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MASTER IN ENVIRONMENT AND SMART ENERGY MANAGEMENT

MASTER'S FINAL PROJECT

Corporate development of vertical gardens and green roof on urban buildings, with analysis of its energy impact, climate change fight and improvement on environmental health

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I declare, under my own responsibility, that the Project presented with the title: **Corporate development of vertical gardens and green roof on urban buildings, with analysis of its energy impact, climate change fight and improvement on environmental health** in the ETS of Engineering ICAI – Universidad Pontificia Comillas, in the course of 2020/21, it is my own, original and unpublished, and it has not been previously submitted for other purposes. The Project is not plagiarism of another, neither totally nor partially and the information that has been taken of other documents is duly referenced

Author: Pablo Rodríguez Cuadrado Date: 04/08/2021

Project authorized by Director:

Fdo.: Mónica Pérez Martínez Fecha: 04/08/2021

DESARROLLO DE UN MODELO DE NEGOCIO PARA LA IMPLANTACIÓN LOS JARDINES VERTICALES Y LAS CUBIERTAS VERDES CON ANÁLISIS DE SUS IMPLICACIONES ENERGÉTICAS, DE LUCHA CONTRA EL CAMBIO CLIMÁTICO Y DE MEJORA DE LA SALUD AMBIENTAL

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Entidad Colaboradora: Suez España

RESUMEN DEL PROYECTO

Este proyecto surge a raíz de las prácticas realizadas en el departamento de Infraestructuras Verdes, Azules y Turismo Sostenible de Suez. De entre sus líneas de desarrollo de negocio se ha optado por los jardines verticales y las cubiertas verdes como tema del trabajo. El proyecto parte de un estudio de las soluciones ya existentes en el mercado y la normativa y sistemas de financiación disponibles para, mediante la incorporación de sistemas complementarios o de mejora de los existentes plantear un modelo de negocio para su implantación en España. Se ha buscado fundamentalmente proponer mejoras en el ámbito de la digitalización y el mantenimiento, así como el uso de sistemas de aprovechamiento de aguas pluviales para reducir los consumos de agua. Además, se ha realizado una investigación de los múltiples beneficios que presentan estos jardines y su utilidad como herramienta para aumentar la eficiencia energética, luchar contra el cambio climático y mejorar la calidad del aire en las ciudades.

Palabras clave: jardines verticales, cubiertas verdes, modelo de negocio, digitalización, aprovechamiento de aguas, eficiencia energética, cambio climático

CORPORATE DEVELOPMENT OF VERTICAL GARDENS AND GREEN ROOF ON URBAN BUILDINGS, WITH ANALYSIS OF ITS ENERGY IMPACT, CLIMATE CHANGE FIGHT AND IMPROVEMENT ON ENVIRONMENTAL HEALTH

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PROJECT SUMMARY

This project arises as a result of the practices carried out in the department of Green, Blue Infrastructures and Sustainable Tourism of Suez. Among its lines of business development, vertical gardens and green roofs have been chosen as the theme of the work. The project is based on a study of the solutions already existing in the market and the regulations and financing systems available in order to propose a business model for their implementation in Spain by incorporating complementary systems or improving existing ones. The main objective was to propose improvements in the field of digitalization and maintenance, as well as the use of rainwater storage systems to reduce water consumption. In addition, research has been carried out on the multiple benefits of these gardens and their usefulness as a tool for increasing energy efficiency, combating climate change and improving air quality in cities.

Keywords: vertical gardens, green roofs, business model, digitization, rainwater storage, energy efficiency, climate change.

Master Thesis

Corporate development of vertical gardens and green roof on urban buildings, with analysis of its energy impact, climate change fight and improvement on environmental health

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Abstract: This project combines a study of the main benefits of the vertical gardens and green roof with the investigation of the different technologies and systems that could be used to fulfill the main objective of the thesis: to develop a business model that allow to offer a catalogue of solutions to choose from based on economic, climatic, technical possibilities of the building and environmental criteria. In order to meet this final objective, there are some previous goals that must be achieved; specific objectives that are required for the final development of the project. Some of these objectives are: study and classify the technical solutions already on the market, Identify the aspects in which this type of infrastructure still has room for improvement, specially on the digitalization area; set up a database of different plants and trees according to its main characteristics; Analyze the effects of green roofs and verticals in saving energy, capturing CO2; study the possibilities of combining these green roofs and verticals with rainwater collecting systems.

Keywords: vertical garden, green roof, business model, digitalization, energy, CO_2

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1. Introduction

This thesis is based on the work that is being carried out by the department of Green, Blue Infrastructures and Sustainable Tourism of Suez [1]; as part of the internship that I have done in this department through the MESEM (Master Environment, Sustainability and Energy Management). This department target is to develop a whole series of solutions that make up a complete service for cities, as a medium and long-term strategy for the company due to the great growth of cities and their population. Among these services the vertical gardens and green roof seem to be the most interesting option for the thesis because of their multiple benefits and applications, the importance of reducing cities environmental impact and energy consumption, and all the different technologies that are involve on its development. The aim of the project is to establish a model to market these gardens so they can be used all over Spain

2. State of the Art

The first aspect that was studied on this chapter were the benefits that these gardens provide both to the building that house them, and to the environment around them. There are several positive effects that can be classified into the next categories:

- CO_2 emissions and fight against climate change.
- Energy consumption and economic savings.
- Improvement of air quality and environmental health.

In order to understand these effects, there are some previous investigations that have been read like the study of the professor Akira Hoyano [2] of Tokyo Technology University, or the work developed by Patrick Blanc [3], the most famous designer of green walls. Among the benefits or positive effects of vertical gardens and green roofs that they have studied, the following have been identified for every 100 m2 of vertical garden or intensive roof:

- They generate approximately 1 kg of oxygen per day, which is equivalent to the consumption of about 90 people.
- It absorbs around 4 tons of CO_2 per year, offsetting the annual emissions of more than 3 cars.
- They filter 35 tons of harmful gases per year.
- They process 13 Kg of heavy metals per year.
- Compensates for the carbon footprint generated by 12 inhabitants of large cities, or 20 of medium-sized cities (less than 800,000 inhabitants).
- Achieves a reduction in wall temperature by 3 ºC in summer and an increase by 2 ºC in winter.
- Savings of 90.000 kWh per year in Tokyo.
- Reduction of 10 dB on the wall.

It is essential to understand that to have a green roof it is not enough to locate a series of pots on the roof; Instead, a complete garden must be formed, that is, with a layer of soil formed by a substrate of organic matter in which the plants develop. Its benefits for the buildings they occupy, as well as for the environment and the urban environment are evident; providing enormous benefits to the economy and ecology compared to traditional “non-green” construction. Another of its main characteristics is the ease of its maintenance, having recently reached significant self-management quotas that limit the need to work on the roofs as much as possible. In this way, a whole new model of urban sustainability is being developed that requires powerful know-how for its implementation and expansion, and which, therefore, is creating jobs with technical knowledge in different disciplines such as gardening, digitization, automation, design of structures, manufacture of mechanical elements, etc. Depending on the type of vegetation used, the structural loads that they entail for the buildings, and the maintenance required, four types of green roofs are distinguished: extensive, intensive, semi-intensive, and biodiverse [4].

<u>Extensive Gardens</u>

is a roof system widely used on roofs that are difficult to access or with a steep slope; and in buildings that cannot withstand heavy loads. They are very economical, light, with practically no need for nutrients or fertilizers and with minimal maintenance. The substrate of these covers has a thickness of between 4 and 15 cm and the total weight of the cover can vary between 30 and 150 kg / m2. The most suitable plants for its installation are, in general, resistant ruderal plants, with little need for irrigation and fertilizers beyond the natural substrate they already use, like sedum species, perennial plants and grasses. This means that in regions with sufficiently humid climates, extensive roofs can be made without any need for irrigation or artificial fertilizer, making them completely self-manageable. Extensive green roofs are designed to minimize the possible problems of weeds or invasive species, since it seeks to minimize the need for maintenance; however, their biodiversity potential is very limited, and they do not have a great capacity for CO_2 capture or oxygen production. All this makes extensive roofs the most comfortable and cheapest option, being accessible to practically 100% of the buildings; but also, the least beneficial both for the inhabitants of the building and for the surroundings and the environment. Nevertheless, as an alternative, they are very interesting for buildings of old construction, but it is advisable to use other types of roofs in new buildings.

<u>Intensive Gardens</u>

This type of roofs are much more complex systems that, due to their variety of plants, require periodic maintenance, with common gardening tasks such as lawn mowing, fertilizing, irrigation, drainage, etc. which makes them much more expensive to maintain. These covers often include rainwater management systems and even runoff recirculation systems for irrigation; since its water needs make it important to make the most of rainwater to reduce consumption and the cost of irrigation. Intensive roofs are based on much richer and more complex substrates that can reach 150 cm in depth, since they must allow the growth of good-sized plants and trees; and they assume a weight of between 250 kg and 1,500 kg, depending on how complex and diverse you want it to be. This means that they require specific structures for their support, which is why their use in buildings already built is extremely difficult, and their use is reduced to new buildings already designed to house these roofs. It is common to find this type of roof on underground car parks or on top of shopping centers as a playful or recreational space, since they are usually used in places that are accessible to the public. However, they are becoming more common in blocks of flats and offices, as they are the roofs that provide greater thermal and acoustic insulation, thus allowing a significant reduction in the energy consumption of a building. In addition, they offer very important environmental benefits, as they have a greater capacity to capture CO_2 and heavy metals and to produce oxygen.

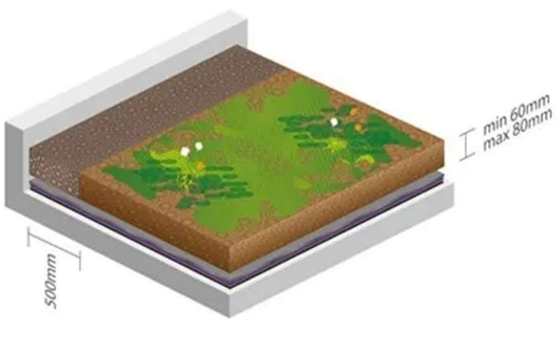
Semi-Intensive Gardens

As its name suggests, it is a system whose characteristics are halfway between the intensive roof and the extensive roof. With an average depth of between 80 mm and 120 mm, a weight between 70 and 220 kg, and some maintenance needs, it is an ideal system for partially accessible roofs. For this reason, they are usually installed on roofs for social or recreational use. They are usually installed on metal or concrete roofs that can support the weight without the need for works to reinforce the structure. Semi-intensive roofs are characterized by having a greater plant variety than extensive ones, being able to support herbaceous plants, grass or small bushes, which require moderate maintenance with sporadic watering. This system can retain more water than an extensive cover and provides greater biodiversity richness. As part of its installation, it is necessary, as was the case with intensive roofs, to have a water drainage system.

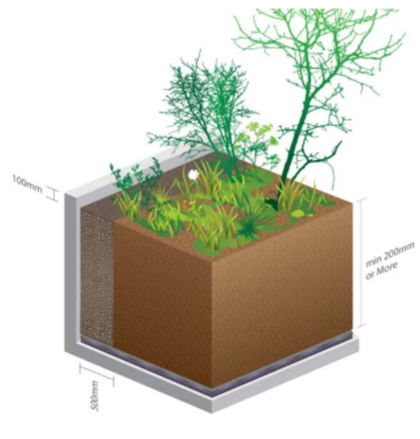
Biodiverse Covers

The biodiverse covers are considered a variation of the extensive ones, but with some structural differences in the type of vegetation that is available on them. They are specifically designed to create a habitat that attracts certain species of plants, insects and birds, generating a habitat like the one that existed in the place before construction, thus seeking to stimulate the natural presence of fauna and flora to thus recover the value of the biodiversity of the area. For this reason, human interaction on these roofs must be very limited, being reduced to the minimum activities essential for their maintenance.

In order to develop the business model that allows offering different solutions depending on the client's demands, the location conditions and the possibilities of the building, a comparison between the different types of roofs is presented in the following table. It is sought to make it easier to identify what kind of cover is the most appropriate for each case.

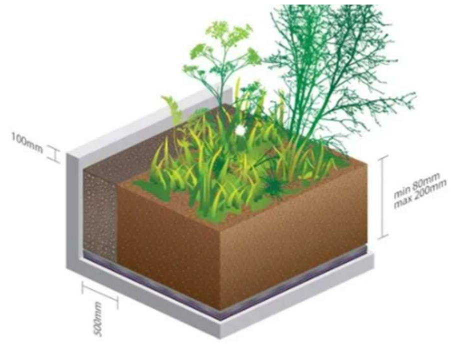


Extensive



Intensive

Biodeverse



Semi-Intensive

Gardens	Vegetation	Location	Maintenance	Weight	Efect
Extensive	Sédum Ruderal Plants Grass	Not accesible rooftops	Low	30 - 150 Kg/m2	Low biodiversity Little CO2 capture Good insulating
Intensive	Trees Green wall Bush	Accesible and playful	Irrigation Pruning Sewer	250 - 1.500 Kg/m2	Great CO2 capture Great oxygen production Very good insulating
Semi-intensive	Bush Grass Green wall	Partially accesible	Irrigation Sewer	70 - 220 kg/m2	Intermediate advantages
Biodiverse	Bush Grass	Not accesible rooftops	Low	50 - 200 Kg/m2	Atracts specific fauna Same effects as the extensive

Table 1: Kinds of gardens. Source: own made

Another aspect has been deeply studied is the rainwater collection systems. It has been decided to integrate a rainwater harvesting system into the design of the roof and the green verticals, as it has been proven that this system is perfectly adaptable to the green infrastructure and that it represents a great contribution to the economic and, especially, environmental impact of the facilities, due to the water savings that can be obtained. To provide an initial estimate of these savings, the annual rainfall and irrigation expenditure data for the last decade are shown below [5]:

- Average rainfall in the peninsula: 636 l/m2.

- Standard garden irrigation requirement: 840 l/m2.

Obviously, vegetation needs a stable irrigation supply over time, so torrential rains do not make a positive contribution; and therein lies the usefulness of integrating systems with which to collect, store and subsequently use rainwater for irrigation. In this way, even if only 30% of rainwater is used, the use of water for irrigation could be significantly reduced, which would have a very positive impact both economically and environmentally.

Taking a 500 m2 roof in Madrid as a reference, this would mean a saving of 95 m3 per year. And if the collection process is optimized, reaching the levels to which companies dedicated to the collection of river water are committed (0.5 in the case of green roofs), up to 159 m3 per year could be obtained.

The first system that has been studied is the RS60 from Zinco [6]:

Multiple solutions already existing on the market for rainwater harvesting have been compared, reaching the conclusion that various systems should be incorporated. This option was chosen in order to be able to offer different solutions depending on the load capacity of the roof, and the need for water storage according to the average rainfall in the region where the installation is to be carried out.

The first option to be added to the roof catalog is the "Zinco RS 60 rainwater regulating roof system", which has been found to be the most suitable for buildings with high load capacity and regions with frequent periods of drought and other periods of torrential rainfall. This solution is already designed, in origin, for use in green roofs and the company in question has a lot of experience in the design and installation of this type of structures; therefore, in the event of any difficulty or problem that arises, they will have resources to offer alternatives and variants. In addition, they offer not only the product itself but also installation and maintenance services and the corresponding warranties.

Figure 1: Zinco RS60 System. Source: Zinco

With Zinco's RS 60 rainwater regulating system, up to 85 l/m² of rainwater can be captured and stored for roof irrigation in times of drought and, in the event of torrential rains, it can be released into the sewage system or, in our case, into the non-potable water tank, for a user-configurable period of between 24 hours and a few days. Rainwater storage takes place inside reticulated modules - the rain load regulators - located under the green roof system. In the meantime, the conditions that are of vital importance for the proper functioning of the green roof (water storage for the plants, water/air balance in the root zone, etc.) remain unchanged and unimpaired, so that they continue to function in the same way.

One of the great advantages is that the accumulation and progressive release operation greatly reduces the possibility of overflows, allowing time for water management in the event of torrential rains, thus greatly reducing the amount of water discarded.

The only requirement or limitation posed by the use of this system is that the structural loads of the roof under which they are placed are admissible; however, they are designed to be able to support not only green roofs but also roofs passable by people and even vehicles, so they present a resistance that will be more than sufficient for the use that is intended for this design.

The main technical characteristics of the Zinco rainwater regulating roof, the solution chosen for water collection, are shown below:

- Material: regenerated polypropylene (PP), chemically inert and does not release substances into the environment or into the stored water.

- Can withstand prolonged exposure to UV rays.

- Dimensions: 50 x 50 x 17 cm.

- Compressive strength: 6 Tn/m2.

- Flexural modulus of elasticity: 1250 MPa.

- Water uptake volume: 85 l/m2.

- Weight saturated with water and with standard garden: 185 kg/m2.

The second solution that has been analyzed and it has been decided to incorporate to the catalog of possibilities for rainwater accumulation is the Drainroof system developed by Geoplast [7]. This system is very interesting for use in old buildings or those that admit small loads on the roofs, as its weight is much lower, although it also has a lower water accumulation capacity. This company markets 2 systems with identical operation, but with different sizes, so working with them offers great flexibility. The most important features of the first of these solutions, the Drainroof H6, are shown below:

- Modular system: easy installation

- Single piece of polypropylene

- Modules of 50x50 cm, thickness 6cm and 1 kg

- Water catchment volume: 40 l/m2

- Weight saturated with water and with standard garden: 90 kg/m2

The other product offered is the Drainroof H2,5; with identical characteristics and functionalities except for the size and weight:

- 50x50 cm modules, thickness 2.5 cm and 0.60 kg.

- Water catchment volume: 16 l/m2

- Weight saturated with water and with standard garden: 60 kg/m2

The installation of the Drainroof rainwater drainage system is really simple thanks to its module structure and the weight of these modules. This means that, as the company itself specifies, it can be carried out by a single operator. However, it is necessary to have safety elements such as harnesses and other means of fall prevention, since the operator will be on a roof at a great height. There are three fundamental issues in its installation:

- Couple the modules together perfectly, through their tabs, to ensure the collection of as much water as possible, as well as the stability of the floor above the modules.

- Make sure that all the modules are correctly arranged and oriented to discharge the excess water to the downspout; so that there is no accumulation of water on the roof or discharges to other areas that cause water losses.

- Correctly regulating the modules so that they do not store more water than calculated is advisable given the load capacity of the building.

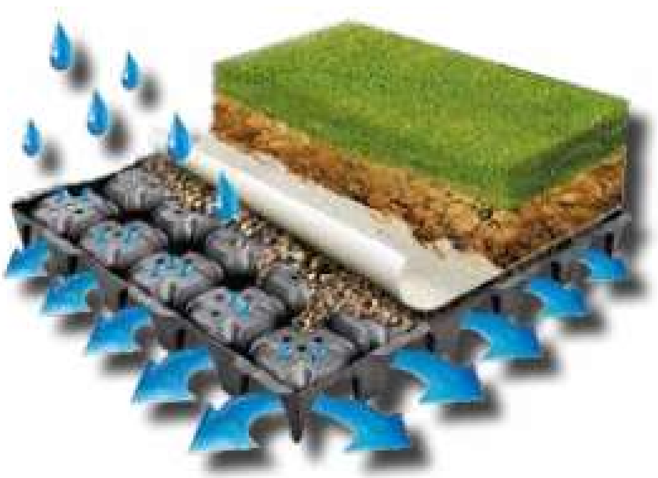


Figure 2: Geoplast Drainroof System. Source: Geoplast

Finally, the last solution that has been analyzed for installing rainwater harvesting systems is the pre-cultivated sédum tiles marketed by the company Topgrass [8]. These tiles include their own rainwater collection system, which makes it possible to cover both the purchase of the vegetation and the water harvesting solution with a single company; and they are also suitable for buildings with low load-bearing capacity. The most important characteristics of this Topgrass system are shown below:

- 54x54 cm modules, thickness 9 cm.

- Volume of water uptake: 35 l/m2

- Total weight (saturated with water and with the sédum): 60 kg/m2

The fact that these modules include the sedum is a very interesting value that can considerably reduce the total price of the gardens. They are not the species with the greatest capacity for CO_2 capture or oxygen production, so other options would be preferable for more ambitious projects. However, it offers a simple and inexpensive solution for projects with lower budgets and older buildings or with low load capacity; and allows to have gardens whose water consumption is practically 0, thus greatly reducing their environmental impact.

The last option studied is the Garoé System by Singular Green [9]. It uses a water storage system by means of a cistern and is designed to support vegetation with low water needs, such as sédum, grasses, and shrub or perennial species. It is a very light water storage system, since with a full cistern it should not exceed a total load of 50Kg/m2. Therefore, this design offers three very clear advantages:

- The water harvesting system is included in the roof assembly itself, so you can have a professional assembly system for a low price.

- By including vegetation with low water requirements, it offers the possibility of developing highly self-manageable roofs, which work almost entirely with rainwater and do not involve high water consumption.

- The total weight of 50 kg/m2 should be affordable for most buildings that are 30 to 40 years old, making it an interesting option for use in these cases.

Another key aspect of the investigation developed in this project is the digitalization. In any sector with a minimum technological development, digitalization, data collection and analysis, and process automation are a basic element for the development of this field. It offers the greatest possibilities of developing a competitive advantage to offer cheaper, more efficient services with a faster response to any problem or issue to be solved. Moreover, from an economic point of view, the development of systems that can be classified as Smart or new generation, opens the possibility to apply for European or national funding, as there are many programs to promote and enhance digitization. This chapter will first present an analysis of the data collection, control and decision-making tools currently present in the gardening and park and vegetation care sector, identifying the most important aspects of these tools and trying to understand what steps should be taken to develop more complete and versatile systems, in order to offer a better service.

The first element of digitalization to be analyzed is the most important and developed now: smart irrigation.

Smart irrigation comprises a whole series of systems that share the objective of saving water, and therefore money, in agricultural crops, parks and gardens. It is an industry that has been in operation since the beginning of the 21st century and that in recent years has been in full growth phase; motivated by the increased scarcity of water and the increase in prices.

To illustrate this situation of increasing water scarcity worldwide, we can access the data presented by the United Nations in the report on climate change published in November 2020:

- In Latin America the availability of water per capita has decreased by 22% in the last 20 years.

- More than 60% of the world's irrigated cropland is severely water-stressed.

- 20% of the world's agricultural land suffers from lack of water.

- With population growth, the world's irrigated areas are expected to double by 2050 compared to 2010.

- Biofuels require between 70 and 400 times more water than conventional fossil fuels.

From just an economic point of view, there is also very enlightening data on the increase in the cost of water. For example, in Spain, water has increased its price, on average, by 93% between 2000 and 2016; there are communities such as Madrid or Catalonia where it has practically tripled. Below is the graph that shows this increase:

Figure 3: Water price evolution in Spain on 2000-2016. Source: iagua.es[10]

Based on the research conducted on smart irrigation systems, the following elements can be distinguished as basic issues of their functions and the service they can currently provide:

- Taking soil temperature and moisture measurements.

- Postponing and/or advancing irrigation according to rainfall or solar intensity.

- Making it possible to establish different irrigation needs for different sectors with the same system, depending on the vegetation in them.

- Ensuring water and fertilizer saving rates, ranging from 10-20% in humid climates and 30-40% in dry climates with a tendency to torrential rainfall.

- There is a great development in the use of sensors and communication with platforms for data analysis.

- The main gap and, therefore, opportunity to develop a competitive advantage is artificial intelligence; decision making without the need for the involvement of technicians.

Through this study, the possibility of developing artificial intelligence systems has been identified, in addition to other control and monitoring systems that can provide more information and thus allow a deeper and more complete analysis of green spaces. However, before showing some of these better control systems, an explanation of the advantages and benefits generated using intelligent irrigation systems will be offered.

In order to explain the importance of smart irrigation systems and their positive effects, research already completed by other institutions and companies has been studied, such as, for example, the study "Efficiency in the use of water in gardening in the Community of Madrid" published in 2010 by Canal de Isabel II [11] in the series "Cuadernos de I+D+i".

The study Eficiencia en el uso del agua en la jardinería en la Comunidad de Madrid, Canal de Isabel II, was carried out with the aim of establishing the most suitable species for use in parks and gardens in Madrid. The study was conducted under the following conditions:

- Vegetation with average irrigation requirement of 2 l/m2 and day (in summer 2.5 l/m2, the rest of the year 1.8 l/m2).

- Space of 1,000 m2 located in Madrid.

- Equipment calibrated to interrupt irrigation with rainfall of 2.5 l/m2.

- System price: 200 €, useful life 10 years (labor costs not included).

In this context, and knowing that in Madrid there are, on average, 26 annual days of rainfall above 2.5 l/m2, the following conclusions were drawn:

- Saving of 52 m3 of water per year.

- With the current cost of water in Madrid, this reduction in consumption implies an average annual saving of 108 €.

Thus, the use of the rain switch could translate into an initial investment of 200 € plus the cost of the installation, and a saving of 108 € and 52 m3 of water per year for 10 years.

The second automatic irrigation control element studied was the irrigation switch based on soil moisture. This system works by means of a sensor that is buried at a depth of 20 cm and is calibrated to interrupt irrigation at a certain moisture level. A clear advantage of this system over the rain switch is that it allows distinguishing different moisture levels for different plants and trees in the same place, thus offering a more detailed and personalized control.

In this trial we worked under the following conditions:

- Vegetation with an average irrigation requirement of 2 l/m2 and day (in summer 2.5 l/m2, the rest of the year 1.8 l/m2).

- Space of 1,000 m2 located in Madrid.

- Equipment calibrated to interrupt irrigation at a certain soil humidity.

- Price of the system: 450 €, useful life 10 years (labor costs not included).

Based on this context, the following results were obtained:

- Irrigation was interrupted on 12% of the days.

- 84 m3 of water were saved.

- With the current cost of water in Madrid, this reduction in consumption implies an average annual saving of 175 €.

Thus, the use of the soil moisture switch could translate into an initial investment of 450 € plus the cost of installation, and a saving of 175 € and 108 m3 of water per year for 10 years.

In order to continue with the research on the benefits generated by smart irrigation systems, more recent studies were sought, in which it was possible to verify that the savings generated by these systems are even greater. Among these studies, the Irrimanlife [12] program was analyzed, developed in Spain by the European Union as part of the Life+ Program, which hosts all environmental and climate change-related initiatives. This program began in 2017 in collaboration with the Polytechnic University of Cartagena, which acts as the project coordinator, the Center for Soil Science and Applied Biology (CBAS-CSIC), the Ministry of Agriculture of the Region of Murcia, the University of Cordoba, and the Federation of Mediterranean Irrigation Communities (Fenacore).

The entire smart irrigation system used in this project is the work of Model Green [13], a very powerful company in the sector that is dedicated to the development of different types of tools and platforms and their sale to other companies. This is a very ambitious project with developments both in terms of sensorization and smart irrigation as well as enhancing the use of reclaimed water for irrigation, the choice of crops more suited to the regions climate in order to reduce the need for irrigation and fertilizer, adjustments for the reduction of runoff and leaching and several other measures, although in this study we will exclusively analyze their developments in terms of smart irrigation.

This Model Green system has implemented the following smart irrigation tools:

- Moisture interruption irrigation system, with an activation rate 10% lower than previously established (this is the current known as deficit irrigation).

- System for measuring the concentration of nutrients and ions present in the soil.

- System with remote activation for the supply of manure and fertilizers; it can be activated by identifying insufficient values in the nutrient and ion measurements.

- Use of solar panels to power pumps, solenoid valves and other elements of the irrigation system.

In December 2018, twenty months after the implementation of the first measures, the following results could be verified:

- 30% water savings.

- Reduction of 30% in energy consumption, amounting to 720 kWh / hectare per year.

- 30% reduction in chemical fertilization, reducing water pollution.

- Reduction of associated CO_2 emissions by 40%.

The Irrimanlife project is still underway today, and different systems and tools are still being developed to improve these results, but in any case, it has already become a reference that is being imitated in many other areas of Europe, as it has demonstrated spectacular levels of savings and reduction of environmental impact.

Finally, the last system that has been studied is the Smart Biosystem [14]. It is an intelligent irrigation system developed by the University of Cadiz that has achieved great recognition for being the choice of the company Paisajismo Urbano to incorporate into their vertical gardens. It is a system that has already been used in the agricultural field as well as in urban gardens and parks and is defined by these characteristics:

- Free software: allows users to access the code, copy it and propose modifications.

- Proprietary hardware: devices based on open sources with robust components that seek to eliminate the need for maintenance and to dispense with programmed obsolescence.

- Modular design: offers ease of scalability of the systems at the user's will and thus adapts to each installation.

The following image shows the Multifunction Board that has been developed and integrates the reading of sensors, a communications module and the control of peripherals such as relays or solenoid valves.

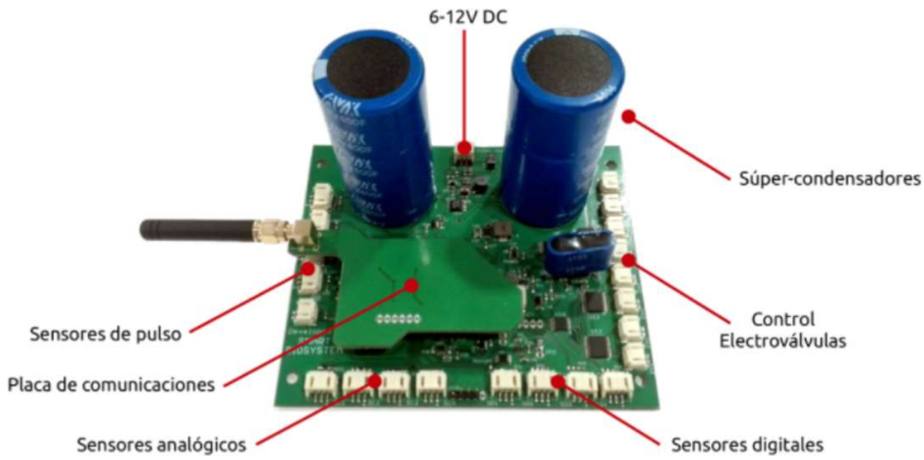


Figure 4: Smart Biosystem design. Source: Smart Biosystem web

The irrigation system is based on several elements:

- Humidity sensor buried in the soil, in the zone of root activity (of plant roots).

- Temperature sensor buried in the soil, as it has been identified as a crucial factor to ensure root health.

- Weather station to provide the necessary information to calculate water losses caused by weather conditions.

- Flow meter to quantify the volume of water used in each irrigation cycle and to identify possible faults by measuring pressure, such as broken solenoid valves.

- Sophisticated irrigation programmer that not only works as a logic gate (open 1, closed 0) but also allows to regulate irrigation time according to humidity and temperature levels.

- Management platform with app access to all data.

With this system, they have recorded water savings of 30% in agriculture and 60% in urban gardens, which means results that have not been found in any other system analyzed.

Based on the analysis of Model Green, which, as explained in its section, markets for other companies, a nursery and plant sales company was discovered that has developed a series of systems to establish traceability of the plants it sells. This company is called Agromillora [15], has more than 600,000 m2 of greenhouses in 25 countries and has developed a method of identification and inventory of trees through QR codes that allow them to prepare traceability reports of the plants, record any maintenance work that has been done on them, maintain control and monitoring of possible problems or diseases that suffer, etc.

From the moment this system was found, it was considered a very interesting tool to incorporate into the work, since it represents a great contribution to the objective of developing a self-manageable system with the highest possible degree of access to data, automation and even artificial intelligence. In addition, it is a great resource to establish a continuous improvement system that would allow identifying the behavior of the species under different irrigation methods, different types of manure and fertilization, use of pesticides, etc.

With a view to the implementation of this technology, it has been found that the use of this system corresponds to a series of products of the company (called Micrograft) that they sell to other nurseries, so there should not be the slightest problem in finding a collaboration with them. This Micrograft series includes species such as nectarines, peaches, flat peaches, apricots, cherries, plums and almonds; however, given the size of the company and the volumes of plants that can be moved with vertical gardens and green roofs, it seems likely that they could be asked to provide the same service for use on other species of trees or shrubs.

Focusing on the use that would be made of this technology in this project, the following functions have been identified:

- Traceability from the origin of the plants and trees used, which would allow a more accurate calculation of the total carbon footprint of each installation and compare it according to the suppliers used.

- Monitoring not only of irrigation and possible breakdowns or failures, but also of the maintenance operations carried out on the plants and their pests and diseases.

- Recording of the evolution and durability of the different species in order to carry out a study and identify the most suitable species according to the climatic conditions; as well as their behavior under different levels of irrigation and/or use of fertilizer and fertilizers.

It is expected to receive a budget from Agromillora to have plants, from its own greenhouses, equipped with QR technology. The next step would be to propose a collaboration with a fixed rate, so to speak, so that this resource could be incorporated both to the plants provided by Agromillora, as well as to those that are not marketed by the company itself and are to be acquired by other means.

3. Objectives

The main objective of this work is to develop a business model that purposes a series of green roof and vertical structures that allow integrating the different solutions existing in this market, proposing and providing innovative alternatives with which to obtain the greatest energy, environmental, and economic and social possible. This business model will offer a catalogue of solutions to choose from based on economic, climatic, technical possibilities of the building and environmental criteria. In order to meet this final objective, a series of previous goals that must be achieved have been identified; specific objectives that are required for the final development of the project. These objectives are:

-Study and classify the technical solutions already on the market for vertical gardens and green roofs.

- Identify the aspects in which this type of infrastructure still has room for improvement, such as continuous monitoring and digitization.

- Set up a database of different plants and trees according to their irrigation and maintenance needs, their adaptation to different climatic environments, their potential for capturing CO_2, their thermal and acoustic insulation capacity; and the relationship between these variables and the weight load they imply for the building in which they are located.

- Analyse the effects of green roofs and verticals in saving energy, capturing CO_2 and other toxic or harmful elements for the environment, and the production of oxygen.

- Establish a close economic relationship between the investment necessary for the development of different types of green roofs and verticals and the energy savings they provide; in order to be able to propose different types of solutions according to the economic possibilities of the project.

- Study the possibilities of combining these green roofs and verticals with rainwater harvesting systems, the use of photovoltaic panels for self-consumption, and other technologies to improve the overall energy efficiency of the building.

- Analyze the effect of these infrastructures on the improvement of biodiversity in urban spaces.

Once all these characteristics and issues have been identified, different solutions will be proposed that allow the design and installation of vertical gardens and green roofs anywhere in Spanish territory, in buildings with different load capacities and for different levels of economic investment. In this way, a more complete and versatile service can be designed, adaptable to all types of clients and climatic conditions.

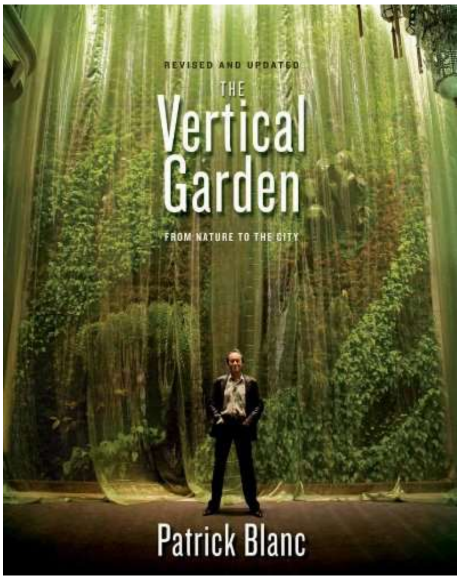
4. Resources

Firstly, there are many studies and previous projects that have been analyzed in order to understand all the aspects that compose the urban gardens and all the advantages they can provide to the buildings and the environment where they are set. Some examples of this studies are:

- Akira Hoyano (Professor, Tokyo Institute of Technology), Vertical Urbans Gardens, 2008.

- Darlington, Urban Gardens, 2001.

- Patrick Blanc, www.verticalgardenpatrickblanc.es



To identify the main resources that can be used for the digitalization of the gardens, there are also several studies that have been read, for instance:

- Efficiency in the use of water in gardening in the Community of Madrid, series Cuadernos de I+D+I, Canal de Isabel II, 2010.
- Irriman Life, irrimanlife.eu
- Smart Biosystem, Universidad de Cádiz.
- iagua.es
- PlantNet
- Agromillora

-

Another chapter among resources would be the study of the companies that are already selling products to build the gardens, like the following:

- SingularGreen
- ModelGreen
- Zinco
- Geoplast
- Topgrass
- Paisajismo Urbano

5. Results

This chapter will present the different solutions that have been devised for the design of green roofs and vertical gardens. The objective of this Master's thesis is to develop a business model for the commercialization of these gardens and roofs, for which a series of fundamental factors have been identified that will define the characteristics of these gardens and roofs. These factors are the following:

- Climatic zones: the study that has been carried out in the tree inventory chapter on the adaptation of species to climatic zones will be completed with a record of average rainfall in these areas. The aim is to select the species best suited to each location in order to minimize the need for maintenance, fertilization and irrigation.

- Structural capacity of the buildings: depending on the loads that the buildings on which the gardens will be placed can support, we will look for the species, substrates and accessory systems, such as water collection systems, that can offer the best results while respecting that load capacity.

- Client's investment capacity: the study carried out in this project has allowed us to conclude that the slightest introduction of vegetation in the urban environment and, more specifically, in the buildings we live in, is very positive. That is why we want to offer this opportunity for the tightest budgets available.

- Possibility of access to the roof: different gardens will be developed according to the use that will be given to them, proposing more interactive and functional environments for those spaces where there will be people often. Even more so if they are public spaces where educational or social activities can be carried out.

This section will present the different possibilities that will be offered for the digitization of gardens. The starting point is the conviction that having an automatic irrigation system is an indispensable condition for the design of any vertical garden or green roof; but beyond that, more complex solutions are offered to improve maintenance, efficient use of water and control over the garden. With this idea in mind, the following options are proposed:

1. For small budgets we choose to offer the DD-6312 Mini-Clik rain interruption system from HUNTER [16], used in the Canal de Isabel II trials. This sensor is priced at 48.91 € (installation cost not included) and has a useful life of 10 years. In the conditions of Madrid, where the test was carried out, it allowed, for a space of 500 m2, a saving of 26 m3 and 54 € per year, amounts that, in locations with more frequent rainfall, could be increased.

Figure 5: DD-6312 Mini-Clik Interruption System. Source: HUNTER

2. For intermediate budgets, the ModelGreen irrigation control system from the Irrimanlife program will be chosen. This system, which must be custom ordered for the garden, also offers fertilizer control by measuring the concentration of nutrients in the root environment; and in the tests carried out it has presented the following results:

a. Savings of 30% of water.

b. 30% reduction in energy consumption by the irrigation system.

c. Reduction of chemical fertilization by 30%, reducing water pollution.

d. Reduction of associated CO_2 emissions by 40%.

It involves a higher investment, which, as seen in the market, can be estimated at 150 €/ 50 m2 of garden; but it also offers levels of savings that allow a higher return on investment and, with current regulations, can be used to avoid fines for excessive pollution.

3. For large budget projects we would incorporate 2 systems that offer a higher level of control and monitoring. First, the Smart Biosystem: developed by the University of Cadiz, and used by the company Paisajismo Urbano [17], which has built some of the largest vertical gardens in the world. It is an open-source system, but with a higher cost for the materials, since it relies on a robust hardware and a modular design that allows scaling it to any garden. It includes humidity and temperature sensors, weather station, watering time control, flow meter and fertilizer management, and has demonstrated great results in urban gardens:

a. Water savings of up to 60%.

b. Energy consumption reduction of 40%.

4. In accessible roofs, the use of the PlantNet [18] program will be offered, so that users have information about plants and trees and can develop related activities. This program is free and accessible on Google Play; the cost would be reduced to include informative signs and design a less vegetated area to carry out these activities.

Below is a table showing the different systems that have been studied and their costs, at least for those systems that are known.

Digitalization level	Systems included	Cost
1	DD-6312 Mini-Clik de HUNTER irrigation interruption	48,91 € / 500 m2
2	ModelGreen irrigation control system	150 € / 50 m2
3	Smart Biosystem	There have been no answer by the companies
	QR Codes Agromillora	
4	PlantNet	Free

Table 1: Digitalization technologies price. Source: own made

The next step is to design alternatives for each of the 5 climatic zones identified in Spain, always according to the criteria already explained. The map of Spain by climatic zones is included below, to provide a reference to help locate them correctly, as well as the rainfall map.

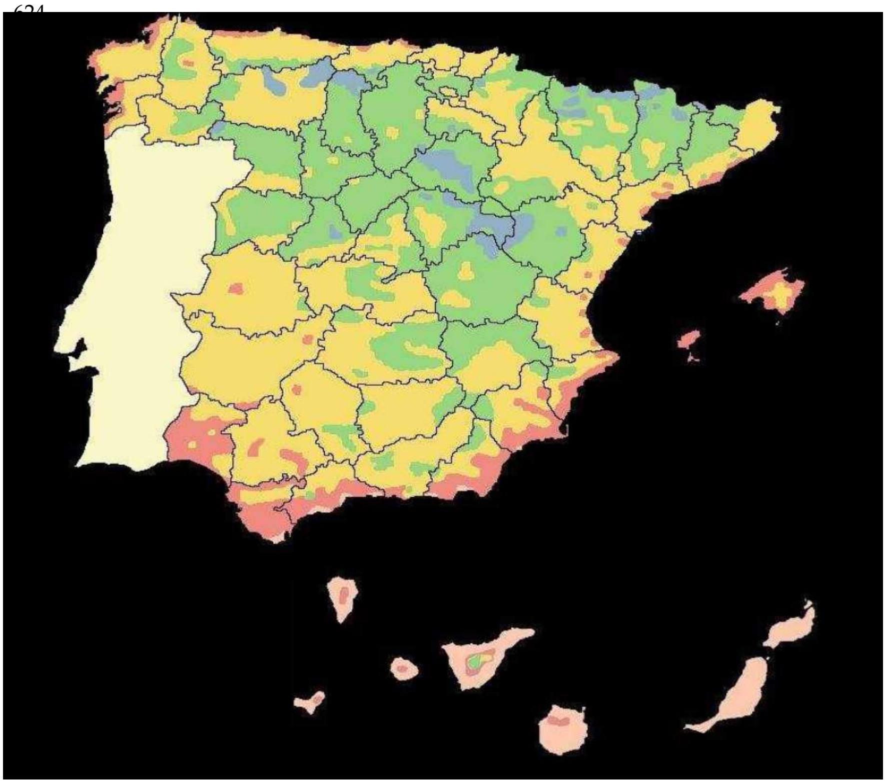


Figure 6: Climate's map of Spain. Source: *arbolesornamentales.es*

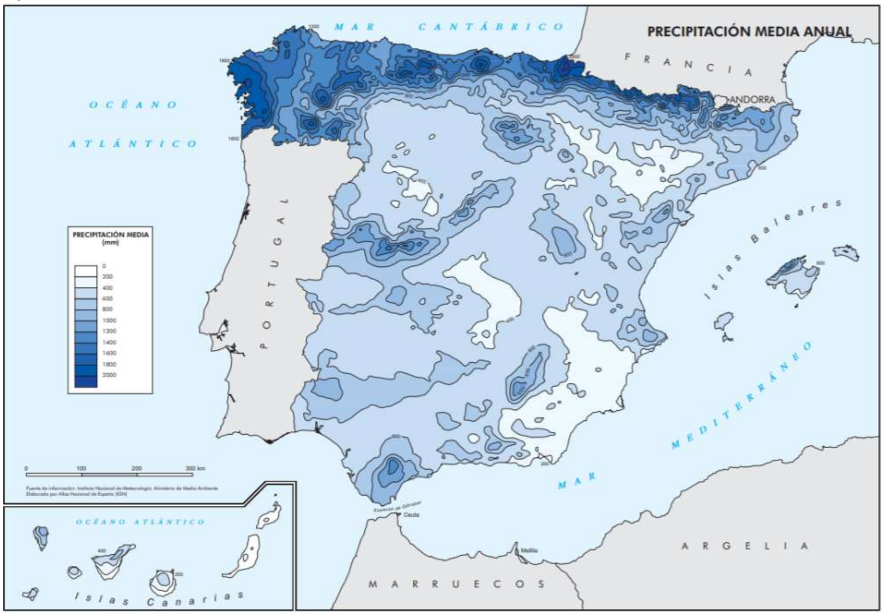


Figure 7: Precipitation map of Spain. Source: *arbolesornamentales.es*

Designs for climate zone 7

This climate zone is located in the Huesca Pyrenees, the southern face of the Coordillera Cantábrica and the southwestern part of the Sistema Ibérico. As can be seen in the precipitation map, a high level of precipitation can be distinguished in the Coordillera Cantábrica and Pyrenees, and a medium-low level in the Iberian System. This is, therefore, the first necessary distinction.

There will be 3 main options according to the level of rain fall on this area: high, medium and low

The first step in considering this design is to identify the plant and tree species that combine good adaptation to very low temperatures with medium or high water requirements, since overwatering is as harmful as underwatering. With these two criteria, the following species are identified.

Species suitable for climate zone 7 locations		
Trees and big bushes	**Plants**	**Climbing plants**
Aleppo pine	Sédum acre	common ivy
Hackberry	Sédum álbum	chocolate vine
Apple tree	privet	
	female ferns	
	photinia	
	rosemary and St.	
	John's wort	
	Cotoneaster	

Table : Species suitable for climate zone 7 locations. Source: own made

The species in this table that are underlined are those that, due to their water needs, are likely to be able to evolve correctly without irrigation, which is a very interesting aspect in order to create gardens with the lowest possible environmental impact and low maintenance requirements.

The first factor to be defined in order to establish the design of these gardens is the need to take advantage of rainwater. For areas with a lot of rainfall, there will be no water storage systems, as it is unnecessary an it would imply an excessive weight that can be better used with a greater load of vegetation. The next step is to identify variants depending on the conditions of the building that will house the gardens, and the budget available to the client.

Design according to building conditions, there will be distinguished 3 options:

1. Newly constructed building whose structure can be built to support heavy loads: 400 - 500 kg/m2.

2. Buildings of firm and/or modern construction with a capacity of 100 kg/m2 overload.

3. Old buildings or buildings in a poorer state of repair that should not exceed 50 kg/m2.

The first possibility will involve the installation of an intensive green roof and green façade, offering, in any case, certain recreational areas if they are accessible roofs. A high density of vegetation will be sought (30 small plants per m2), the use of medium-large trees to have a greater impact on air quality, and, if there is not a high level of rain fall, a big or medium-sized rainwater storage system will be included: the Drainroof H6 or the RS60 Zinco, in order to reduce the need for irrigation as much as possible.

In the second case, an extensive green roof and green façade will be designed, offering, in any case, certain recreational areas if they are accessible roofs. A high to medium density of vegetation will be sought, and, , if there is not a high level of rain fall, a small rainwater storage system such as the Drainroof H2'5 will be included to reduce the need for irrigation to some extent.

In the third case, an extensive green roof and green façade will be provided, which will not be accessible, as it would pose a risk. In order to have the highest possible density of vegetation, water collection systems will be dispensed with, it does not matter the level of rainfall

The client's investment capacity will define three issues that can greatly improve the performance of the garden:

- Level of digitization of the garden, whose possibilities have been explained in the first point of this chapter.

- Installation of horizontal structures on the facade for the placement of deciduous trees that cover the windows in summer, but not in winter, thus helping air conditioning in both seasons.

- Use of species with less or more need for irrigation.

Use of deciduous trees in front of windows. Given the continental climate of this area, the use of deciduous trees that do not reduce exposure to the sun in winter is very interesting for thermal and comfort reasons. These trees would be placed in horizontal structures located under the windows, since these are the areas of the wall with the greatest transmission of solar radiation. They entail a considerable cost due to the need for construction work, and are only viable in facades with medium or high load capacity, subject to a previous load study.

Choice of species according to irrigation needs:

- For intensive covers, in any case, Aleppo pine and hackberry will be used, as they are the most suitable species with the highest CO_2 uptake and low water needs. These trees will be complemented with the species indicated for extensive cover.

- In semi-intensive roofs, privet and cotoneaster will be used because of their great thickness (which improves insulation) and their low water requirements, and lavender because of its good smell, color and low water consumption. If more irrigation capacity is available, female ferns and photinia, which offer, respectively, very good CO_2 uptake and good insulation, will be used. On the other hand, if it is necessary to adjust water consumption, rosemary and St. John's wort, which improve the appearance of the garden and require less irrigation, will be chosen.

- In the extensive covers the same plants will be included as in the intensive ones except for large shrubs, such as privet and photinia. And species with a lower density will be used.

- On the facades, the species recommended for extensive roofs will be used and two options will be added:

  - Hackberry as a deciduous tree on horizontal structures under windows.
  - If there is a need to reduce water consumption, common ivy and chocolate vine will be used instead of the more water-intensive species such as ferns. These species require more maintenance, as they can be invasive to the rest of the plants in the garden; but they offer very fast growth with little need for water.

Designs for climate zone 8

This climatic zone is scattered between the interior of Catalonia, the province of Huesca, most of the territory of Castilla y León, and a good part of Castilla-La Mancha. It includes areas of medium and low rainfall, so this will be the first distinction to be made.

The first step is to identify the plant and tree species that combine good adaptation to low temperatures in winter with medium or low water requirements. Using these two criteria, the following species are identified:

Species suitable for climate zone 8 locations		
Trees and big bushes	**Plants**	**Climbing plants**
Olive tree	Sédum acre	Chocolate vine
Monterrey pine	Sédum álbum	Common ivy
Melia	Rosemary	
	Lavender	
	St. John's wort,	

Table : Species suitable for climate zone 8 locations. Source: own made

The species in this table that are underlined are those that, due to their water needs, are likely to be able to evolve correctly without irrigation, which is a very interesting aspect in order to create gardens with the lowest possible environmental impact and low maintenance requirements.

The first factor to be defined in order to establish the design of these gardens is the need to take advantage of rainwater. In the present case, since there will be few rainwater, which will be irregular in time due to the continental climate, it is decided to use systems with a large capacity for water storage, since rainwater will not be enough and there is an important need to reduce water consumption.

Having established these general criteria for all the designs to be used in these conditions, the next step is to identify variants depending on the conditions of the building that will house the gardens, and the budget available to the client.

According to building conditions there will be 3 possibilities:

1. Newly constructed building whose structure can be built to support heavy loads: 400 - 500 kg/m2.

2. Buildings of firm and/or modern construction with a capacity of 100 kg/m2 overload.

3. Old buildings or buildings in a poorer state of repair that should not exceed 50 kg/m2.

The first possibility will involve the installation of an intensive green roof and green façade, offering, in any case, certain recreational areas if they are accessible roofs. A high density of vegetation will be sought (30 small plants per m2), the use of medium-large trees to have a greater impact on air quality, and a large rainwater storage system will be included: the Zinco RS60, in order to reduce the need for irrigation as much as possible.

In the second case, a semi-intensive roof and green façade will be designed, offering, in any case, certain recreational areas if they are accessible roofs. A high to medium density of vegetation will be sought, and a medium rainwater storage system such as the Drainroof H6 will be included to reduce the need for irrigation to some extent.

In the third case, an extensive green roof and green façade will be provided, which will not be accessible, as it would pose a risk. In order to have the highest possible density of vegetation, water collection systems will only be include on really dry places, then it will be used the Garoé System from Singular Green, which includes the water storage system as an element of the design.

Design according to the client's investment capacity

The client's investment capacity will define three issues that can greatly improve the performance of the garden:

- Level of digitization of the garden, whose possibilities have been explained in the first point of this chapter.

- Installation of horizontal structures on the facade for the placement of deciduous trees that cover the windows in summer, but not in winter.

- Use of species with less or more need for irrigation.

Use of deciduous trees in front of windows. Given the continental climate of this area, the use of deciduous trees that do not reduce exposure to the sun in winter is very interesting for thermal and comfort reasons. These trees would be placed in horizontal structures located under the windows, since these are the areas of the wall with the greatest transmission of solar radiation. They entail a considerable cost due to the need for construction work, and are only viable in facades with medium or high load capacity, subject to a previous load study.

Choice of species according to irrigation needs:

- For intensive covers, in any case, monterey pine and olive trees will be used, as they are suitable species for the area, with high CO_2 uptake, and low water needs; therefore, they could develop correctly without the need for additional irrigation. In addition, if more water is available for the care of the garden, specimens of Aleppo pine, which offers a greater capacity for CO_2 capture, will be included. These trees will be complemented with the species indicated for the semi-intensive and extensive covers, which in this cover will be arranged in a very high density.

- In semi-intensive roofs, privet and cotoneaster will be used because of their great thickness (which improves insulation) and their low water requirements, and lavender because of its good smell, color and low water consumption. If more irrigation capacity is available, female ferns and photinia, which offer, respectively, very good CO_2 uptake and good insulation, will be used. On the other hand, if water consumption needs to be adjusted, rosemary and St.

John's wort, which improve the appearance of the garden and require less irrigation, will be chosen.

- In the extensive covers the same plants will be included as in the intensive ones except for large shrubs, such as privet and photinia. And species with a lower density will be used.

- On the facades, the species recommended for semi-intensive and extensive roofs will be used, according to the load-bearing capacity of the facade and two options will be added:

- Melia as a deciduous tree in the horizontal structures under the windows.
- If there is a need to reduce water consumption, common ivy and chocolate vine will be used instead of more water-intensive species such as ferns. These species require more maintenance, as they can be invasive to other plants in the garden; but they offer very fast growth with little need for water.

Designs for climate zone 9

This climatic zone is the most common in Spain, as it can be found in all the communities of the peninsula, as well as in the interior of Mallorca.

The first step in this design is to identify the species of plants and trees that combine a good adaptation to medium-low temperatures in winter, with low, medium or high water requirements, since there are areas with very different levels of rainfall on this zone. With these two criteria, the following species are identified:

Species suitable for climate zone 9 locations		
Trees and big bushes	**Plants**	**Climbing plants**
Aleppo pine	Sédum acre	Chocolate vine
Hackberry	Sédum álbum	Common ivy
Eucaliptus	Rosemary	Coral climber
Kiri	Aptenia	Ferns
Melia	St. John's wort,	
	Photinia	

Table : Species suitable for climate zone 9 locations. Source: own made

The first factor to be defined in order to establish the design of these gardens is the need to take advantage of rainwater. As it has been peviosly explained there will be different options according to the rainfall level.

Having established these general criteria for all the designs to be used in these conditions, the next step is to identify variants depending on the conditions of the building that will house the gardens, and the budget available to the client.

According to building conditions there will be 3 possibilities:

1. Newly constructed building whose structure can be built to support heavy loads: 400 - 500 kg/m2.
2. Buildings of firm and/or modern construction with a capacity of 100 kg/m2 overload.
3. Old buildings or buildings in a poorer state of repair that should not exceed 50 kg/m2.

The first possibility will involve the installation of an intensive green roof and green façade, offering, in any case, certain recreational areas if they are accessible roofs. A high density of vegetation will be sought (30 small plants per m2), the use of medium-large trees to have a greater impact on air quality, if there is not a high level of rain fall, a big rainwater storage system will be included: the RS60 Zinco, in order to reduce the need for irrigation as much as possible.

In the second case, a semi-intensive roof and façade will be designed, offering, in any case, certain recreational areas if they are accessible roofs. A high to medium density of vegetation will be sought, and, for those areas with low level of rainfall, a small rainwater storage system such as Drainroof H6 or H2.5 will be included to reduce the need for irrigation to some extent.

In the third case, an extensive green roof and green façade will be provided, which will not be accessible, as it would pose a risk. In order to have the highest possible density of vegetation, water collection systems will only be include on really dry places, then it will be used the Garoé System from Singular Green, which includes the water storage system as an element of the design.

The client's investment capacity will define two issues that can greatly improve the performance of the garden:

- Level of digitization of the garden, whose possibilities have been explained in the first point of this chapter.

- Use of species with less or more need for irrigation.

Choice of species according to irrigation needs:

- For intensive covers, Aleppo pine and kiri will be used because they are species suitable for the area, with high CO_2 uptake, and low water needs; therefore, they could develop correctly without the need for additional irrigation. Eucalyptus trees could also be included, because, despite the fact they need more irrigation, have a high CO_2 uptake and rapid growth. These trees will be complemented with the species indicated for semi-intensive and extensive canopies, which in this canopy will be arranged in a higher density.

- In the semi-intensive roofs, photinia and aptenia will be used because of their thickness, which offers very good insulation, and their low need for irrigation; and St. John's wort because of its decorative color and low water consumption. If additional irrigation is planned, ferns, which have a high CO_2 absorption, will be included.

- Extensive roofs will have the same vegetation as semi-intensive roofs, with the exception of photinia, which is too heavy, but with a lower density.

- On the facades, the species recommended for semi-intensive and extensive roofs will be used, depending on the load capacity of the facade. If there is a need to reduce water consumption, common ivy should be used instead of species with higher water consumption, such as ferns and coral climbers, which, although they require more water than ivy, are very colorful and also consume less water than most other plants. These species require more maintenance, as they can be invasive to other plants in the garden; but they offer very fast growth with little need for water.

<u>Designs for climate zone 10</u>

This climatic zone is mainly located on the Mediterranean coast and in the Atlantic area of Andalusia, with average or scarce rainfall.

The first step for this design is to identify the species of plants and trees that combine a good adaptation to medium temperatures in winter with medium-low water requirements. These two criteria are used to identify these species:

Species suitable for climate zone 10 locations		
Trees and big bushes	**Plants**	**Climbing plants**
Aleppo pine	Sédum acre	Coral climber
Carob	Sédum álbum	Sea foam
Cork oak	Yellow broom	Common ivy
Olive tree	Indian basil	
Adelfa	Sansevieria	
	Durillo	

Table : Species suitable for climate zone 10 locations. Source: own made

The species in this table that are underlined are those that, due to their water needs, are likely to be able to evolve correctly without irrigation, which is a very interesting aspect in order to create gardens with the lowest possible environmental impact and low maintenance needs.

The first factor to be defined in order to establish the design of these gardens is the need to take advantage of rainwater. In the present case, given the average rainfall, it was decided not to use systems with a large capacity for water storage, since this would imply an excessive weight that could be better used with a greater load of vegetation. Having established these general criteria for all the designs to be used in these conditions, the next step is to identify variants depending on the conditions of the building that will house the gardens, and the budget available to the client.

According to building conditions there will be 3 possibilities:

1. Newly constructed building whose structure can be built to support heavy loads: 400 - 500 kg/m2.

2. Buildings of firm and/or modern construction with a capacity of 100 kg/m2 overload.

3. Old buildings or buildings in a poorer state of repair that should not exceed 50 kg/m2.

The first possibility will involve the installation of an intensive green roof and green façade, offering, in any case, certain recreational areas if they are accessible roofs. A high density of vegetation will be sought (30 small plants per m2), the use of medium-large trees to have a greater impact on air quality, and a medium-sized rainwater storage system will be included: Drainroof H6, in order to considerably reduce the need for irrigation.

In the second case, a semi-intensive roof and green façade will be designed, offering, in any case, certain recreational areas if they are accessible roofs. A high to medium density of vegetation will be sought, and a small rainwater storage system such as Drainroof H 2.5 will be included to reduce the need for irrigation to some extent.

In the third case, an extensive green roof and green façade will be provided, which will not be accessible, as it would pose a risk. In order to have the highest possible density of vegetation, water collection systems will only be include on really dry places, then it will be used the Garoé System from Singular Green, which includes the water storage system as an element of the designDesign according to the client's investment capacity

The client's investment capacity will define two issues that can greatly improve the performance of the garden:

1. Level of digitization of the garden, the possibilities of which have been explained in the first point of this chapter.

2. Choice of species according to irrigation needs:

- For intensive coverings, Aleppo pine and cork oak or carob will be used because they are suitable species for the area, with high CO_2 uptake, and low water needs; so they could develop properly without the need for additional irrigation. These trees will be complemented with the species indicated for the semi-intensive and extensive covers, which in this cover will be arranged in a very high density.

- In semi-intensive roofs, yellow broom and durillo will be used because of their thickness, which offers very good insulation, and their low need for irrigation; and sansevieria, which has a very fast growth with little need for irrigation and/or maintenance. If more irrigation capacity is available, Indian basil, which offers a great aroma and a much lighter weight in relation to its CO_2 absorption, will also be available.

- In extensive covers, a first layer of sédum acre will be laid on top of which the same vegetation will be placed as in semi-intensive covers, except for the durillo, which has too much weight, but will be laid at a lower density. To reduce the weight, less yellow broom will be used, and more sansevieria and Indian basil, which are very light.

- On the facades, the species recommended for semi-intensive and extensive roofs will be used, depending on the load-bearing capacity of the facade. If there is a need to reduce water consumption, common ivy and sea foam will be used instead of species with higher water consumption, such as Indian basil. These species require more maintenance, as they can be invasive to the other plants in the garden; but they offer very fast growth with little need for water.

Designs for climate zone 11

This climatic zone is found mainly in the Canary Islands, as well as in some areas of Cadiz, Malaga and Granada. Areas with medium and low rainfall are distinguished, so that will be the first distinction.

The first step in this design is to identify the species of plants and trees that combine a good adaptation to medium temperatures in winter with medium-low water requirements. With these two criteria, the following species are identified:

Species suitable for climate zone 11 locations		
Trees and big bushes	**Plants**	**Climbing Plants**
Cork oak	Sédum álbum	Coral climber
Olive tree	Sédum acre	Sea foam
Adelfa	Yellow broom	Yellow trompet
Carob	Sansevieria	
Canary pine	Aptenia	
	Kalanchoe	

Table : Species suitable for climate zone 11 locations. Source: own made

The species in this table that are underlined are those that, due to their water needs, are likely to be able to evolve correctly without irrigation, which is a very interesting aspect with a view to creating gardens with the lowest possible environmental impact and low maintenance requirements.

The first factor to be defined in order to establish the design of these gardens is the need to take advantage of rainwater. In the present case, given the average rainfall, it was decided not to use systems with a large capacity for water storage, since this would imply an excessive weight that could be better used with a greater load of vegetation.

Having established these general criteria for all the designs to be used in these conditions, the next step is to identify variants depending on the conditions of the building that will house the gardens, and the budget available to the client.

Design according to building conditions

In this area three possibilities will be distinguished:

1. Newly constructed building whose structure can be built to support heavy loads: 400 - 500 kg/m2.

2. Buildings of firm and/or modern construction with a capacity of 100 kg/m2 overload.

3. Old buildings or buildings in a poorer state of repair that should not exceed 50 kg/m2.

The first possibility will involve the installation of an intensive green roof and green façade, offering, in any case, certain recreational areas if they are accessible roofs. A high density of vegetation will be sought (30 small plants per m2), the use of medium-large trees to have a greater impact on air quality, and a medium-sized rainwater storage system will be included: the Drainroof H6, in order to considerably reduce the need for irrigation.

In the second case, a semi-intensive roof and green façade will be designed, offering, in any case, certain recreational areas if they are accessible roofs. A high to medium density of vegetation will be sought, and a small rainwater storage system such as Drainroof H2'5 will be included to reduce to some extent the need for irrigation.

In the third case, a roof and an extensive green façade will be provided, which will not be accessible, as it would pose a risk. In order to have the highest possible density of vegetation, water collection systems will be dispensed with.

The client's investment capacity will define two issues that can greatly improve the performance of the garden:

1. Level of digitization of the garden, the possibilities of which have been explained in the first point of this chapter.

2. Choice of species according to irrigation needs:

- For intensive coverings, Canary Island pine and cork oak or carob trees will be used because they are suitable species for the area, with high CO_2 uptake, and low water needs; therefore, they could develop correctly without the need for additional irrigation. These trees will be complemented with the species indicated for the semi-intensive and extensive covers, which in this cover will be arranged in a very high density.

- In semi-intensive roofs, yellow broom and cotoneaster will be used because of their thickness, which offers very good insulation, and their low need for irrigation; and sansevieria, which has a very fast growth with little need for irrigation and/or maintenance. If more irrigation capacity is available, aptenia, which also has a high level of density and is very colorful, will also be available.

- In extensive covers, a first layer of sédum acre will be placed on top of which the same vegetation as in semi-intensive covers will be placed, with the exception of the durillo, which is too heavy, but will be placed at a lower density. To reduce the weight, less yellow broom will be used, and in its place will be planted sansevieria and Kalanchoe, which are lighter.

- On the facades, the species recommended for semi-intensive and extensive roofs will be used, depending on the load-bearing capacity of the facade. If there is a need to reduce water consumption, yellow trumpet, which needs little water and is very decorative with its bright yellow color, will be used.

Summary of proposed solutions, approximate costs.

In order to configure the business model sought through this work, it is essential to be able to offer the costs of the different proposed solutions, even if only in an approximate way.

In the field of digitization and automation systems, the prices of the different systems chosen have already been indicated, as can be seen in Table 1.

Regarding the roof models, the following costs can be offered:

- Vertical gardens, depending on vegetation:

    - Intensive gardens: 400 - 450 €/m2.
    - Semi-intensive gardens: 250 - 350 €/m2.
    - Extensive gardens: 150 - 250 €/m2.

- Rainwater harvesting systems: first of all, we must distinguish between water storage panels on roofs, and water collection systems to redirect it to a tank from which it can be used in the building.

- The piping has been found to be carried out by companies for a price of 2,500 - 3,000 € including the tank, but not the subsequent internal piping of the building. However, this work would only be considered in the case of new buildings, where it is already foreseen beforehand.
- For the water storage systems on the roofs themselves, it has not been possible to obtain an estimate from the companies that market them; however, the differentiation made in the project can be made according to the complexity of each system. There are modular systems, which can be installed by a single person, and others that require construction work.

- Gardening works: according to the budgets that have been obtained in cronoshare, the following approximate prices can be established, assuming that no tools are provided, the gardens are developed in an urban environment, and with freedom of schedules:

- Personal cost: 17 € / hour / gardener.
- Cost of standard plants: 20-30 € / m2.
- Cost of imported plants: 50 - 70 € / m2.
- Cost of medium trees: 120 - 200 € / unit.
- Cost of large trees: 250 - 400 € / unit.

- Horizontal structures on facades: in this element there are multiple factors that determine the price, such as the material of the facade (as it is not the same to work on brick as on stone or concrete); the need to use scaffolding versus the possibility of making the fixings by hanging from the roof; the resistance of the structures to be placed depending on the trees that are to be placed on them; etc.

- Scaffolding: for facades up to 250 m2, with a maximum height of 20 m, a company has been found that charges 3,015 €. Below is their ad on habitissimo.
- Steel structures with capacity to support trees: will vary depending on the size and weight to be supported, but for a standard size of 10 x 1 meter (width of window areas x depth) can be considered an approximate price of 2,000 €.

6. Conclusions

In this section we will make a final reflection on what has been learned through this work, as well as the possibilities for development in this area.

The following conclusions drawn from the work can be identified:

1. Urban gardens are a booming sector, with a growing presence in European capitals, and with clear prospects for development thanks to the benefits they generate and the various regulations that are being approved and that will promote them, even making them a requirement in new construction.

2. The reduction of CO_2 emissions and other polluting gases in cities is one of the great challenges of the coming decades, given the large volume of pollution produced by cities. And the use of vegetation is one of the most powerful tools to collaborate in this mission, due to its capture capacity, its low cost compared to other systems that require more work, and its help in reducing energy consumption.

3. On a social level, the development of this sector also offers a very good opportunity for the creation of green and quality employment, as it combines the need for digitalization, construction and refurbishment work, gardening and plant care, and transportation.

4. From an economic point of view, given the general increase in the price of electricity, the use of these structures is already, and will be even more, a very profitable investment in the medium and long term. It will mean for the buildings that use them, a significant reduction in energy tariffs.

5. Their future development will essentially involve the following challenges:

   - An increase in digitization to achieve gardens as automated as possible, thus reducing the need for maintenance work.

   - An in-depth study of the different species to create databases to identify the most suitable trees and plants according to climate, water needs, decontamination objectives, isolation, etc.

   - The development of complementary systems such as rainwater collection and use, self-consumption of energy by means of panels on facades or blinds, etc.

Appendix A: Alignment with the SDG

This Master's Thesis was developed from the MESEM internship at Suez, in the Directorate of Urban Sustainable Development, and as such has, in its very essence, a clear alignment with SDG 11: Sustainable Cities and Communities. In addition, the project's main objectives include reducing the carbon footprint, improving energy efficiency, rainwater harvesting and biodiversity conservation, all of which are closely related to the following SDGs:

- SDG number 9: Industry, Innovation and Infrastructure.
- SDG 12: Responsible production and consumption.
- SDG 13: Climate action.

<u>SDG 11: Sustainable Cities and Communities.</u>

Firstly, there are several noteworthy data obtained from the United Nations' own website:

- The world's cities occupy only 3% of the world's land area, but account for 60% to 80% of energy consumption and 75% of global carbon emissions.

- Rapid urbanization is putting pressure on freshwater supplies, wastewater, the living environment and public health.

- As of 2016, 90% of urban dwellers breathed air that did not meet safety standards set by the World Health Organization, resulting in a total of 4.2 million deaths due to air pollution. More than half of the world's urban population was exposed to air pollution levels at least 2.5 times higher than the safety standard.

The same United Nations analysis of this SDG includes a series of targets to be pursued in order to meet the goal:

- By 2030, reduce the per capita negative environmental impact of cities, including by paying particular attention to air quality and municipal and other waste management.

- Support positive economic, social and environmental linkages between urban, peri-urban and rural areas by strengthening national and regional development planning.

- By 2020, significantly increase the number of cities and human settlements that adopt and implement integrated policies and plans to promote inclusiveness, resource efficiency, climate change mitigation and adaptation, and disaster resilience, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, comprehensive disaster risk management at all levels.

These targets align perfectly with the project's objectives, as further development of urban gardens will achieve this reduction in the environmental footprint of cities; develop a new sector offering green and digital jobs; and reduce the effects of climate change.

<u>SDG 9: Industry, Innovation and Infrastructure</u>

The alignment with this SDG comes from how this TFM seeks to develop a new line of business that entails the design, manufacture and installation of new products and solutions. First, several noteworthy data obtained from the UN's own website are shown:

- The job multiplication effect of industrialization has a positive impact on society. Every job in industry creates 2.2 jobs in other sectors.

- Small and medium-sized enterprises engaged in industrial processing and manufacturing production are the most critical in the early stages of industrialization and are generally the largest creators of jobs. They constitute more than 90% of enterprises worldwide and account for 50-60% of employment.

The same United Nations analysis of SDG 9 includes a series of targets that must be pursued to meet the goal and with which this project is clearly aligned:

- Develop reliable, sustainable, resilient and quality infrastructure to support economic development and human well-being.

- By 2030, modernize infrastructure and retrofit industries to be sustainable, using resources more efficiently and promoting the adoption of clean and environmentally sound technologies and industrial processes, and getting all countries to take action in accordance with their respective capabilities.

Throw this project it is possible to contribute to the achievement of these goals, as green building will lead to more sustainable infrastructures and buildings.

<u>SDG 12: Responsible production and consumption</u>

The economic and social progress achieved over the last century has been accompanied by environmental degradation that is endangering the very systems on which our future development (and indeed, our survival) depends. Sustainable consumption and production is about doing more and better with less. It is also about decoupling economic growth from environmental degradation, increasing resource efficiency and promoting sustainable lifestyles. Below is a series of data related to this SDG obtained from the United Nations' own website:

- If the world's population were to reach 9.6 billion in 2050, the equivalent of almost three planets would be needed to provide the natural resources needed to maintain today's lifestyles.

- Excessive water use contributes to global water scarcity.
- Despite technological advances that have promoted increased energy efficiency, energy use in Organization for Economic Co-operation and Development (OECD) countries will continue to grow by another 35% by 2020. Household and commercial energy consumption is the second fastest growing area of energy use, after transportation.

- Households consume 29% of the world's energy and, consequently, contribute 21% of the resulting CO_2 emissions.

The same United Nations analysis of SDG 12 includes a series of targets that must be pursued to meet the goal set and with which this project is clearly aligned:

- By 2030, achieve sustainable management and efficient use of natural resources.

- Develop and implement tools to monitor the impact on sustainable development, in order to achieve sustainable tourism that creates jobs and promotes local culture and products.

The alignment of the project with this SDG comes from two of its fundamental objectives, which are: to reduce the energy consumption of buildings, which will lead to lower emissions; and to create carbon sinks to capture CO_2 and other harmful gases to reduce net emissions. The development of these structures will be associated with the creation of jobs for both their installation and maintenance and will make it possible to recover spaces that could be attractive for attracting tourism.

<u>SDG 13: Climate action</u>

2019 was the second warmest year ever and marked the end of the warmest decade (2010-2019) on record. Levels of carbon dioxide (CO_2) and other greenhouse gases in the atmosphere increased to record levels in 2019. Climate change is affecting every country on every continent. It is disrupting national economies and affecting different lives. Below is a series of data referring to this SDG obtained from the UN's own website.

- The oceans have warmed, the amount of snow and ice has decreased, and sea levels have risen. Between 1901 and 2010, the average sea level rose by 19 cm as the oceans expanded due to warming and melting ice. Arctic sea ice extent has shrunk in recent decades since 1979, with an ice loss of 1.07 million km2 each decade.

- Given the current concentration and continued emissions of greenhouse gases, the global temperature increase by the end of the century is likely to exceed 1.5 degrees Celsius compared to the period from 1850 to 1900 in all but one scenario. The world's oceans will continue to warm and ice melt will continue. Average sea level rise is projected to be between 24 and 30 cm by 2065 and between 40 and 63 cm by 2100. Most climate change issues will persist for many centuries, even if emissions are curbed.

- Global carbon dioxide (CO_2) emissions have increased by almost 50% since 1990.

- Between 2000 and 2010 there was a greater increase in emissions than in the previous three decades.

- If a wide range of technological measures and behavioral changes are adopted, it is still possible to limit the increase in global average temperature to 2 degrees Celsius above pre-industrial levels.

The same United Nations analysis of SDG 13 includes a series of targets that must be pursued to meet the goal and with which this project is clearly aligned:

- Strengthen resilience and adaptive capacity to climate-related risks and natural disasters in all countries.

- A binding target for the EU in 2030 of at least 55% less greenhouse gas emissions compared to 1990.

This project is framed within the SDG for climate action because of two of its fundamental objectives, which are: to reduce the energy consumption of buildings, which will lead to lower emissions; and to create carbon sinks to capture CO_2 and other harmful gases in order to reduce net emissions. This reduction in consumption and emissions will make cities more adapted and resilient to climate change.

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