in the study areas

In an increasingly urbanized world, nature—rich in intelligent and efficient solutions to the challenges of cities—has been forgotten in the design and management of urban spaces. Many of the green (vegetation) and blue (water) surfaces have been transformed over time into gray (impermeable) surfaces, with serious implications for the quality of life of the inhabitants and increasing environmental risks.

Currently, some of this natural engineering has been trying to rescue some of this natural engineering for cities in order to ensure sustainable, cost-effective, multifunctional, and flexible solutions to various environmental challenges. This movement recognizes that it is more advantageous—ecologically and economically—to work alongside nature and nature than against it.

The European Union developed the EU Research and Innovation policy agenda on Nature-Based Solutions and Re-Naturing Cities [17, 18], which aims to position the EU as a leader in "Innovating with nature" for more sustainable and resilient societies. The EU defines nature-based solutions "as solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social, and economic benefits and help build resilience. Such solutions bring more and more diverse nature and natural features and processes into cities, landscapes, and seascapes, through locally adapted resource-efficient and systemic interventions."

The project My Building is Green aims to strengthen and support cities, and EU within the shift of the old urban paradigm based on gray surfaces, and works to contribute with specific and innovative nature-based solutions (more efficient, more sustainable, and greener) to the adaptation of buildings and improve the bioclimatic comfort and quality of life of users [12–14], which also act (each school), for example, as inspiration and a starting point for shift and adapt to climate change in cities.

Hereafter, some innovative solutions developed and projected within the project will be presented. However, it has to be mentioned that there are multiple NBSs that can be applicated for the adaptation of buildings to climate change, according to the type of construction to the climate and the vulnerability expected [7].

### 3.1 Prototype roofs mBiGWTray for application in Évora pilot

This system was created by the CARTIF Team in collaboration with SingularGreen and consists of a multilayer tray to maintain cover vegetation that is encapsulated with a white waterproof sheet to collect rainwater and reduce water loss [7]. The design of the system, including the selection of the appropriate plant species, is done so as not to require the installation of auxiliary irrigation. In the upper part of the encapsulation, there are some holes for planting plant species.

Schematically, the system would be a system of extensive vegetative cover pocketed to make it more resistant to rainfall shortages (**Figure 1**).

This system allows the installation of the trays on the roof directly occupying 50% of the surface with the vegetal part initially and the rest with a white surface that avoids the excessive capture of thermal energy. The installation is carried out using a checked system in which the planting surfaces alternate with the water collection surfaces.

In the joining area of each module, there are some holes that allow the entrance of water from the zone of collected water toward the zone with the vegetal system.

The bags have a drainage hole at the surface of the tray to allow the greatest amount of water to be stored avoiding the pooling of the substrate in which the roots of the plants are found.

Both the weight of the tray itself and its flat design mean that, in principle, an auxiliary roof anchor system is not necessary. However, if the prevailing winds in the area were very strong, the system could be weighed down using draining aggregate as partial filling of the holes in the tray.

The components of the System are:

- The encapsulation material can be made of white EPDM or PVC in order to get adequate durability. In principle, white PVC is selected as the first option by price mainly. The durability of the two materials is similar for this application, both with a 10-year warranty.

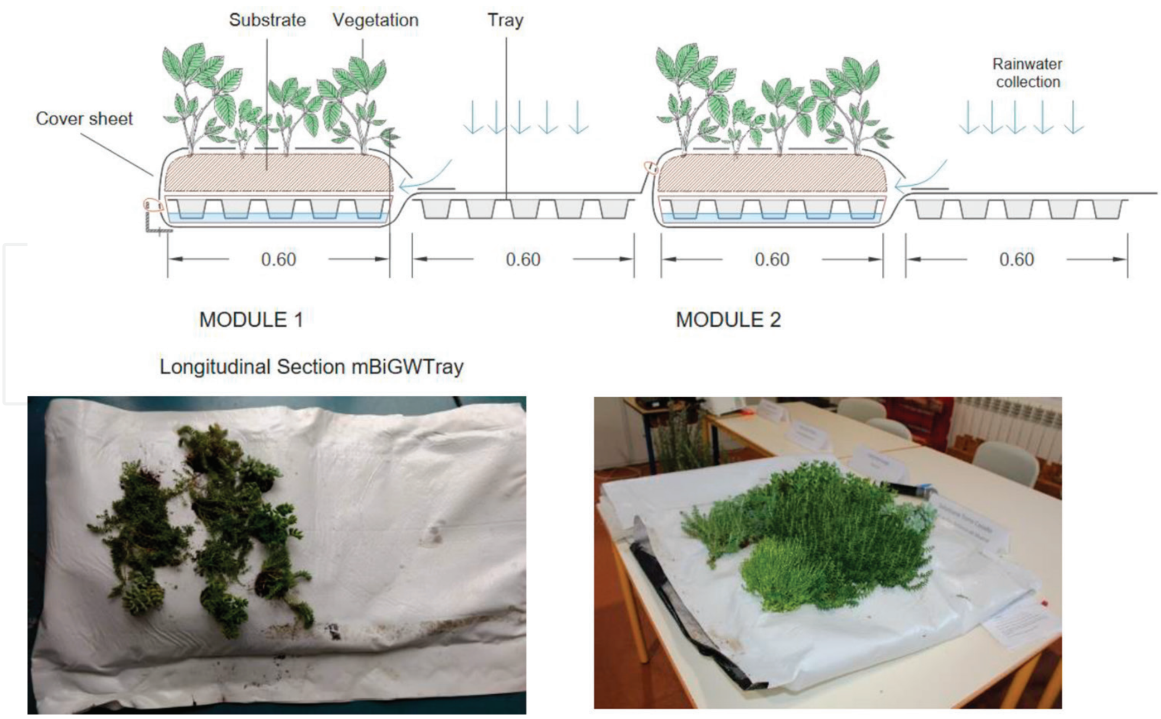


**Figure 1.**
*Prototype mBiGWTray: Schema and implementation.*

- The tray is composed of support with cavities to contain the planting substrate of the plants to be included. This is a MODI H50 ventilated pavement plate that is covered with a non-woven felt geotextile and inserted into the capsule. This tray allows structuring the planting of the vegetation, providing rigidity for handling the bagging, and creating spaces for water storage inside.

- Between the tray and the geotextile is the material that acts as a substrate that can be both sheep's wool and sphagnum or other similar materials. This layer allows transport by capillarity from the water storage area to the upper zone.

- Above the geotextile is a layer of substrate encapsulated in a light geotextile. In this area, it is where it contains the root part of the vegetation that is integrated into the system.

- The characteristics of the selected species are underwater requirement, creeping and surface roots, native species, and species indicated as beneficial for pollinators. A plantation of 16 plants per tray would be carried out. Initially, there would be bands covered with vegetation and bands without vegetation but over the years one could have a complete green cover.

On the other hand, the system is compatible with drip irrigation that can be integrated into the base structure. A more homogeneous vegetation maintenance would be achieved throughout the year. However, the initial design has been carried out so that the implementation of an irrigation system is not necessary and the previous tests that are going to be carried out are aimed in this direction.

### 3.2 Prototype facades mBiGToldo for creating vertical green surfaces in Évora

This system has been designed to create vertical surfaces with vegetation of very low thickness to create shading with a contribution of humidity to the environment. The system consists of an impermeable sheet on which a nonwoven felt is adhered and a semi-woven substrate is projected. Due to the low substrate thickness, hydroponic irrigation is integrated that is distributed by gravity across the surface of the substrate (**Figure 2**). In the lower zone, a channel for collecting excess irrigation is integrated and returned to the irrigation station.

Irrigation is done through a hydroponic irrigation station with adequate programming to cover the needs of the vertical garden at all times of the year and the environmental conditions that are to be generated. It is necessary to connect the irrigation station, to be installed under the level of the mBiGToldo, with all the gardens, both to provide the irrigation and to collect [7].

The components of the System are:

- Support frame: Structure with the appropriate dimensions made with the material with which the vertical wall structure that will support the prototypes of the facade is built.
- Waterproof support. It must be a sheet-shaped material resistant to punching and tearing to facilitate fixing. The currently recommended material is a PVC awning sheet but more sustainable materials are being sought.
- Root fixing sheet based on nonwoven felt or rock wool.
- Mix of substrate and compatible seeds that is applied by projection.

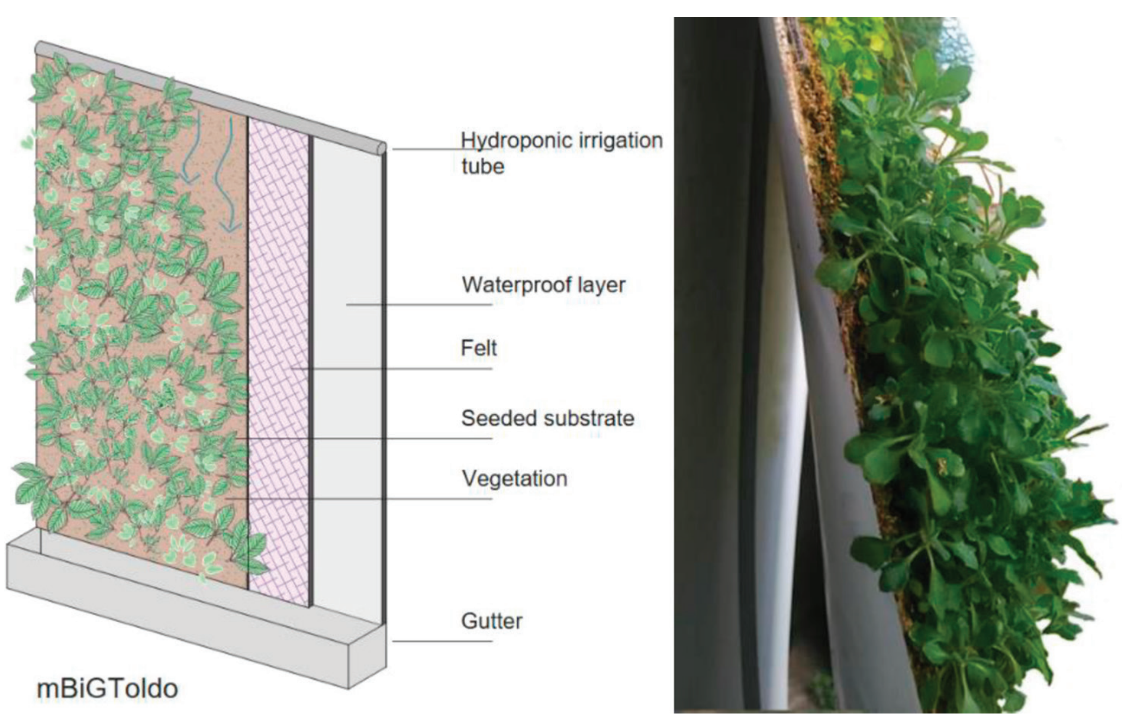


**Figure 2.**
*mBiGToldo schema and implementation.*

- The characteristics of the selected species will be easily propagated by seeds.
- Drip irrigation tube in the upper part and water collection gutter and injected to leftover water collection tube.

The system is only compatible with hydroponic drip irrigation that can be integrated into the support structure of the awning. The design includes a system for collecting excess irrigation water and returning it to the tank for optimization of water consumption.

Among the species that can be used are the *Festuca rubra*, *Agrostis stolonifera,* and *Sagina subulata*, but others can be evaluated depending on the location and suggestions made by the Royal Botanic Garden.

### 3.3 Prototype roofs mBi_GUL for application in Porto pilot

The mBi_GUL is a prototype solution inspired by Green Urban Living System (GUL), an innovative option develop under the Green Urban Living project (greenURBANLIVING), promoted by Amorim Isolamentos, Itecons, Neoturf, and ANQIP, and financed by European Commission through European Regional Development Fund. The Green Urban Living (GUL) is a multifunctional system based on expanded cork agglomerate for the construction of green roofs and living façades (**Figure 3**).

This system was developed within a national project, which aims to develop and validate new roof systems and green façades structured in expanded cork agglomerate (ICB), with a higher environmental and energy profile than conventional solutions and with a high capacity for energy customization and prefabrication. In these eco-designed systems, ICB will simultaneously provide: thermal insulation of the building; drainage functions; retention functions; and carbon capture.

Cork is a raw material that is so perfect that no industrial or technological processes have yet been able to replicate it. It has numerous advantages and benefits due to its key characteristics, and it represents an innovative opportunity to incorporate cork-based materials in green roof systems. Some of the cork's key characteristics are:

- Very light material—Over 50% of its volume is air, which makes it very light, it weighs just 0.16 grams per cubic centimeter and can float.

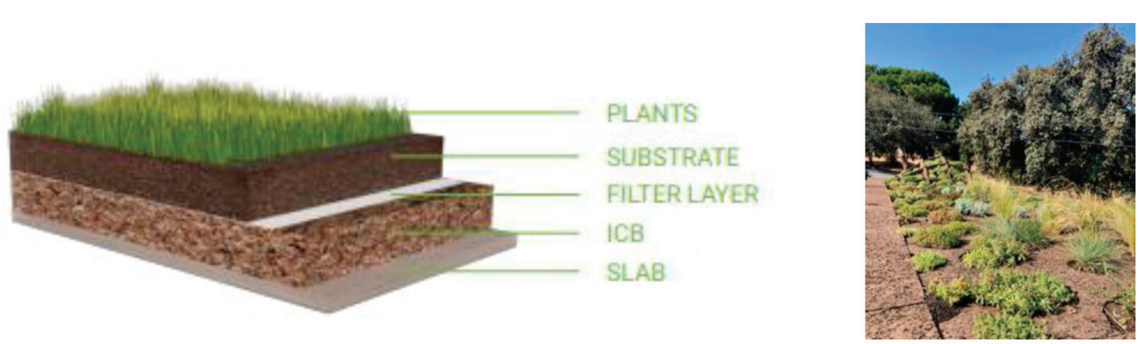


**Figure 3.**
*Prototype layer scheme based on the GUL system (left). Example of an installation using the GUL system. Source: Neoturf (right).*

- Elastic and compressible—It is the only solid that, when compressed on one side, does not increase in volume on another; and as a result of its elasticity, it is able to adapt, for example, to variations in temperature and pressure without suffering alterations.

- Impermeable to liquids and gases—Thanks to the suberin and ceroids contained in the cell walls, cork is practically impermeable to liquids and gases. Its resistance to moisture enables it to age without deteriorating.

- Thermal and acoustic insulator—Cork has low conductivity to heat, noise, and vibration. This is because the gaseous components contained in cork are enclosed in small impermeable compartments, isolated from each other by a moisture-resistant substance.

- Fire retardant—Cork is also a natural fire retardant: it burns without a flame and does not emit toxic gases during combustion.

- Highly abrasion-resistant—Cork is extremely resistant to abrasion and has a high friction coefficient. Thanks to its honeycomb structure, its resistance to impact or friction is greater than that of other hard surfaces.

- Hypoallergenic—Because cork does not absorb dust, it helps protect against allergies and does not pose a risk to asthma sufferers.

- Natural touch—The natural texture of cork combines softness and flexibility to the touch with a naturally uneven surface. The variable degree of irregularity is given by the type of cork used and the finish chosen.

The cork also plays an important role in Portuguese Economy, representing 2% of Portuguese total exports, and due to its sustainable, environmental, and economic benefits, it seems to be an excellent material to incorporate in the project, as well as the use of the GUL, in order to test it to the adaptation to a climate change in a school building.

### 3.4 Prototype for exterior: mBiGPond: exterior solution to promote water infiltration into the soil and reduce air temperature

It was important for LIFE-mybuildingisgreen project to address also the blue areas, from the perspective of water management, which may be due to the increase of the permeable areas (favorable to the infiltration of water into the soil), the reuse of rainwater, and the reduction of water for irrigation.

Following the solutions related to water, it would be important for the project to also contribute to the strengthening of this built urban relationship—permeabilized soil. In this context, urban ponds play an important role in the formation of small aquatic ecosystems of low demand and complexity.

The ponds are masses of standing water or very low current of a permanent or temporary nature, depending on the climate, the geology of the land, and the availability of water. The ponds are characterized by their low depth, total penetration of light into the water, possibility of occurrence of plants throughout their area, and absence of water stratification, and may originate from natural, geological or, ecological processes, or more commonly, as a result of human activities, intentional or not.

Ponds present themselves as a nature-based solution that act in water management in several dimensions: ensure the establishment of an aquatic ecosystem; ensure the availability of water (for fauna and flora); promote biodiversity; increase permeable area; boost water infiltration into the soil; and reduce the need for water for watering.

## 3.5 Facade prototypes in the pilot building in Badajoz. mBiFAVE 1 and mBiFAVE 2 systems

It has been decided to make systems superimposed on the façade that generate shadows in the gaps, preventing the direct incidence of solar rays, for this purpose canopies or cantilevered elements have been created, made up of NBS, plants, and plant species, in addition, so that the implantation of these elements does not prevent sunlight in the winter months, deciduous species have been used.

They consist of a removable modular substructure of laminated tubular frameworks, which support containers or pots with climbing plants, equipped with an irrigation system through pipelines adapted to the substructure. These systems are mainly constituted by a removable modular substructure of laminated tubular framework, of modules with dimensions 2x2 and 3 meters high, in hot galvanized steel profiles of 60.60 and 120.60, anchored to the façade and to the ground.

Formed by vertical elements (tubular steel pillars) and horizontal elements (crossbars and tubular steel beams), which support their own weight and that of the plant containers. It has been called FAVE (Vegetable Facade), in it, horizontal and vertical surfaces are generated on the holes and in front of them.

Two variants have been adapted in this system:

### *3.5.1 "mBiFAVE 1" systems*

Containers or pots of guide plants, of the vine type, that upholster and generate surfaces that are opaque to the sun, will be arranged in the tubular framework. Two varieties of vines have been selected as guide plants: *Parthenocissus quinquefolia* (Virgin vine, originally from the USA) and *Parthenocissus tricuspidata* (Japanese vine or vine, originally from Asia). The system incorporates a mesh of galvanized steel wires that serves as a guide for plant growth (**Figure 4 left**).

### *3.5.2 "mBiFAVE 2" systems*

Vegetated awnings are arranged in the tubular framework, continuous surfaces on racks on which species grow superficially on both sides (**Figure 4 right**).

The double vegetated awning is made up of:

- Rectangular frame of 0.80 × 2.90 mt, made with hot-dip galvanized tubular steel, anchored to the substructure.
- Leaf.skin tensioned membrane formed by anti-root PVC sheet fixed by linear clips on the frame.
- Hydroponic geotextile substrate.
- Lower gutter made of sheet steel, connected to a drain to collect excess water.


**Figure 4.**
*Sketch of mBiFAVE 1" systems (left). Sketch of mBiFAVE 2" systems (right).*

- Irrigation system is installed at the top from where the water falls by gravity soaking the entire substrate. The water provides the fertilizer, keeping the vegetation in perfect condition.
- Mixture of seeds that are projected on the geotextile, after a few months the membrane will be completely upholstered.

### 3.6 Cover prototypes in the pilot building in Badajoz. mBiCUVE 1, mBiCUVE 2, and mBiCUVE SUS systems

Three roof systems have been implemented, whose main function is to reduce the effects of solar radiation in the hot months and reduce energy losses in winter months and thus $CO_2$ emissions and energy consumption in heating, easy to implement and adaptation to any building.

#### *3.6.1 System "mBiCUVE 1": (VEgetable Roof 1)*

It is implanted on the existing flat roof, separated from it, generating an air chamber between both.

To do this, some racks are arranged, supported on concrete "plots", on which we place removable "trays" that house a thin extensive roof solution, with an improved substrate in which native species are planted. The system is made up of:

- Supports or plots: made in situ with concrete, with a height depending on the roof to achieve horizontal leveling of the frame.
- Removable modular frame: made by means of a framework of hot-dip galvanized tubular steel, with approximate dimensions of 4.5 m long x 1 m wide, formed by stringers and crossbars.
- Galvanized sheet steel trays: with side tabs for support (**Figure 5**).

#### *3.6.2 System "mBiCUVE 2": (Vegetable Cover 2)*

A system similar to the mBiCUVE 1 system, as a variant on the racks, large containers would be implanted, at ends and intermediate points, where the two varieties of vines that we have used for planting are planted. Façade systems, mBiFAVE 1.

*3.6.3 System "mBiCUVE SUS": (Vegetable Cover with SUBSTRATE)*

An extensive cover system is used with an improved substrate, including recycled aggregates for the realization of the cover drainage. A layer of protection, a drainage sheet, a filter, and the improved substrate in which native species are planted are placed on the waterproofing of the roof on which the action is being carried out.

## 4. Applications in Alentejo Central, Oporto and Badajoz

By analyzing the existing conditions, namely strong solar incidence in classrooms and the great thermal discomfort associated with high thermal oscillation, the intervention goes through the installation green wall that will work with vegetation curtain. Also, due to pathologies at the level of existing roofs such as poor waterproofing and nonfunctional pendants, green roofs of three typologies will be installed: extended sloped coverage, extensive coverage with gul system, and a green cover with solar panels—Solar bio roof.

With the concern of closing the water cycle, the surplus of rainwater from two sloping roofs will be routed to two tanks and later, by gravity, to a pond of natural infiltration, located in Horta das Oliveiras. Thus, the water will be returned to the natural soil, being able to recharge the aquifers.

For the monitoring and study of the ecosystem services of green roofs, equipment such as a weather station, various thermal sensors and humidity, and caudameters will be installed.

### 4.1 Green roofs prototypes

Green roofing has increasingly established itself as an important element in the strategies of "Nature-based Solutions" for Portuguese cities, thanks to the numerous environmental, financial, and social benefits they present (**Figure 6**).

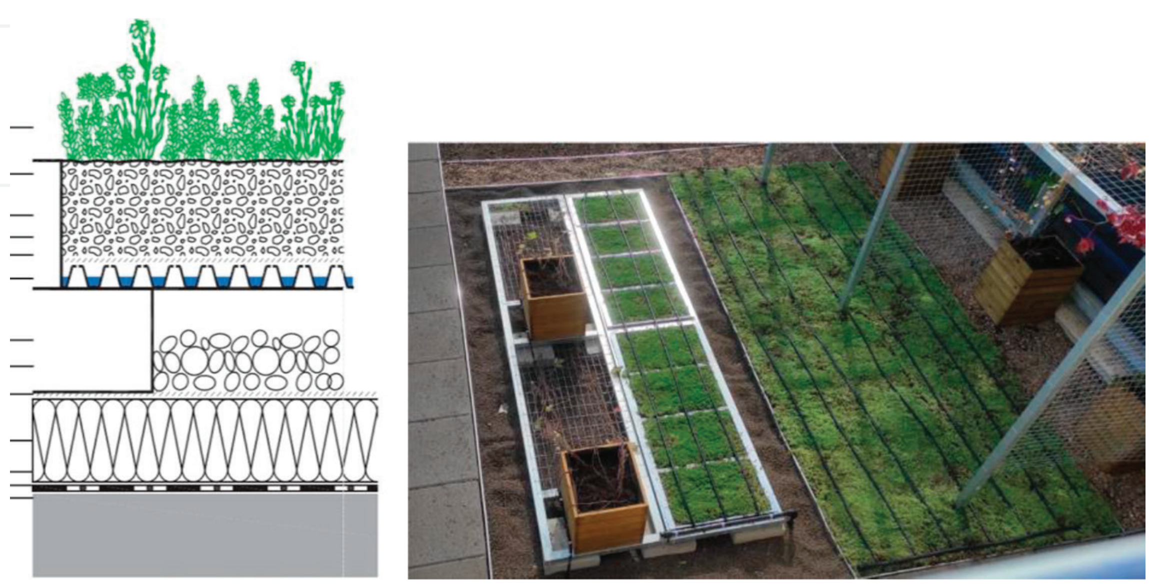

**Figure 5.**
*Sketch of mBiCUVE 1" system (left). The three roof systems: mBiCUVE 1, mBiCUVE 2, and mBiCUVE SUS (right).*

For the success of the implementation of mass green roofs in cities and for their dissemination and acceptance by the professional groups involved and the general population, it is essential that there are examples of model projects promoted by the municipalities themselves as a demonstration of their advantages and promotion of good implementation and maintenance practices.

### 4.2 The mBi_GUL system

The GUL roof will be installed with the innovative green roofing system with expanded cork agglomerate—ICB. The cork agglomerate, with 8 cm thickness, will perform the functions of drainage of excess water, thermal insulation, protection of waterproofing, and sound insulation. Using cork as a building material—biomaterial—this system captures carbon in its production cycle.

The substrate profile will be 12 cm and herbaceous species will be planted in alveole. The planting strategy aimed to promote biodiversity in the green cover. Perimeter gravel strips 30 cm wide will be installed.

### 4.3 Solar bioroof prototype

The SOLAR BIOROOF green roof is a system that combines the installation of solar panels with the existence of vegetation. The substrate profile will have the thickness of 10 cm, where a pre-cultivated Sedum carpet will be installed. Perimeter strips of gravel with variable width between 22 and 30 cm will be performed.

The fixation of the solar panels will be carried out through solar bases with ballast, without drilling the slab, ensuring the tightness of the slab. The ballast will consist of 7 cm of river gravel. A counterweight life system is planned to be installed. This system consists of anchoring bases and steel cable, where the operators will have to secure themselves through sliding carts and harnesses. This system is also not intrusive, also ensuring the preservation of waterproofing.

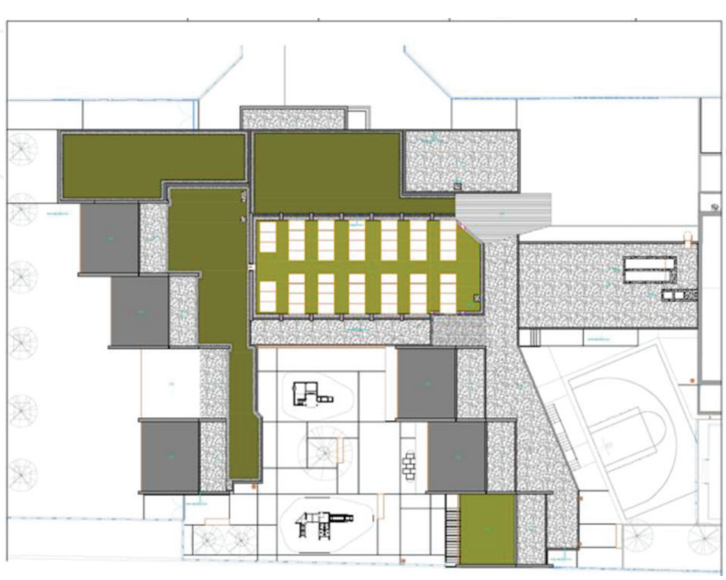

**Figure 6.**
*Blueprint of green roofs in EB1 do Falcão. In different greens the 3 green roofs prototypes: GUL system, solar bio roof, and sloping green roof (ANCV—Associação Nacional de Coberturas Verdes).*

### 4.4 Sedum carpet—sloping green roof prototype

The sloping green cover will be performed using the green roofing system up to 20° slope that holds supports to be installed along the lowest point of the cover. The substrate profile will be 10 cm and will be populated by the genus sedum in pre-cultivated carpet.

The excess water from the roofing system will be routed to a water tank.

### 4.5 Green façade

Green facades for a pleasant atmosphere. Putting vegetation on the facades is so far something that is usually left to chance. Attractive growth systems can be built for micro-vertical gardens with some easy-to-assemble components made of high-quality stainless steel.

Green facades are attractive, ecologically sensitive, and useful. They create a shadow area on the façade which makes the temperature more mild. In the case of the EB 1 do Falcão, due to the sun exposure and size of the windows, the thermal conditions felt inside the building cause discomfort during the warmer months, especially in the classrooms. To lower the temperature, it was suggested the implementation of a wall of steel cables covered by a deciduous vine.

The species selected is *Parthenocissus tricuspidata* because it is fast-growing, losing the leaves in winter, so that light can enter and heat the space so that it is more energy-efficient. This species changes its hue throughout the year, adding beauty and dynamism, transforming the landscape of the place with the seasons.

The vine is placed from 60 to 60 cm, being placed 10 feet along the façade, in a 50 cm wide construction site, supported by squares connected to the upper area of the façade from that extend stainless steel cables with a thickness of 6 mm and length of 6 meters. These cables have an intermediate attachment point on the balcony slab. As it is a small construction site, irrigation has been implemented using the drop-by-drop system.

The vegetation must be pruned to maintain its growth within the area assigned to it, at its base should be placed mulch and the weeds will have to be plucked.

The green wall structure should be composed of a cement or buried concrete base structure, about 20 cm. This 570 cm long piece will serve as a base anchorage for the steel cables installed by placing a 60-in-60 M10 eye. The 6 mm steel cable will be supported by two eyelets at each end, locking the cable with four 6 mm, two-wire cables at each end. Central fixation is placed through a third eye nailed to the building.

### 4.6 mBiG_Pond prototype

The construction of artificial lakes, creating water reserves for biodiverse purposes, are examples of fundamental hydraulic works in rational water management. In order to reduce the water losses of these structures, appropriate waterproofing techniques should be used (**Figure** 7).

The waterproofing of the pond is carried out with the placement of a geotextile fabric to prevent the rupture of the waterproofing screen. The water coming from two covers of the EB1 do Falcão, one with vegetation and the other without, is directed from the retention tanks to the lower level where the pond is located.

The vegetation proposed for this area will serve as a remediation plant, thus helping to maintain the quality of the water that is being infiltrated into the soil.

This space is of great importance because it creates a biodiverse area, where plants of riparian characteristics will arise and that small amphibians and insects can enjoy.

Both spaces will be areas of excellent learning opportunity for the students of the EB1 do Falcão, as they will be able to observe the natural dynamics present in this project, the change and cycles of nature, the emergence of new wildlife in the area of the pond, and the reduction of temperature inside their rooms, thus allowing greater thermal comfort.

## 5. Expected results and conclusions

With the execution of this project, the following results are expected:

- Climate adaptation of the pilot buildings (three educational centers) through the implementation of NBS prototypes.

- Well-being improvement and thermal comfort for around 1.000 citizens in the 3 pilot buildings and communities.

- The elaboration of Reference Reports and Good Practice Manuals on the application of NBS in public buildings of education services for the 3 climatic risk areas of the EU.

- For the entire Project it is expected to reduce the production of 27 Ton of CO2/year and 144 kg of NOx (reduction 20% and 7% respectively).

- It will be collected about 2.700 m3/project of rainfall that represents 30% of each building.

- Increase in the area of green areas in each building by approximately 0.5 ha.

- Reduction of 50% of the energy costs for cooling and 10% for heating. This amount to 1000€/building.

- Integration of NBS into regulations, action plans, and environmental programs

- Execution of expert meetings, demonstration workshops, expert workshops, online seminars and transnational conferences, stakeholders training, website, publication of articles, connection with media associations, and videos.

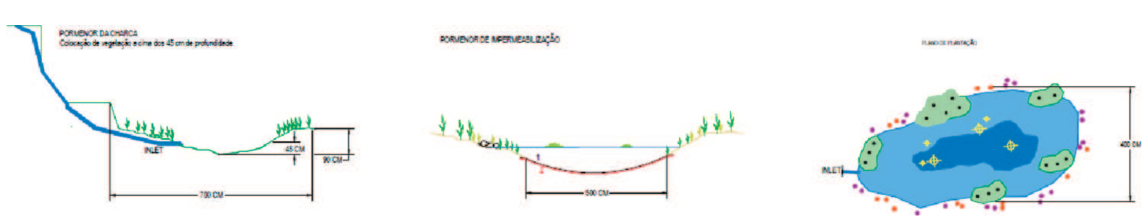

**Figure 7.**
*Details of the mBiGPond—profile and top view of the pond.*

The overall conclusion is that NBS can be a technical and scientific solution for this type of building allowing a more affordable and energy-efficient solution for the adaptation to climate change in Mediterranean regions.

It is already observed that the climate is changing, locally proved by the PIAAC study so it is time to act in order to use Mother Nature's knowledge to prevent more damage to Earth's environment.

Of particular relevance is the application in two study areas, Alentejo and Badajoz, since they correspond to two territories with the lowest population density and the lowest GDP in Portugal and Spain. In addition, these areas are suffering severe depopulation and economic crisis in their rural areas, so these technologies can help improve their social conditions.

## Author details

Teresa Batista[1*], Salustiano Torre[2], José Fermoso[3], Nuno Morais[4], Ramona Avila[5], Carlos Pinto Gomes[6,7], Rui Alexandre Castanho[8,9,10] and José Cabezas Fernández[9,11]

1 CIMAC—Intermunicipal Community of Alentejo Central and MED—Mediterranean Institute for Agriculture, Environment and Development, Instituto de Investigação e Formação Avançada, Universidade de Évora, Évora, Portugal

2 Real Jardín Botánico, CSIC, Madrid, Spain

3 CARTIF Technology Center, Parque tecnológico de Boecillo, Valladolid, Spain

4 Câmara Municipal do Porto, Porto, Portugal

5 Diputación de Badajoz, Spain

6 Department of Landscape, Environment and Planning (DPAO), University of Évora, Évora, Portugal

7 Institute of Earth Sciences (ICT), University of Évora, Évora, Portugal

8 Faculty of Applied Sciences, WSB University, Dąbrowa Górnicza, Poland

9 VALORIZA—Research Centre for Endogenous Resource Valorization, Polytechnic Institute of Portalegre (IPP), Portalegre, Portugal

10 CNPQ Research Group Aquageo Ambiente Legal, University of Campinas (UNICAMP), Brazil

11 Research Group on Environment and Spatial Planning (MAOT), Universidad de Extremadura, Badajoz, Spain

*Address all correspondence to: mtfb@uevora.pt

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