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Article

Use of Drought-Resistant Vegetation on Green Roofs: A Method for Digital Photographic Monitoring of Its Development

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Abstract: The increased number of buildings in urban areas limits the creation of vegetated areas, leading to the search for alternatives to create spaces to promote contact with nature. In this context, green roofs have been increasingly studied. These structures have specific microclimatic conditions requiring an accurate study of the most appropriate vegetation to use. This study aims to analyze the long-term viability of vegetation installed on an experimental green roof open-air lab. This analysis was done through images obtained from photographic records and later inserted into the ImageJ program, to identify species and evaluate the area covered by vegetation. Only a few of the species that were planted in the test beds over the years have persisted to the present, while other species have spontaneously appeared. Also, surveys were used to learn about people's preferences for the vegetation on these test beds. These showed that people favor recognizable plants with plenty of vibrantly colored blossoms. It was feasible to choose the best plants for green roofs in the studied conditions as a result of the analysis, taking into account the ground cover percentage by vegetation, its persistence, and the preferences of the respondents.

Keywords: native plants; digital image analysis; Population preferences; ImageJ

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1. Introduction

Vegetation, namely trees, plays an essential role in urban ecosystems, assuming, also, a cultural role [1]. Just as all science and technology have evolved, so has Nature's appreciation and the knowledge of it [2,3]. Since ancient times, several predecessors of green roofs, such as the Ziggurats of Ur and the Hanging Gardens of Babylon, or even the Sod Roofs created by the Vikings of Norway, were identified [4]. Therefore, according to the principles of ecological continuity, green roofs have become a new area of activity that is increasingly desired by the population [5,6,7].

In the late 1980s the need to pursue a development that does not compromise future generations arose, leading to the adoption of the concept of "sustainable development" [5,8]. Through the use of this concept, similar to the concept of conservation [9]humanity's cooperation with Nature allows to use it while maintaining its balance. Since then, in Europe, there has also been a great increase in the number of green roofs, since they are seen as a solution to many of the problems in cities, namely the lack of space for the creation of new gardens and parks, as well as the reduction of rainwater runoff, preventing the degradation of water and air quality and mitigate the heat island effect [7,10] As such, a growing number of studies and projects related to this type of structure are emerging, namely regarding their plant and substrate composition, and their benefits to the environment and for private owners [11], including economic aspects. Thus, projects such as GENESIS are emerging, which aim to analyze the cost-benefit of having a green roof [12].

Although there is a lot of information about the various structures designated as green roofs, there is less literature about the vegetation to select under Mediterranean conditions. Some studies are, however, available, as, for example [13,14,15], addressing the interaction between plants and i)

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the sub-surface runoff, ii) substrate type and irrigation frequency, and rainfed conditions, respectively.

Frequently, there is a suggestion to use native plants since they have greater adaptability to the local climate and are more resistant than exotic plants to the harsh conditions on rooftops. Rooftop microclimates often present strong and constant winds, high exposure to solar radiation, high temperatures, and high levels of humidity and precipitation during part of the year [16,17,18]. Native plants generally have a lower water consumption than exotic plants and need less maintenance, which presents some advantages when compared to the latter. Also, they attract and promote fauna, including birds and their preys[19,20].

The objective of this study was to analyze the development of the vegetation installed over the years (planted, sowed, or spontaneous), in *the green roof lab* (http://www.facebook.com/thegreenrooflab/). This rooftop open-air laboratory (School of Agriculture, University of Lisbon, Portugal) has several test beds that simulate different green roofs under Mediterranean conditions, allowing to study the adaptation of native vegetation. The persistence and development of plants installed since 2014, in the frame of several projects (NativeScapeGR - Native Scape Green Roof, ApiWall - Another Plant in the Wall, and ApiMat - Another Plant in the Mat [18,21,22,23,24]) were studied, as well as colonization by spontaneous herbaceous species, native or non-invasive exotics.

Photographic records allowed measuring the percentage of vegetation covering each test bed, and identifying the plant species responsible for it. Species identification was also done to understand which species persisted from the plantings/sowings made over time in *the green roof lab* projects and which ones emerged spontaneously.

Finally, to obtain a set of species that are the most suitable for installation in green roofs, population surveys were used to determine which plants are preferred, from the ones that were maintained from the initial set, comprised of the ones with the ability to persist after planting/sowing or to install spontaneously.

2. Materials and Methods

2.1. Experimental site

The experimental site, *the green roof lab,* is located on the rooftop of "João de Carvalho e Vasconcellos" Herbarium building, School of Agriculture, University of Lisbon, Portugal (38°42′28.8″N 9°11′04.4″W, Figure 1).

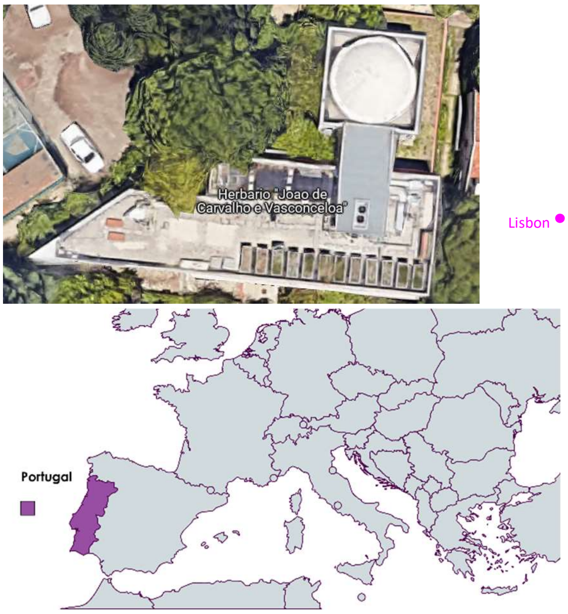

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Figure 1. Aerial view of *the green roof lab* (School of Agriculture, University of Lisbon, Portugal) and localization map.

According to the Köppen-Geiger classification, Lisbon has a Csa climate type with hot, dry summers and rainy winters. The mean annual temperature is 17.0 °C, and the mean annual maximum and minimum temperatures are 21.4 °C and 13.5 °C, respectively. The mean annual rainfall is 744.6 mm (IPMA, *Instituto Português do Mar e da Atmosfera* https://www.ipma.pt/bin/file.data/climate-normal/cn_81-10_LISBOA_GAGO_COUTINHO.pdf, boletim normal climatológica). Figure 2 indicates monthly rainfall and the minimum and maximum temperatures, collected at a nearby (approx. 9 km away to the east direction) automated weather station (IPMA Lisboa - Gago Coutinho, 38° 45′, 9° 7′, 104 m, a.s.l.), during the period addressed in this study (2014-2022).

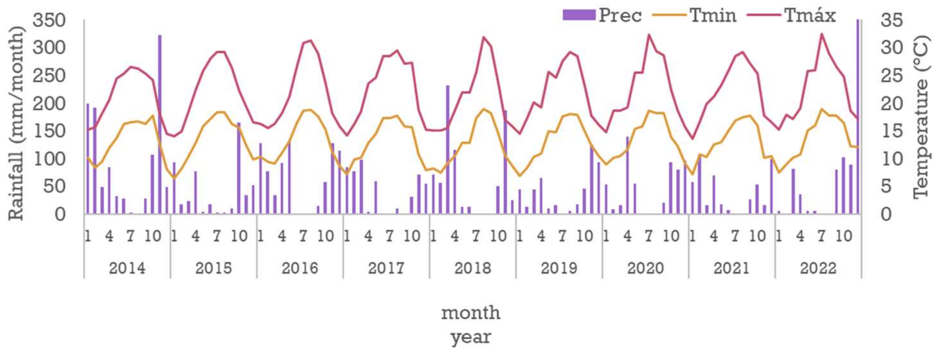

Figure 2. Monthly rainfall and minimum and maximum temperatures, collected at a nearby automated weather station (IPMA Lisboa - Gago Coutinho, 38° 45′, 9° 7′, 104 m, a.s.l.).

In the period from April to June 2022, it was possible to obtain data from an automatic weather station installed on the roof of the Herbarium building (T_METEO all in one, Terrapro, Portugal). Figure 3 presents precipitation and irrigation data from December 2021 until June 2022, including those, corresponding to the period during the collection of photographic records, which was necessary to analyze and understand vegetation development. The precipitation data from December to March were obtained from IPMA Lisbon/Gago Coutinho station. For the period December 2012 to June 2022, maximum precipitation was registered in March, with a total of 132.20 mm.

Irrigation amounts were registered according to the information introduced in the irrigation programmer, equipped with a rain sensor. Irrigation increased towards the end of the study period, which corresponds to the months of May and June. Irrigation was applied at two different levels, calculated as 60% and 100% of reference evapotranspiration (test beds 1 to 7 and 8 to 12, respectively, from a total of 12 as explained further).

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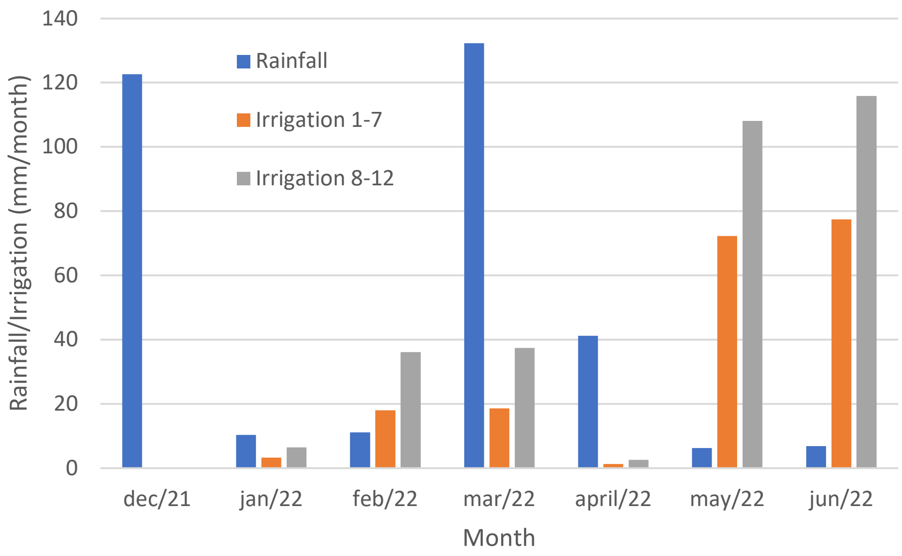

Figure 3. Rainfall and Irrigation from December 2021 to June 2022 at *the green roof lab* (Irrigation 1-7 refers to an amount calculated as 60% of reference evapotranspiration and Irrigation 8-12 to an amount calculated as 100% of reference evapotranspiration).

The experimental set is composed of an array of twelve horizontal metallic test beds (2.5 × 1 × 0.2 m^3), elevated 1 m above the roof surface, and with a slope of 2.5% towards the south direction (Figure 4). The test beds are used to mimic different types of green roofs and were constructed with technical characteristics similar to commercial green roofs: a protection and retention mat (SSM45 – ZinCo, Neoturf, Portugal), a drainage and water storage element of thermoformed recycled polyolefin (Floradrain® FD 25E, ZinCo, Neoturf, Portugal), and a thermally strengthened filter sheet of polypropylene (filter sheet SF, Zinco, Neoturf, Portugal) and a specific commercial substrate for green roofs, made up mostly of organic material, humus, and blond peat mulches (Siro Roof, Siro, Portugal) [17,20].

Figure 4. Partial view of the test beds at *the green roof lab* (School of Agriculture, University of Lisbon, Portugal).

2.2. Vegetation analysis

In the first project of *the green roof lab* (NativeScapeGR, 2014 [21] http://www.isa.utl.pt/proj/NativeScapeGR/) an analysis of the behaviour of a group of native species

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(*Lavandula luisieri* subsp. *luisieri* (L.), *Rosmarinus officinalis* L., *Brachypodium phoenicoides* (L.) Roem. & Schult., *Pleurochaete squarrosa* (Brid.) Lindb., *Homalothecium* sp.,

Brachythecium plumosum Schimp., *Neckera* sp.) was carried out, which, in the case of vascular plants, were lent by the company SIGMETUM or were collected from nature, in the case of bryophytes. In the ApiWall [22] project, all plant material to be studied was initially collected from the facades, walls, and roofs of old buildings in the city of Lisbon, namely the Ajuda National Palace, and further cultivated. Consequently, 15 new vegetation species were inserted, and care was also taken to keep, from the previous project, the moss species *Pleurochaete squarrosa* [25]. Finally, the last project, ApiMat [23], aimed to develop vegetation mats with a mix of native species, namely from the Estremadura region in Portugal. All seeds of the 23 species included were purchased from the company "Sementes de Portugal" and sowed in mats in a nursery, to be later selected and some transferred to the test beds of *the green roof lab*[23].

Table 1 presents the list of the species installed during those three projects and Table 2 presents its distribution in each test bed at the time of planting/sowing. All the introduced plants were native species.

Table 1. Vegetation that was installed (planted or sowed) in projects before this study, in *the green roof lab*.

NativeScapeGR (2014)	ApiWall (2018)	ApiMat (2020)
Brachypodium phoenicoides	*Antirrhinum linkianum*	*Briza maxima*
Brachythecium plumosum	*Asphodelus fistulosus*	*Sedum sediforme*
Homalothecium	*Briza maxima*	*Silene scabriflora*
Lavandula stoechas	*Capsella bursa-pastoris*	*Stachys germanica*
Neckera	*Centranthus ruber*	*Teucrium scorodonia*
Pleurochaete squarrosa	*Centranthus calcitrapae*	*Trifolium angustifolium*
Rosmarinus officinalis	*Papaver rhoeas*	*Trifolium incarnatum*
	Phagnalon saxatile	
	Pleurochaete squarrosa	
	Reichardia picroides	
	Sanguisorba verrucosa	
	Sedum sediforme	
	Silene scabriflora	
	Stachys germanica	
	Teucrium scorodonia	
	Trifolium angustifolium	

Table 2. Vegetation distribution in the test beds as originally planted or sowed in projects before this study, in *the green roof lab*.

Species/ Test beds	1	2	3	4	5	6	7	8	9	10	11	12
Antirrhinum linkianum	•	•	•	•	•			•	•	•		
Asphodelus fistulosus	•	•	•	•				•	•	•		
Brachypodium phoenicoides	•				•							
Brachythecium plumosum	•											•
Briza maxima	•	•				•	•	•				
Capsella bursa-pastoris			•	•					•	•		
Centranthus calcitrapae	•	•	•	•				•	•	•		
Centranthus ruber	•	•	•	•	•			•	•	•		
Homalothecium	•											
Lavandula stoechas	•				•							
Papaver rhoeas			•	•					•	•		
Neckera												•
Phagnalon saxatile	•	•	•	•				•	•	•		

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Pleurochaete squarrosa	•				•						•	•
Reichardia picroides	•	•	•	•				•	•	•		
Rosmarinus officinalis	•				•							
Sanguisorba verrucosa			•	•					•	•		
Sedum sediforme	•	•	•	•	•	•		•	•	•		
Silene scabriflora	•	•					•	•				
Stachys germanica	•	•				•	•	•				
Teucrium scorodonia	•	•				•	•	•				
Trifolium angustifolium	•	•					•	•				
Trifolium incarnatum						•						

To analyze the vegetation, a mixed methodology was created: i) analysis of the vegetation persistence and development; ii) population acceptance concerning the best-suited species from the previous analysis.

The method developed to analyze the evolution and identification of vegetation, allowed obtaining the vegetation areas through overhead photographs, inserted and worked on the ImageJ program [25]. The area of vegetation that has developed over time was monitored and the species present were identified and photographically recorded. The gathered data allowed its use in surveys, to study which vegetation the population prefers for use on green roofs.

One of the objectives of the present study was to analyze which species survived after being sown or planted, and which species emerged spontaneously, without human intervention. Spontaneous species were allowed to stay in the test beds as long as they were not invasive or woody.

2.3. Image acquisition

In the first phase of the study, digital overhead photographs of the laboratory test beds' vegetation were obtained every week. Photographs were taken from the first day of Winter 2021 (December 22nd) to the first day of next Spring (March 20th, 2022), every week (i.e., every Wednesday). With the onset of spring, the vegetation tends to grow quickly, and, to keep up with this development, the photographs were taken every Monday and Friday until the beginning of summer, June 21, 2022. Photographs were taken from December until June, allowing to study the vegetation's development through these six months.

The images were taken with the aid of a structure, a giraffe - PHOTTIX Giraffe Balance 395 with a maximum height of 395 cm, with 3/8 STUDIOKING mounting spike and MANFROTTO MHXPRO-BHQ2 XPRO Ball Head in Magnesium, with 200PL shoe, which allowed placing the camera - Canon PowerShot SX740 HS - at a height of 2.20 m. Since the placement height does not allow manual access to the shutter, the Camera Connect application from Canon was installed on a cell phone to allow taking pictures without having to remove the camera from the location.

The structure was placed between two test beds and aligned by the identification of what was being photographed, by the "N" - north - or "S" - south - side of each test bed.

Each test bed was 2.5 m long by 1 m wide, 20 cm deep, and with a 2.5% slope. They were photographed twice because the camera cannot reach enough height to be able to frame the whole test bed in one picture. Each of the test beds, and consequently each photograph, was identified with the North and South sides of the test beds, with a mark in the middle of the board, at 1.25 m.

The inclination of the test bed, of 2.5%, from North to South, had to be accounted for and it could be concluded that this generates a difference of 6.25 cm between the North and South height of the bed edges. Associated with this difference, 2.20 m of the giraffe's height were added, which means the camera, on the North side takes the pictures at a distance of 1.20 m from the board. However, on the South side, this difference becomes 1.26 m. Taking into account this 6.25 cm increase in the distance of the camera to the south side of the bed, it is estimated that the error in this evaluation of the photographs was 4.95% ((0.06*100) / 1.26). It is also necessary to consider the effect that the gravel on the floor causes on the placement of the giraffe, which cannot be accounted for. By accounting for the 4.95% error of the photographs, with the effect of the gravel, it is reasonable to estimate that, in the end, the error was less than 10%, in these measurements.

2.4. Image Analysis

To obtain results with the photographs previously taken (Figure 5), it was necessary to work the images in two different programs, first in Photoshop and then in Java ImageJ. The first step, in Photoshop, was to crop the images by the inner limit of the test bed, leaving visible only the substrate area and the vegetation there, and all the rest of the image was left with a black background (Figure 6).

Figure 5. Original image as acquired by the camera.

Figure 6. The same image of Figure 1, after being worked in Photoshop.

Once arranged in Photoshop, the images were then placed in ImageJ. To be able to work with the images in this program, it was necessary to install a 64-bit version of ImageJ and, subsequently, that its *Memory & Threads* settings (Edit - Options) were changed. This was done by selecting a maximum memory value that is at most 1 000 MB below the computer's RAM (if the computer has 16 GB of RAM, then the Maximum memory should be changed to 14 000 MB or 15 000 MB).

Afterward, the Trainable Weka Segmentation plug-in (https://imagej.net/plugins/tws/index) [12] was used, which allows the segmentation of the images of the boards, that is, it simplifies the images so that their analysis is made easier. This simplification is done through colors, coloring all the areas referring to the substrate in green and the vegetation in red (Figure 7) [23].

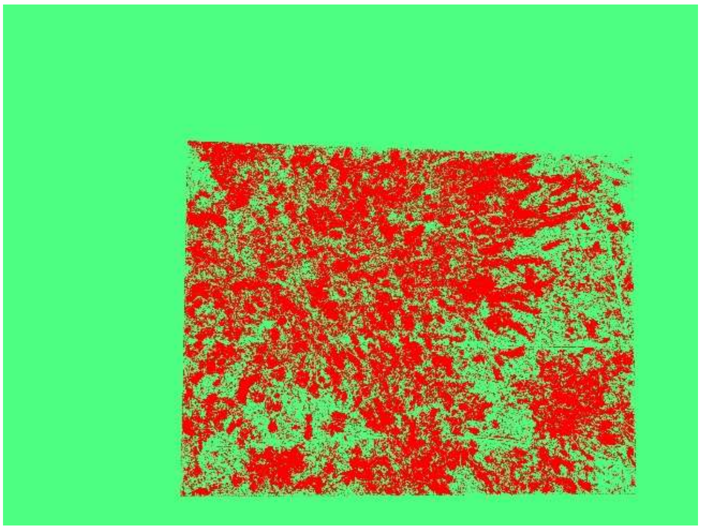

Figure 7. The same image of Figures 5 and 6 worked on WEKA Segmentation.

With the plug-in already open, the *classifier* was defined. In this case, only two classes were used for all the images inserted in the program, Substrate, and Vegetation. This *classifier* was then saved in the folder to be used on the remaining photographs. To be able to use the same analysis criteria on

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all the photographs, it was necessary to create, for each one of them, associated *data*. To create these *data*, it is necessary to indicate to the program, manually selecting three to four areas (Figure 8), that correspond to the substrate and another three to four areas that correspond to the vegetation, that is, to indicate what the content of each class of the *classifier* is.

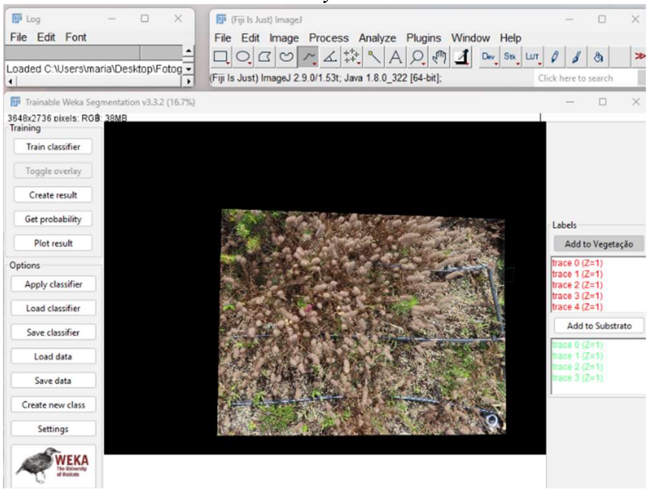

Figure 8. Vegetation-selected areas (Red) and Substrate selected areas (Green). by using Trainable Weka Segmentation in ImageJ

After marking the areas, the *data* settings that correspond to each photograph were saved so that the *data* created could be used again for the following week's photographs. To simplify, for all the photographs taken on December 22, two *classifiers* were created (to identify vegetation and substrate) and twenty-four *data* sets (one for each half of the test bed). *Data* one corresponds to the definitions of the North side of test bed one, *data* two corresponds to the definitions of the South side of test bed one, *data* three corresponds to the definitions of the North side of test bed two, and so on.

With the *data* and the *classifier* already inserted in the plug-in, the program is put to run by clicking on *Train classifier*. In the end, it originates an image of only two colours: green, which are the areas marked as substrate, and red, which are the areas corresponding to vegetation. For the remaining photographs, the *classifier* and the *data* were uploaded, to keep the same evaluation in all photographs.

2.5. Quantification of vegetation-covered areas

Following segmentation, images were reintroduced in the ImageJ program to calculate the vegetation areas, previously marked in red. Furthermore, they were transformed into an 8-bit image, which means a black-and-white image. This transformation was done using the *Image - Type - 8-bit functions*. To select the area to be evaluated, each image was submitted to the *Image - Adjust - Autothreshold* settings, where only the options *Default* on the *Method* and *White object* on the black ground were selected. Afterward, the *Polygon selection tool* was used to select the entire surroundings of the test bed.

Once all the vegetation areas of the test bed were selected, the functions *Analyze - Analyze particles* were used to find out the percentage occupied by them, and then data were centralized in an *Excel spreadsheet* file, where further analysis was performed.

The photographs that were taken throughout the study (December 2021 until June 2022) were transformed, as described in 2.2, to obtain the necessary *data* for the analysis of the vegetation area. However, from 900 photographs taken, only 618, maintaining the chaining of one photograph per test bed every week, were selected.

In the case of test bed one, there is no data between April 25th and May 27th, since a peacock used it as a nest to hatch her eggs.

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At the end of the study, to select the test beds with greater development of vegetation area, those that had an increase of 0.50 m^2 or more were considered, which corresponds, at least, to a 20% increase in the covered area of the test bed, between the beginning and the end of the study.

2.6. Surveys to understand the population's preferences

Green roofs are becoming more common in cities, and, along with this, questions arise from the population, since, for many, the subject of green roofs is still unfamiliar. However, people are the main driver for the implementation of green roofs. With this in mind, a survey was created, through Google Forms with the aim of better understanding people's preferences, regarding vegetation and assessing their understanding and willingness to install a green roof on their dwelling, if they had the necessary means.

The questionnaire was shared through e-mails, tgrl's Facebook page (https://www.facebook.com/thegreenrooflab), and WhatsApp groups, on the 29th of May and on the 12th of August, with a total of 220 answers.

The survey was structured in five parts. The first consisted in collecting information about the respondent and the second was about familiarity with the topic of green roofs. The next part focused on understanding how willing each respondent was to install a green roof and the fourth part aimed to study how much each respondent was willing to spend on the installation of green roofs. Finally, the last and fifth part was related to the vegetation to be installed on the green roofs, to understand each respondent's preferences, and to create seed mixtures that would meet the general taste of the population. For this, pictures of the vegetation installed in the experimental test beds of *the green roof lab* were presented. A simple descriptive statistics analysis was performed to describe the representability and the structure of the sample and of the results, including an age frequency distribution, with seven categories of age ranges defined.

3. Results

3.1. Image Analysis

Table 3 presents the measurement results of the percentage of area covered by vegetation in the 12 test beds at tgrl. The values are presented for North and South areas and for the dates December 22nd, 2021 the first day of photographs, and June 20th, 2022, the last day of photographs. The total coverage area of the referred test bed, in both days of photographs, is also presented.

Table 3. Areas covered by vegetation for the 12 test beds.

Test Bed	Date	North Area % (m^2)	South Area % (m^2)	Total Area (m^2)
1	*December 22nd*	*45.25 (0.57)*	*37.10 (0.46)*	*1.03*
	June 20th	*53.84 (0.67)*	*44.13 (0.55)*	*1.22*
2	*December 22nd*	*21.50 (0.27)*	*30.20 (0.38)*	*0.65*
	June 20th	*42.03 (0.53)*	*57.75 (0.72)*	*1.25*
3	*December 22nd*	*31.80 (0.40)*	*31.80 (0.40)*	*0.80*
	June 20th	*38.91 (0.49)*	*60.70 (0.79)*	*1.28*
4	*December 22nd*	*24.00 (0.30)*	*19.40 (0.24)*	*0.54*
	June 20th	*42.43 (0.53)*	*55.43 (0.69)*	*1.22*
5	*December 22nd*	*40.70 (0.51)*	*22.80 (0.29)*	*0.80*
	June 20th	*31.97 (0.40)*	*29.61 (0.37)*	*0.77*
6	*December 22nd*	*65.0 (0.81)*	*32.30 (0.40)*	*1.21*
	June 20th	*51.49 (0.64)*	*50.71 (0.63)*	*1.27*
7	*December 22nd*	*25.10 (0.31)*	*24.30 (0.30)*	*0.61*
	June 20th	*30.99 (0.39)*	*55.79 (0.70)*	*1.09*
8	*December 22nd*	*23.20 (0.29)*	*34.70 (0.43)*	*0.72*
	June 20th	*45.79 (0.57)*	*61.48 (0.77)*	*1.34*

9	*December 22nd*	*28.80 (0.36)*	*17.70 (0.22)*	*0.58*
	June 20th	*63.57 (0.79)*	*56.65 (0.71)*	*1.50*
10	*December 22nd*	*17.40 (0.22)*	*12.20 (0.15)*	*0.37*
	June 20th	*47.17 (0.59)*	*61.08 (0.76)*	*1.35*
11	*December 22nd*	*21.20 (0.27)*	*29.20 (0.37)*	*0.64*
	June 20th	*44.00 (0.55)*	*41.24 (0.52)*	*1.07*
12	*December 22nd*	*9.40 (0.12)*	*19.50 (0.24)*	*0.36*
	June 20th	*27.19 (0.34)*	*38.31 (0.48)*	*0.82*
Average		*36.36*	*38.50*	*0.94*
Standard deviation		*14.34*	*15.66*	*0.34*

Figure 9a synthesizes the information about the total surface coverage area by vegetation: from a total area of 30 m² (12 test beds with an area of 2.5 m² each), 14.18 m² were covered with vegetation, almost equally divided between the North and South sides (Figure 9b).

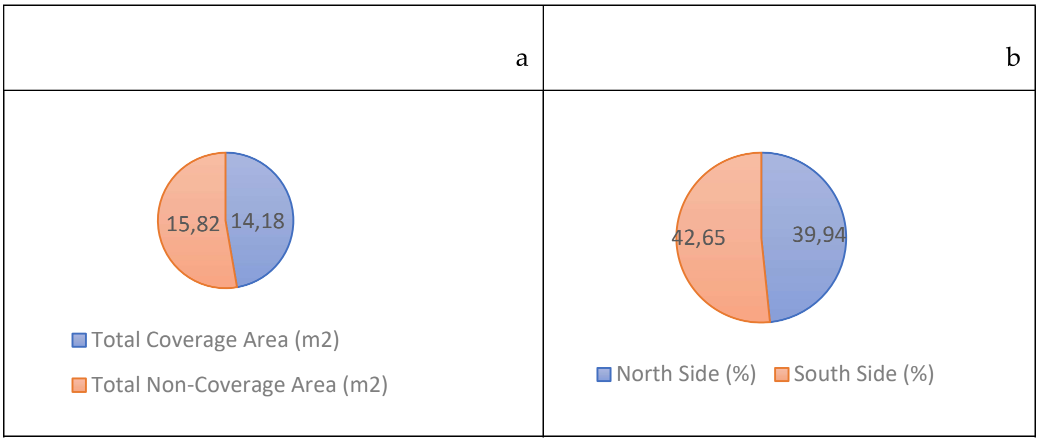

Figure 9. Surface coverage area by vegetation (%) and non-coverage area (a); mean percentage of vegetation coverage on each side of the test beds (b).

Although, it's important to refer that there is a human error since a mobile structure for the photographs was used. Every day the camera was attached to the giraffe which, in turn, was mounted and moved for each photograph. Later, for the analysis and to obtain results, cuts were made in the images, which, being manual, do not guarantee that all the photographs covered the same area. Still referring to the cuts in the images, it should be noted that these were made by the inner limit of the test bed so that all plants that grew outside the limits of the test bed were not accounted for.

3.2. Vegetation Analysis

Considering the vegetation introduced in previous projects, it was possible to understand which species appeared spontaneously.

Many plants have been introduced over the years - 37 species – however, few persisted, as only 16 have remained until the moment this study was finished (Table 4).

Therefore, the presence of the following species was identified in the test beds: Antirrhinum linkianum, Anagallis arvensis, Asphodelus fistulosus, Briza maxima, Brachypodium phoenicoides, Bromus madritensis, Centaurium grandiflorum, Centranthus ruber, Dittrichia viscosa, Geranium purpureum, Holcus lanatus, Lavandula stoechas, Laphangium luteoalbum, Lathyrus tingitanus, Papaver rhoeas, Reichardia picroides, Rosmarinus officinalis, Silene vulgaris, Stachys germanica, Teucrium scorodonia, Trifolium angustifolium, Trifolium arvense, and Vulpia myuros.

Table 4. Vegetation that remained in the test beds from previous projects (planted or sowed).

NativeScapeGR (2014)	**ApiWall (2018)**	**ApiMat (2020)**

Lavandula stoechas *Rosmarinus officinalis* *Brachypodium phoenicoides*	*Asphodelus fistulosus* *Antirrhinum linkianum* *Briza maxima* *Centranthus ruber* *Papaver rhoeas* *Reichardia picroides* *Stachys germanica* *Teucrium scorodonia* *Trifolium angustifolium*	*Briza maxima* *Stachys germanica* *Teucrium scorodonia* *Trifolium angustifolium*

For each test bed, the analysis of which species were preserved, and which were spontaneous was carried on and the results are presented in Table 5. At the end of the period under analysis, the number of spontaneous species was higher than the number of installed species, particularly in the test beds receiving higher irrigation amounts. The species *Brachypodium phoenicoides, Lavandula stoechas* and *Rosmarinus officinalis* have remained since 2014, originating from reseeding.

Table 5. Vegetation that remained from previous projects and spontaneous species that appeared in each test bed.

Test bed	**1**	**2**	**3**	**4**	**5**	**6**
Installed vegetation	*L. stoechas* *R. officinalis* *T. angustifolium* *T. scorodonia*	*T. angustifolium* *T. scorodonia*	*A. linkianum* *A. fistulosus* *R. picroides* *B. maxima*	*A. fistulosus*	*L. stoechas*	*B. maxima* *T. angustifolium* *T. scorodonia*
Spontaneous vegetation	*V. myuros* *C. grandiflorum*	*L. luteoalbum* *V. myuros*	*G. purpureum* *L. luteoalbum* *T. angustifolium*	*L. luteoalbum* *L. tingitanus* *V. myuros* *T. angustifolium*	*L. luteoalbum* *V. myuros* *T. angustifolium*	*A. arvensis* *B. phoenicoides* *L. tingitanus* *V. myuros*
Test bed	**7**	**8**	**9**	**10**	**11**	**12**
Installed vegetation	*B. phoenicoides* *P. rhoeas* *S. germanica* *T. angustifolium* *T. scorodonia*	*B. maxima* *R. picroides* *T. angustifolium* *T. scorodonia*	*R. picroides*	*A. fistulosus* *R. picroides*		
Spontaneous vegetation	*A. linkianum* *G. purpureum* *R. picroides* *V. myuros*	*D. viscosa* *L. luteolbum* *L. tingitanus* *S. vulgaris* *V. myuros*	*B. maxima* *G. purpureum* *L. luteoalbum* *R. officinalis* *S. vulgaris* *T. scorodonia* *T. angustifolium* *T. arvense* *V. myuros*	*B. madritensis* *C. ruber* *D. viscosa* *G. purpureum* *L. luteoalbum* *H. lanatus* *T. angustifolium* *V. myuros*	*A. linkianum* *B. phoenicoides* *B. madritensis* *G. purpureum* *H. lanatus* *R. picroides* *T. arvense* *V. myuros*	*B. phoenicoides* *B. madritensis* *G. purpureum* *R. picroides* *T. angustifolium* *T. arvense* *V. myuros*

3.3. Responses obtained from the survey

The survey was answered by 220 respondents with a proportion of questionnaires given to the sample that are completed (survey response rate) of 18.3%. Among the respondents, 139 were women, and 81 were men, in a range of ages from 17 to 80. The age frequency distribution, with seven categories of age ranges defined, is presented in Figure 10.

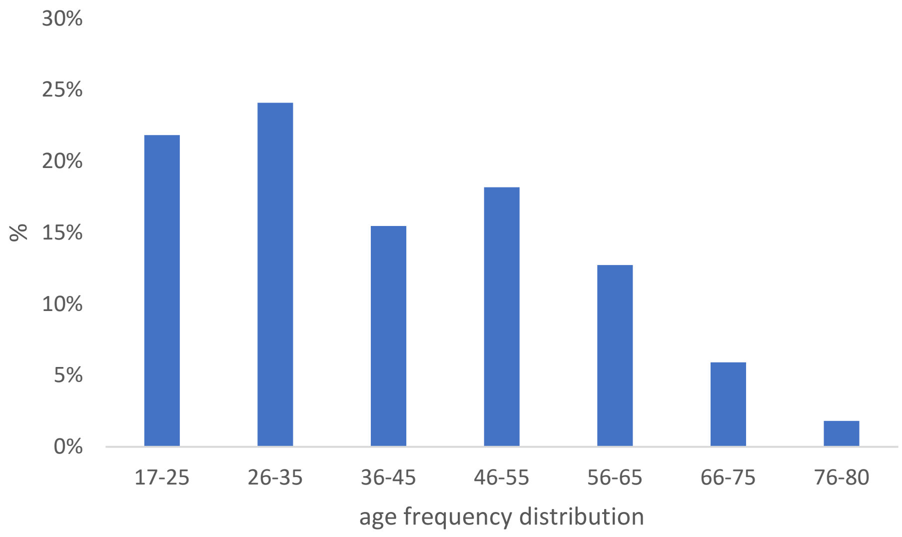

Figure 10. Age frequency distribution of the questionnaire respondents.

Regarding the housing typology, for the "Building" option, 157 answers were obtained, and the "Private House" option was chosen by 63 respondents.

In the fourth question, about familiarity with the topic of green roofs, 157 respondents answered that they are familiar with the topic, but 63 respondents answered that they are not.

The answers to the sixth question were as varied as possible since this was an open-ended question. To evaluate the answers, keywords were used, i.e., the number of persons who mentioned some of the keywords, or synonyms, was counted, which in its turn reflects the concept of green roof. Therefore, the keywords were Vegetation, Canopy, and Building, and out of 220 respondents, 68 mentioned all three keywords, 28 did not use any of the words, or synonyms, and their answers deviated from the concept, and 12 answered that they did not know what green roofs are. Thus, removing the incorrect answers and those who do not know what to answer, the number of answers to be analyzed becomes 180, and, in this total, are included 68 people that have indicated the three main keywords related to green roofs; 136 people identified that a green roof involved the construction of a structure on a roof, 83 people recognized that a green roof would be associated with buildings and construction, and finally, 146 people indicated that a green roof would be composed of vegetation. In all these answers, synonyms of the keywords were accepted.

The next two questions referred to the willingness of each person to install a green roof, assuming they had the conditions in their dwelling to do so. Of a total of 220 respondents, 141 answered that they would install a green roof, 60 answered that they might install a green roof, and only 19 answered that they would not. For those respondents answering "maybe" and "no", an additional question was asked, the eighth question of the survey, where were asked whether they would install a green roof if they had some kind of financial support from the state. Of those 60 who answered maybe, 44 responded that they would consider installing a green roof, however, 16 reversed their previous response by answering that they would not install it despite the subsidy. Of the 19 who answered "no", only two changed his answer to "yes" and 17 kept their answer.

It was also asked how much each respondent would be willing to spend to install a green roof. For 115 people, representing 61% of the respondents, the answer was 50 € per m^2, 62 would spend up to 100 € per m^2 and only 10 would be willing to spend 150 € per m^2.

In the next question they were asked about the purpose of the green roof, that is, if they would like it to be a space they could enjoy. The option "Intensive Covering" was chosen by 101 and the other option, "Extensive Covering" was answered by 86 respondents. The next two questions were intended to assess the public's preferences and to understand which plants they would eventually

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appreciate and choose for the green roofs. For this, there were several options, with their respective photographs, and, of these options, only one had more than 90 votes - equivalent to 50% of the respondents. Thus, the options and the respective number of choices were synthesized (Figure 11).

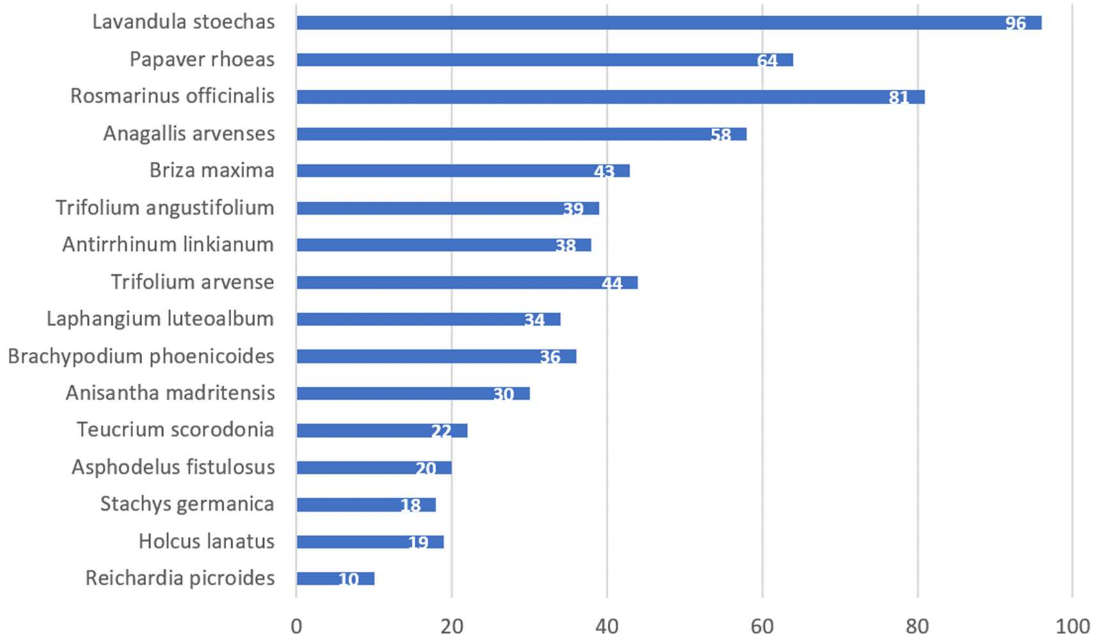

Figure 11. Public's preferences regarding plant species (question 11 of the questionnaire).

Finally, in the last question, the 12 test beds, which were created in the green roof lab, were presented as 12 vegetation mixtures to install on green roofs. Mixture four (largely dominated by *Lathyrus tingitanus*), that is, test bed four, was the most chosen, with 99 people electing it. On the other hand, the last three test beds – seven, ten and 12 - had the least choices, with seven, ten, and five people selecting them, respectively.

Thus, of the 220 people who answered the survey, 187 demonstrated a willingness to install a green roof if they had the necessary conditions (money to invest and maintain, space, and load capacity in a building's roof). For these respondents, the most chosen species were *Lavandula stoechas, Papaver rhoeas, Anagallis arvensis*, and *Rosmarinus officinalis.*

4. Discussion

4.1. Image Analysis

Figure 12 summarizes the evolution of the area covered by the vegetation of the different test beds. The percentage of change in the area covered between the months of study, namely between December 22nd, 2021, and June 20th, 2022, was marked with dark points. There was a generalized increase in the area covered by vegetation during the period when digital analysis was performed, with a global average of 19.55% and a maximum of 39.2% for test bed 10. An exception was observed for test bed five, which presented a negative coverage change.

In the northern part of test bed three, there was a small increase in the area covered but, in the southern zone, there was almost a doubling of the area covered with vegetation, which can be justified by the strong presence of *Trifolium angustifolium*. This species showed a high capacity to reseed in the test beds where it was previously sowed, as, in the end of the period under analysis, it was present in all of them. Also, it showed the ability to colonize other test beds, since it spontaneously appeared in test beds 3, 4, 5 and 6. The high persistence of this species has already been documented previously by other authors, in similar climates, by comparison to other annual self-reseeding legumes [26].

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For test bed four, there has been an increase of 0.68 m² in vegetation and it was completely dominated by the annual climbing species *Lathyrus tingitanus*. This is in accordance with the growth and development habits of this species, documented by other authors as having the greatest canopy heights and providing the most ground cover in comparative trials with other legume species [27,28].

Regarding test bed seven, there has been an increase of 0.48 m² of vegetation, and, for test bed eight, as in most of the other test beds, an increase in the area of vegetation occurred for both areas. At the end of the study, the total increase in vegetation was 0.62 m² for this test bed.

Concerning test bed nine, the values in Table 2 indicate that there has been an increase of 0.92 m² of vegetation area. This was justified by the presence of specimens of *Trifolium arvense*, which predominate in the test bed.

For test bed 10, on both sides of the test bed, there is an increase of 0.98 m², and this increase is higher in the southern zone. This could have been caused by the existence and great development of *Holcus lanatus* specimens, which prevail in the southern zone of this test bed.

Regarding test bed 11, the area in the northern zone increased more than in the southern area. Thus, at the beginning of the study, the area of covered vegetation was 0.64 m² and, at the end of the records, its area became 1.07 m², which translates to an increase of 0.43 m². This increase can be reflected by the large growth of *Trifolium arvense*, which began to develop during the month of April.

In test bed 12, there was an increase of 0.46 m² in the area of vegetation, which may be a consequence of the presence of a high number of *Trifolium arvense* specimens in the southern part of the test bed, and, in the northern part by the existence of specimens of *Vulpia myuros*, which, in the meantime, have developed.

Trifolium arvense is referred by other authors as being relatively independent of dormancy habits, with the ability to germinate whenever soil moisture and temperature conditions are favorable, particularly in spring, and well adapted to low rainfall and extreme temperature environments [29]. Specifically for green roofs, it is also referred as being drought tolerant and a dominant species [30]. This corroborates the observed behavior of this species in the test beds, related to dominance and to the relatively easy adaptation to the conditions of the rooftop.

Some small sources of error could be identified and must be noted. In the spring months - the end of March until the end of June - some flowers began to appear, thus contributing to the increase of the vegetation area, but these were not in bloom throughout all these months, and some did not develop at all. Adding to these, there are also factors resulting from meteorological conditions, such as the wind that, in taller plants, can cause them to occupy a larger area momentarily because they are inclined.

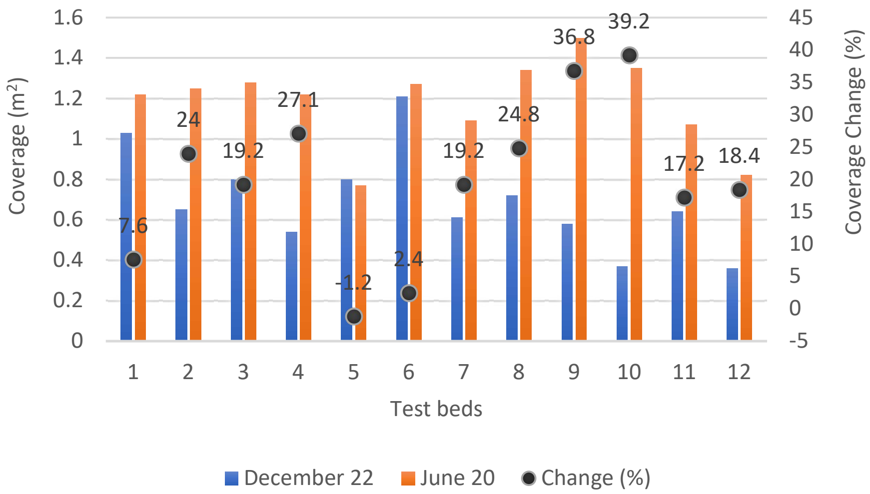

Figure 12. Total areas of vegetation coverage.

As mentioned in section 2.3, test beds with an increase of 0.50 m^2 or more were considered for further analysis (test beds two, four, eight, nine, and ten). For these, it was possible to see that the species that occupy a larger area are, for test bed two, the specimens of *Teucrium scorodonia and Trifolium angustifolium*, for test bed four, the specimen of *Lathyrus tingitanus*, for test bed eight, *Dittrichia viscosa, Teucrium scorodonia,* and *Trifolium angustifolium*. For test bed nine are *Trifolium angustifolium, Trifolium arvense, Teucrium scorodonia*, and *Rosmarinus officinalis*. Finally, for test bed ten, are specimens of *Teucrium scorodonia, Trifolium angustifolium, Holcus lanatus,* and *Dittrichia viscosa*.

Except for test bed number five, it is possible to conclude that, in general, the percentage of area covered by vegetation has an increasing trend during the study period.

Finally, it should also be noted that there are species that, despite not being relevant in contributing to the increase of vegetation cover, are present in most of the test beds, being the spontaneous species *Geranium purpureum, Laphangium luteoalbum* and *Vulpia myuros* and, sometimes, of those previously planted, *Trifolium angustifolium*.

4.2. Vegetation Analysis

Considering the data presented in section 3.2, it is possible to note that several plant species appeared spontaneously: Bromus madritensis, Centaurium grandiflorum, Dittrichia viscosa, Geranium purpureum, Holcus lanatus, Laphangium luteoalbum, Lathyrus tingitanus, Silene vulgaris, Trifolium arvense, and Vulpia myuros, being all native species, except for L. luteoalbum, which is a non-invasive exotic, and that some of the vegetation emerged from previous introductions: Lavandula stoechas, Rosmarinus officinalis, Brachypodium phoenicoides, Asphodelus fistulosus, Antirrhinum linkianum, Briza maxima, Centranthus ruber, Papaver rhoeas, Reichardia picroides, Stachys germanica, Teucrium scorodonia, Trifolium angustifolium, and Anagallis arvensis (Table 4).

The *Brachypodium phoenicoides* specimens present in test beds six, seven, 11, and 12 may have arisen from the NativeScapeGR project in 2014, which planted them in test beds one, three, five, seven, and nine.

On the other hand, the existence of *Antirrhinum linkianum* in test beds three, seven, and 11 could be justified by its pre-planting in 2018, following the ApiWall project, in test beds one, two, three, four, eight, nine, and ten.

Regarding the *Reichardia picroides* specimens, they were installed in test beds two, three, four, eight, nine, and ten at the time of the ApiWall project, in 2018, and are currently unintentionally in test beds seven, 11, and 12.

The *Stachys germanica* specimens exist only in test bed seven, however, they were planted in test beds one, two, six, and eight, in 2018, by the ApiWall project, and, in 2020, they were installed in test beds six and seven according to the ApiMat project.

The spontaneous existence of *Teucrium scorodonia* specimens in test beds seven and nine, on the other hand, should be based on their previous sowing in test beds one, two, six, and eight in 2018, for the ApiWall project, and in test beds six and seven, at the time of planting for the ApiMat project.

The existence of *Briza maxima* specimens in test bed nine must be justified by their installation in 2018, for the ApiWall project, in test beds one, two, six, and eight, or else by their subsequent planting in test beds six and seven on behalf of the ApiMat project.

As for the *Rosmarinus officinalis* specimens in test bed nine, this must originate from their planting in 2014, by the NativeScapeGR project, which installed them in test beds one, five, six, and eight.

The existence of *Centranthus ruber* specimens in test bed ten may have come from the ApiWall project, which planted them in test beds one, two, three, four, five, seven, and eight.

Finally, it is possible to understand that, despite the plantations, the sowing, and the transplantations in certain test beds, the vegetation could propagate to other test beds, which means that, in a green roof, for these species and conditions, it is likely to expect such a behavior. As previously noted [31], the colonization by spontaneous species in a green roof may not necessarily be considered a failure, as it is also an opportunity to improve the functioning of the system and to achieve a more balanced system, closer to natural conditions. In the present situation, not only the

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colonization by spontaneous species, but also that of neighbor test beds by introduced species, denote an approach to natural equilibrium of the green roofs mimicked in this study, as the better adapted species thrive and are able to install in new locations.

4.3. Responses obtained to the survey

Through the survey, it was possible to understand the preferences of the population, their willingness and availability to install a green cover, and how much information they have about the subject. The results indicate that the most chosen plants by the population were *Lathyrus tingitanus*, *Rosmarinus officinalis*, *Lavandula stoechas*, *Papaver rhoeas*, and *Anagallis arvensis*. That is, people chose the plants they are more familiar with and that bring more color - through larger flowers and, consequently, more visible - to the green roofs.

Regarding familiarity with the subject of green roofs, from the 220 respondents, only 157 said they were familiar with the subject, which indicates that there is still some lack of information on the subject among the population.

Finally, the third objective of this survey consisted in understanding the disposition of the respondents towards the possibility of installing green roofs in their residences and, from the total sample, 141 answered that they would install them without any kind of financial incentive from the government, 46 would only install them if they had access to support and 33 answered they would not install them, regardless of the existing support.

Given the answers, it can be concluded that the measures created, such as monetary incentives, allow more people to be willing to install green roofs, which end up having an impact on the common life of all citizens. These results also show that more research is needed on this topic to increase knowledge, and the variety of species available, and to find more attractive and equally favorable specimens for green roofs.

5. Conclusions

In recent years, green roofs have been presented as a solution to many of the problems of cities, namely the lack of green spaces, because of the dense and sometimes disorganized urban development.

Green roofs, although they imply an investment, either at the moment of their installation or for their maintenance, have several benefits not only for the buildings where they are incorporated and for their inhabitants, but also for the environment and for the neighborhood, city, and country where they are located. Therefore, they are an interesting theme, and it is important to improve knowledge in this area.

This study had as its primary objective the analysis of the evolution of the vegetation that has been installed, since 2014, in the test beds of an outdoor laboratory at the School of Agriculture of the University of Lisbon, Portugal - *the green roof lab* -, as well as the creation of a methodology that would allow this evaluation.

From all the species that have been planted or seeded throughout the years, the specimens of Antirrhinum linkianum, Asphodelus fistulosus, Brachypodium phoenicoides, Briza maxima, Lavandula stoechas, Reichardia picroides, Rosmarinus officinalis, Teucrium scorodonia, Trifolium angustifolium, and Papaver rhoeas were the ones that persisted until the publication of this study. Simultaneously, it was possible to observe that species once planted in certain test beds, were later found in other test beds. This suggests that birds, insects, and wind may have been the elements that provided the transfer of seeds between test beds, as is the case of Centranthus ruber, Stachys germanica, and Anagallis arvensis.

Regarding the appearance of Anagallis arvensis, Bromus madritensis, Centaurium grandiflorum, Dittrichia viscosa, Geranium purpureum, Holcus lanatus, Laphangium luteoalbum, Lathyrus tingitanus, Silene vulgaris, Trifolium arvense, and Vulpia myuros, it was possible to conclude that these specimens spontaneously appeared in the test beds, without being introduced on behalf of previous projects.

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Concerning the percentage of vegetation cover, the test beds with an increase of at least 0.50 m^2 between the beginning and the end of the study, were test beds two, four, eight, nine, and ten. For these test beds, it was possible to determine, through the digital analysis, which species stood out the most, and, from there, make a selection of plants - *Dittrichia viscosa, Rosmarinus officinalis, Teucrium scorodonia Trifolium angustifolium, Trifolium arvense* (all introduced natives), *Holcus lanatus* and *Lathyrus tingitanus* (both spontaneous).

The methodology developed for digital image analysis in this project proved to be effective, however, with some sensibility for human error. As far as the photographs are concerned, the system should be static and not repeatedly assembled and disassembled, to reduce the probability of errors. As for the image analysis, the images were worked in a succession of operations, to obtain the percentages of vegetation areas. Although it has been observed, in general, an increasing trend of the percentages of the area covered with vegetation over the time of the study, it was also possible to observe that the values obtained were quite oscillating. This may indicate that the images may have accumulated successive errors resulting from the constant transformations they underwent, which may have then impacted the results. For further studies, it is suggested to minimize steps to avoid errors.

Conjugating the results obtained from the surveys, with the results relating to the species with the highest occupation in the test beds, it was possible to obtain a set of 11 species that proved to be the most resilient, with the greatest development and preferred by people enquired. These were *Anagallis arvensis*, *Dittrichia viscosa*, *Holcus lanatus*, *Lathyrus tingitanus*, *Lavandula stoechas, Rosmarinus officinalis*, *Teucrium scorodonia*, *Trifolium angustifolium, Trifolium arvense,* and *Papaver rhoeas.*

Author Contributions: Conceptualization, Pedro Arsénio and Teresa Paço; Data curation, Teresa Paço; Formal analysis, Pedro Arsénio; Funding acquisition, Teresa Paço; Investigation, Madalena Rodrigues; Methodology, Madalena Rodrigues, Pedro Arsénio and Teresa Paço; Resources, Teresa Paço; Supervision, Pedro Arsénio and Teresa Paço; Validation, Pedro Arsénio and Teresa Paço; Writing – original draft, Madalena Rodrigues; Writing – review & editing, Madalena Rodrigues, Pedro Arsénio and Teresa Paço.

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