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In the Search for Sustainable Vertical Green Systems: An Innovative Low-Cost Indirect Green Façade Structure Using Portuguese Native Ivies and Cork

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Abstract: Green façades in the urban environment represent points of biodiversity value, contributing to species conservation, acting as urban wildlife corridors connecting elements, and also aiming at sustainability, when the materials and structure are thoughtfully chosen. Ivies (*Hedera* spp.) are perennial climbing evergreen plants that are easy to cultivate and demand little input, and their use in vertical green systems is much appreciated but may lead to damage to the constructions in the long term. Among the 14 species of *Hedera* currently recognized, a few have been bred into cultivars and are available in the market for cultivation, often as exotic species. Four *Hedera* spp. are native to Portugal, but most cultivated species in this territory are exotic and the suitability of native species for their use in green façades has not been documented. Thus, in the present work, we describe the installation of a low-cost indirect green façade structure supported on cork panels using plants belonging to the native *H. iberica* and *H. hibernica*. The structure is installed at the Ajuda Botanical Garden, under Mediterranean conditions, on a brick and cement wall, and will enable researchers and landscape architects to follow the development of this structure as a long-term experiment, prompting the use of native species toward increased biological and technical sustainability. The preliminary results indicate that the cork structure is able to provide adequate support for the plants and that these were able to climb and develop in this structure, avoiding direct contact with the wall and the possible subsequent damage. Therefore, the structure provides a viable solution to implementing sustainable green façades with native species, on brick-cement walls, able to be replicated in other urban locations under similar environmental conditions.

Keywords: indirect green façade; insulated cork panels; ivy; *Hedera iberica*; *Hedera hibernica*; Ajuda Botanical Garden

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1. Introduction

The use of climbing plants for covering building walls has a favorable effect on thermal stability [1], contributing to energy saving and facing climate change. Also, such soil and plant ecosystems harbor microorganisms, insects, and birds, among others, thus contributing to biodiversity and ecological balance in urban environments. However, such living structures also raise concerns, namely the long-term damage to buildings, increased humidity, the release of allergens, and the presence of undesired insects or reptiles [2].

Ivies (*Hedera* spp.) are appreciated for their dark green and brilliant perennial foliage, ease of conduction as a climber or for ground cover, capacity to hold to structures on their own, pleasant but delicate scent, lack of thorns or hard branches, and delicate bloom. Ivies are easy to cultivate and present relatively adequate growth. They thrive in various soil types and diverse temperate latitudes, have few sanitary problems, and are quite tolerant to drought, a valuable plant feature under Mediterranean conditions [3,4]. Ivies are native to Asia and Europe and have been cultivated since Classical Antiquity as ornamental plants, but only a few species were developed into cultivars. Such cultivars are available in the market for cultivation, in some circumstances replacing native species, raising an additional sustainability issue. When possible, the cultivation of native species is in principle preferred over that of similar exotic species, a situation that is particularly evident in the case of ivies, as the morphological differences among species are small and of little ornamental relevance. Such use, however, must be sustained by examples that allow landscape architects to evaluate the behavior of native species in vertical green systems.

Ivies have been used in the façades of buildings for centuries, and sometimes these are named traditional green façades [5,6]. Those façades consist of just a vegetation cover adherent to the façade, with the plant roots located in the ground and the plants climbing along the walls. More contemporary green façades commonly use supporting elements such as cables, meshes, nets, or a climbing trellis [7], attached to the building façade providing support for the development of plants, not directly on the surface of the building, made of time- and load-resistant materials [8]. These materials are very often metal, such as galvanized steel wires (e.g., [9]) or aluminum trellises [10]. These common support materials have, however, some inconvenience regarding sustainability, as metals are a non-renewable resource, and their production is responsible for carbon emissions. Green façades are an example of vertical green systems, which can be defined as construction solutions using vegetation to cover the vertical surfaces of buildings. They comprise two different groups, green façades and living wall systems, with the last designated by wall-attached or self-sustained systems, when the plant medium is attached to the wall or not, respectively [11]. In comparison to living walls, green façades have, however, the advantage of lower construction costs, as they require a simpler structure and fewer materials. Vertical green systems can be part of the urban green infrastructure, providing solutions for the lack of horizontal space, linking other green structures, facilitating the cooling and the wind movement [12], and participating in the establishment of wildlife corridors. They also interact with the surrounding environment, increasing the outdoor and indoor comfort, ecological value, biodiversity, and improvement in the air quality [13,14].

Although both green façades and living walls can present several advantages for the environment, green façades require simpler structures, with less materials and lower maintenance in relation to living walls. Still, indirect green façades often use materials such as metals than can possibly be replaced with other, more sustainable ones.

In this article, we describe the installation of a low-cost indirect green façade structure supported on cork panels using plants belonging to *H. iberica* and *H. hibernica*, the two native *Hedera* species from mainland Portugal. This demonstration structure is installed at the Ajuda Botanical Garden (in Lisbon, Portugal), the first Portuguese botanical garden, created in 1768 for botanical and horticultural experimentation and teaching, belonging to the Instituto Superior de Agronomia of the University of Lisbon since 1910. The main objective of the present study is to contribute to improving the sustainability of indirect green façades, regarding the present state of the art, testing a new sustainable supporting material and using native plants.

2. Indirect Green Façades

Vertical vegetated structures along wall surfaces are generally designated as green walls. In turn, green walls can either take the form of living walls, where several materials and technologies are used as an input to the system, or green façades, where plants grow along the wall covering it. Green façades are characterized by the use of climbing vegetation, and between those two main systems, the following can be pointed out: one has the plants directly attached to the building wall (direct green façade) and the other has a supporting structure between the vegetation and the building (indirect green façade) [7,15].

Indirect green façades are commonly built using structural support for vegetation, allowing plants to spread both vertically and horizontally, and the structure usually consists of continuous or modular guides, such as tensile cables, stainless steel, grids, etc. [16]. Even if indirect green façades are considered a nature-based solution [17] and although metals are recyclable, they are a non-renewable resource and responsible for carbon emissions during their production process, as referred to in Section 1. For example, steelmaking currently contributes around 7% of the world's total carbon emissions, this industry being the biggest industrial greenhouse gas emitter globally [18]. Because the most used materials for the indirect green façades structure are metals, these façades can still be enhanced from the point of view of sustainability, if organic, degradable materials replace the metals. For example, the guides can be made of bamboo, which is recognized as a good construction material [19,20]. However, although a solution for indirect green façades using bamboo as guides has been studied [21], there are still no constructed façades referred to in the literature with this material as the support. Another sustainable approach for the construction of such structures would be the use of cork as the support for plant development. Cork is a natural, organic material obtained from the suber layer of *Quercus suber* L. trees. This is an impermeable and buoyant material, also known for its fire-retardant properties, which make it interesting for use in construction. It is also capable of high water retention, up to 20 kg $m^{\mp 3}$, and the quick drainage of excess water [22] which is particularly interesting for climates with Mediterranean conditions, with hot, dry summers and rain concentrated in other periods. Cork is also a recyclable and renewable material, being produced in savannah-type ecosystems of evergreen oak woodlands [23], which were shaped over the centuries by human action and are therefore capable of contributing to the process's sustainability.

No studies exist to our knowledge that use cork as a vegetation support to build indirect green façades. However, a new modular living wall system made of insulation cork boards was presented by [24] with a particular concern for the thermal insulation and water retention properties of this material, also providing an eco-friendly alternative to plastic and metal. Even so, as found by [25], living walls may not be as sustainable as green façades due to the support systems used, because green façades require less supporting material. Living walls also require higher installation and maintenance costs than indirect green façades, making the latter more cost-effective [15]. This was also found by [26] in a study developed for Mediterranean conditions in the north of Italy, where it was concluded that the living wall system analyzed could not be considered economically sustainable due to high installation and maintenance costs, when compared to direct or indirect green façades.

Green façades present, however, some disadvantages in what concerns the limitations for plant selection. Sometimes cork is also used as building insulating material [27] but not frequently, having in mind the dual function of insulation and support. So far, cork has been used for a new solution in the construction of modular green walls [28] but not for indirect green façades. To propose a simple and sustainable solution for the development of a low-cost green wall, the present study, therefore, addresses the development of an innovative indirect green façade, using cork as supporting material.

3. Ivies

The genus *Hedera* is a member of the Araliaceae, a botanical family with plants mostly occurring in Tropical Asia [29]. *Hedera* naturally occurs in temperate regions, distributed from Japan westward through Asia, North Africa, and Europe up to the Macaronesian archipelagos of the Canary Islands, Madeira, and the Azores. Among the 14 species of *Hedera* currently recognized [30,31], a few occur in Asia (Japan, the Himalayas, and the Caucasus), but the breadth of diversity increases westward, as eight species are found in the western Mediterranean/Macaronesia area (Table 1). Ivies also occur, as cultivated and often becoming naturalized and assuming invasive behavior, in temperate regions of other continents [32,33].

Table 1. Species of ivies (*Hedera* spp.) that are currently recognized, with reference to their native distribution and usage as ornamentals.

Species	Geographical Distribution	Ornamental Use
H. algeriensis	Coastal Algeria and Tunisia	A few cultivars available (e.g., 'Gloire de Marengo')
H. azorica	Azores Islands	No cultivars registered
H. canariensis	Canary Islands	Available in the market as *H. canariensis*
H. colchica	Caucasus and northern Turkey	A few cultivars are available (e.g., 'Sulphur Heart')
H. crebrescens	Europe (Netherlands to Hungary)	No cultivars registered
H. cypria	Cyprus	No cultivars registered
H. helix	Most of Europe	Many cultivars available
H. hibernica	Atlantic coast of Europe	Several cultivars available
H. iberica	SW Iberia	No cultivars registered
H. maderensis	Madeira Island	No cultivars registered
H. maroccana	Morocco	A few cultivars available (e.g., 'Morocco')
H. nepalensis	Nepal and the Himalayas (to Afghanistan and Thailand)	No cultivars registered
H. pastuchovii	Caucasus and Iran	A few cultivars available (e.g., 'Ann Ala')
H. rhombea	China (Taiwan), Korea, and Japan	No cultivars registered

Ivies are appreciated as ornamentals since the Greek and Roman antiquity (Pliny the Elder; [34]), and this also became reflected in the Arab civilization [35]. The selection of attractive forms (namely variegated plants) has long been carried out. In most of Europe, selected material and naturally occurring plants have been used for cultivation in urban gardens but also in farms and elsewhere in the countryside, leading to the propagation of such plants into nature, which may have led to the naturalization of species exotic to a given location. *Hedera helix* was, for a long period, the single ivy species recognized and is the main native species across most of Europe. It is also the species for which there are more cultivars registered, according to both the Royal Horticultural Society (UK; https://www.rhs.org.uk/, accessed on 17 November 2022) and the American Ivy Society (USA; http://www.ivy.org/, accessed on 17 November 2022). Several cultivars are available from *H. hibernica* and less so from *H. colchica*, *H. algeriensis*, *H. maroccana*, and *H. pastuchovii*. Still, plants occurring in nature are amenable to propagation and are used by people. For instance, ivy plants cultivated in urban parks and gardens in the Azores islands belong to *H. azorica*, even if there are no cultivars available from this species. Ivies may thus occur both in cultivation and naturally, and in either case, they may represent native species collected locally or cultivars purchased in the market. The distinction between species of *Hedera* is not easy as many morphological traits overlap, the trichome type and the ploidy level being the most unequivocal characters for species differentiation [31].

Whereas *H. helix* is the most common species in most of Europe, the westernmost region of Europe (Lisbon/Sintra area, in Portugal) is the meeting point of the two western European species, *H. hibernica* and *H. iberica*. *Hedera hibernica* occurs on the Atlantic coast of Europe, from Scotland to Sintra, whereas *H. iberica* occurs in SW Iberia, from Sintra to Algeciras (Spain) [31,36]. It has been noted that ecotypes of *H. hibernica* occurring in the most SW area of its distribution differ in trichome morphology from those occurring elsewhere [37]. The ivies in parks and gardens in the Lisbon area are thus from native *H. iberica* and local ecotypes of *H. hibernica* but also from cultivars of exotic species, mostly *H. helix*, *H. algeriensis*, *H. hibernica*, and *H. canariensis*.

4. The Ajuda Botanical Garden

The first botanical garden of Portugal, Ajuda Botanical Garden (https://www.isa.ulisboa.pt/en/visitors/ajuda-botanical-garden), was created in 1768 by King D. José (1714–1777). To build the garden, the Museum of Natural History, the Cabinet of Physics, and the drawing house king's minister Sebastião José de Carvalho e Melo (1699–1782) invited the Italian Domingos Vandelli (1735–1816) and he had installed more than 5000 species. From 1811 to 1828, under the direction of Portuguese Félix Avelar Brotero (1744–1828), the botanical collection was registered with a catalog of 1370 plant species. Since 1910, the administration of this garden was trusted to Instituto Superior de Agronomia from Universidade de Lisboa. Presently, the garden still maintains the original layout, divided into terraces, an area of 3,8 ha, and it is self-sufficient in water.

Over its more than 250 years of existence, the Ajuda Botanical Garden has been strengthening the aspects of education and culture, and the research strand continues to be a priority in this garden's activities, namely in research projects, doctoral theses, and master's dissertations in various thematic areas, such as botany, horticulture, and landscape architecture applied to botanical and historical gardens. Figure 1 presents a map of the Botanical Garden with the location of the indirect green façade constructed in the frame of this study.

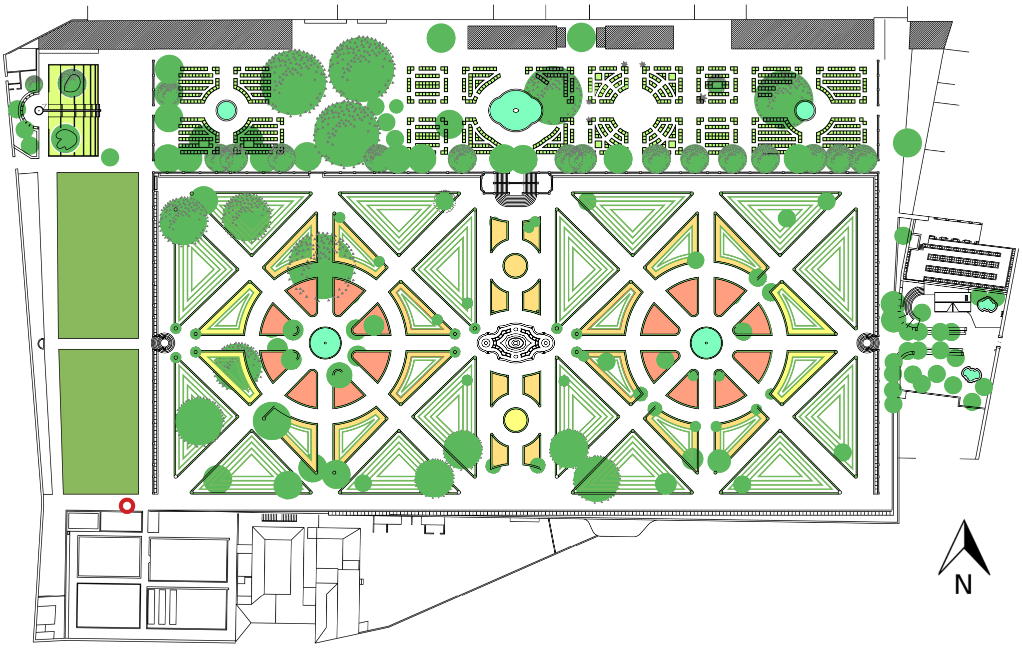

Figure 1. Map of Ajuda Botanical Garden (Lisbon, Portugal) with the location of the wall with the indirect green façade constructed in the frame of this study (red circle).

The Ajuda Botanical Garden is located on the western side of Lisbon. Lisbon climate is classified as Csa (temperate, hot dry-summer climates), under the Köppen–Geiger climate classification. The average annual rainfall is 766 mm, the average annual medium temperature is close to 17 °C, with an average minimum of 8 °C in the coldest month (January) and an average maximum of 28 °C in the hottest month (August). The average annual number of days with precipitation events, larger than 1 mm, is close to 75 [38]. The soil is a Vertisol from basaltic and calcareous origin, with a pH close to 7.

5. The Indirect Green Façade Structure of Ivies at JBA

Species adapted to local soil and climate conditions will likely perform better than exotics [3], but the suitability of native Portuguese species for their use in green façades has not yet been documented. For such purpose, an experiment has been set using a low-cost indirect green façade structure supported on cork panels to evaluate the suitability of three ivy native specimens for use in green façades. The experiment was installed at the Ajuda Botanical Garden. The three ivy specimens represent a local ecotype of *H. iberica* (naturally occurring in the Monsanto Hills where the Ajuda Botanical Garden was installed in the XVIIIth century), a local ecotype of *H. hibernica* (collected in Sintra), and a continental ecotype of *H. hibernica* (collected at Alijó, NE of Portugal).

The green façades were built using expanded cork agglomerate boards (MDFachada, Amorim Cork Insulation S.A, Portugal) with the dimensions 1000 × 500 × 40 mm and the following technical characteristics: density, 140 +/−10 kg m^{-3}; thermal conductivity, 0.043 W m^{-1} K^{-1}; fire reaction, Euroclass E; and short-term partial immersion water absorption, 0.18 kg m^{-2}. Another relevant characteristic of this material is the traction resistance perpendicular to the faces (kPa) 67.81 kPa, and information from the manufacturer company regarding the resistance in time indicates the absence of alterations for at least 23 years. Cork board characteristics can be found at [39].

These boards are commercially intended for external coating of buildings, given their acoustic and insulation properties. This material receives a vapor treatment at a high temperature (370 °C) and pressure (40 kPa), which promotes its compaction, providing the necessary density and resistance to exterior conditions. The boards were disposed of in September 2021, in a 2.5 m high outer wall made of bricks and cement, of the Ajuda Botanical Garden (Lisbon, Portugal), using sets of four (forming a panel with the dimensions 2 × 1 m), replicated nine times (Figure 2). The wall side with the boards faces north and extends linearly both westward and eastward (Figure 1). To the north of the wall there is a ca. 2 m width pass, and then there is an arboretum, composed of diverse tree and shrub species representing the native flora of the Lisbon area. This presence of a near vegetated area might produce a mild effect in the local microclimate. To the south of the wall there is a water tank and a vegetable bed.

Figure 2. Expanded cork boards used to build the indirect green façade, disposed of in an outer wall of Ajuda Botanical Garden ((**left panel**), the whole set; (**right panel**), detail of the cork boards).

The cork boards were fixed on the wall using an elastic fixing putty, with an immediate initial setting and high strength (GOFIX MS 280 XFAST, Sintra, Portugal) formulated for elastic bonding. This fixing putty has a thermal resistance ranging from −40 °C to +100 °C, resistance to UV radiation and humidity, and a resistance to traction of approximately 22 kg cm^{-2}. The upper ends of the boards were topped with the same putty to prevent the entry of water between the wall and the boards.

Before fixing the cork boards, the wall was treated with a one-component primer, based on a polyisocyanate solution in a solvent medium (GOFIX Primer 99, Sintra, Portugal), acting as a binder, to reinforce the adhesion of the elastic fixing putty on the porous cement surface of the wall, giving it greater cohesion. The primer also provides a slight waterproofing of the surface. Ivies were planted on December 2021 according to the plantation scheme described in Figure 3, with a plantation distance of 1 m and with bare roots.

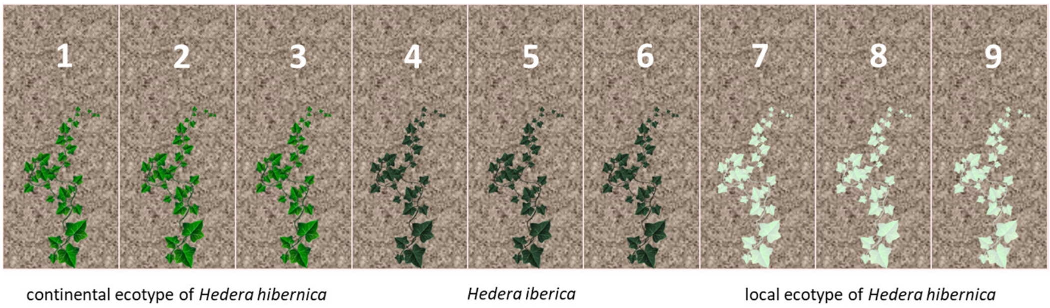

Figure 3. Ivy plantation scheme in the expanded cork boards used to build the indirect green façade at Ajuda Botanical Garden, Lisbon, Portugal.

6. Preliminary Results

Ivies are slow-growing plants and only had a growth period of approximately one year since their plantation was available for analysis. Thus, the results concerning the development of ivies are preliminary, as only a small growth occurred in that period. Nevertheless, some observations of plant behavior were performed and are hereafter referred to.

After the plantation, in December 2021, the plants showed no sign of a transplantation crisis. By February 2022, most of the plants had reached the level of the lower side of the cork panels (20 cm above the ground on average) and became adherent to them, although their development height was only ca. 25 cm above the ground (Figure 4). Some months later, by July, the plants' development showed the same tendency, with little increments in height (for most of them it was inferior to 10 cm). From July to December 2022, a higher growth was observed, with the taller plant (plant number 5, a specimen of *H. iberica*, Figures 3 and 5) showing a growth increment of 111 cm in that period (155 cm total height), while it was only 17 cm for the same plant in the previous period (February to July 2022).

Figure 4. Ivy plants adhering to cork boards of the indirect green façade at Ajuda Botanical Garden, Lisbon, Portugal (February 2022).

Figure 5. Plant number 5 (*H. iberica*) of the indirect green façade in February 2022 (**left panel**), July 2022 (**center panel**), and December 2022 (**right panel**).

An interesting observation was that all the plants searched for the cork panels, growing in the direction of these, not spreading on the ground in other directions. The climbing preferential behavior of ivies has been well known for a long time, as described by [40] in 1872 and more recently studied by several authors (e.g., [41,42]), which connects this behavior to the need of the plants to leave the ground as a survival strategy. On the ground, the juvenile form of ivies faces strong competition from other plant species, which compels the climbing, and also differentiating juvenile (prostrate) and adult (climbing) phases as a response to the relative levels of gibberellins in apices [41,43,44]. Concerning this evident behavior for all the plants, there was only an exception for plant number 8, which reached the cork boards' inferior side but, by December 2022, was not yet climbing them.

So far, the cork boards seem an adequate medium for ivies to climb, given the numerous fissures and holes on the boards' surface that can be used by the plant to hold on to it. Because cork shows an intermediate hydrophobic/hydrophilic behavior, and that, at the molecular level, it can be considered a hydrophilic material [45], it also has some capacity to hold water, available to the adventitious roots of ivies. This can be regarded as an advantage in the use of this material in green façades. Given the specific characteristics of the expanded cork material used regarding water absorption (0.18 kg m^{-2}, vd. Section 5) it is estimated that each panel (comprised of 4 cork boards), which is the available area for each ivy plant to explore, would be capable of retaining 0.36 mm of water, admitting that rainfall would have the same effect as a quick immersion. Because ivy irrigation requirements can be considered low to moderate [46], and as low as 20% of the reference evapotranspiration (ET_o, evapotranspiration of a well-watered grass surface, with a fixed crop height, surface resistance, and albedo [47]), as quantified by [48], it is estimated that 0.36 mm can have a contribution of up to 40% of the daily irrigation requirements (the day after raining), for example, for spring periods, with non-daily rainfall. This is an interesting result from the point of view of reducing irrigation amounts, saving water and energy.

Regarding the future stability of the structure, it can be observed that (1) the fixing putty, used to fix the cork boards to the wall, has a resistance to traction of approximately 22 kg cm^{-2}; (2) the water holding capacity of the cork is around 0.18 kg m^{-2}; and (3) the weight of the cork boards is ca. 5.6 kg m^{-2}. Therefore, the total weight of the structure under wet conditions (cork + water) would be around 5.8 kg m^{-2}. This is still under and very far from the maximum traction supported by the fixing putty (220000 kg m^{-2}) and it can be concluded that the fixing system can bear the weight of the cork boards, even if wet. Furthermore, the boards can support a maximum traction of ca. 6939 kg m^{-2}, derived from the traction resistance perpendicular to the faces (67.81 kPa), and the weight of the plants is likely to be way under this last value. Therefore, it can be concluded that the boards can bear the weight of the plants.

The results of this study allow for replicating this methodology to other plant species under study at the Ajuda Botanical Garden. As well, they allow the dissemination of the use of ivies in practical applications of landscape architecture projects, where the success of the growth of ivies and also the requirement of little water for irrigation and minimal maintenance are adequate.

7. Final Remarks

The three species of ivies used in the indirect green façade adapted well after transplantation and showed a small growth during a period of approximately one year, compatible with the common development process of ivies. So far, there were no significant differences among the species, concerning their development.

The plants were able to reach the cork boards and initiated the climbing process. Cork has particular characteristics that make it an adequate support material for vegetation such as being (i) impermeable and thermally insulating; (ii) capable of retaining an interesting quantity of water, decreasing irrigation requirements because ivies have an aerial root system; (iii) fire resistant; (iv) adequate for the climbing of the plants; (v) natural, organic material; and (vi) recyclable and renewable. Thus, given that the cork boards were an adequate medium for the climbing of ivies, expanded cork can be considered an interesting material to include in the construction of indirect green façades, having in mind the previously referred to properties. Given the mechanical properties of the cork boards and the fixing putty, it could be concluded that the structure can bear the weight of the plants, even under wet conditions.

Further work will be needed following the plants' development in the next years, to evaluate the adequacy of both plant species and support materials, to provide a commercially viable indirect green façade, with a low-cost sustainable system.

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