Green roofs in Mediterranean climate

Proposal of a maintenance plan

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Extended abstract

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1. Objectives and motivations

Numerous studies have been developed on the benefits of green roofs, not only social and environmental benefits but also economic. The regulation of urban temperature [1], improvement of air quality, rainwater management [2], noise level [3] and creation/preservation of habitats are some of the environmental benefits. Regarding the economic benefits, this constructive solution requires labour in its installation and improves energy efficiency by reducing costs associated with climate control of buildings [4]. Moreover, there is the possibility of water reuse and increment of the waterproofing membrane´s life, as mentioned in [5]. There is also the need to evaluation the overall costs equation of a green roof, which should combine the benefits of green roofs with the correct projection, construction and maintenance planning throughout its service life [7]. Maintenance is a key element for a correct in-service performance of green roofs, having a significant weight in the overall costs. As mentioned by [8], a proper maintenance management relies on the definition of strategies since the project phase, promoting effective and economic interventions and ensuring a good in-service performance. Literature is still sparse regarding maintenance plans of green roofs [9, 10, 11, 12], particularly in the Mediterranean climate.

This article aims to propose a proper maintenance plan for green roofs in the Mediterranean climate. In order to do so, ten green roofs were inspected in Portugal, a Mediterranean climate [13], evaluating the parameters that influence the degradation state of green roofs and correlating them with the implemented maintenance actions and anomalies. This study was developed in order to accomplish the following aims:

- ✓ Evaluate the degradation of in-service green roofs and existing maintenance techniques;
- ✓ Develop a proposal for an adequate maintenance plan, simple, easy to read and execute;

Both studies developed by [8] and [12] contributed to assess the maintenance plan proposed in this dissertation.

2. Maintenance of green roofs

For proper design and planning of a green roof it is essential to understand how the system will be maintained, since maintenance is the main factor to ensure not only the growth and development of gardens on green roofs, but also to guarantee its performance throughout its life cycle.

2.1. Types of green roofs

Green roofs can be installed on flat or sloped systems, can be accessible areas or with limited access and, according to [9], they are classified into 3 groups: intensive, extensive and semi-intensive.

Extensive solutions are well suited to roofs with little load bearing capacity. The costs are lower than the other types. Regarding intensive green roofs, this type represents higher cost and higher amount of maintenance than the other types. Semi-Intensive green roofs in terms of requirements fall in between extensive and intensive green roof systems.

2.2. Maintenance actions and frequencies

One of the most relevant maintenance actions is the roof´s cleaning. The accumulation of debris and undesirable vegetation leads to the development of anomalies. Irrigation is another maintenance action essential for correct performance of green roofs. The water requirements vary with the inclination, and

the weather exposure [7, 10]. Areas where the vegetation has roots with a high level of aggression require careful and regular inspections to assess the effectiveness of the conservation and restraint systems of these roots [9]. It is also important to plan frequent inspections of the different elements so as to enhance the ability to prevent the appearance of anomalies. In defining the frequency of each maintenance action it is important to consider the green roof´s age. There are three phases that can be considered in the life cycle of a green roof, which require different maintenance frequencies, according to [9] and [10]. The first is the post-implementation, followed by the development phase and the maintenance phase. The frequency of maintenance actions may also vary depending on the type of green cover. Intensive green roofs may require more frequent maintenance actions than extensive ones. The allocation of responsibilities ensures the correct performance of in-service green roofs. Gardening actions are the responsibility of gardening teams. More specific interventions shall be the responsibility of specialized technicians. The owner may also play a key role in maintaining the green roof throughout their life, through visual monitoring and control of it.

3. Methodology adopted and case studies

3.1. Adopted methodology for the inspections

There were analysed 10 case studies, located in Portugal, in order to understand which factors affect the performance of in-service green roofs, regarding their maintenance. The information about their construction systems was collected as well as the most common anomalies and applied maintenance techniques. Data was collected through visual inspections and supplemented, whenever possible, with technical documentation provided by owners, designers, installers or managers. Different types of green roofs, utilities, ages, position relatively to the building, constructive processes and maintenance techniques were analysed. Information relating to past anomalies and respective interventions were also included. There was a concern in schedule the inspections with favourable weather conditions, ensuring the most correct visual inspection possible. During the visual inspections the data was collected with the resort of photographs and punctual measurements (e.g., height of the perimeter walls, areas). Information on the inner layers of some green roofs was achieved through available documentation. Drainage systems were visually inspected whenever possible.

3.2. Inspection sheet

A checklist type inspection form, divided into six distinct parts, was developed in the present work. Most aspects of the common guidelines, e.g. [9, 10], were included. Figure 1 shows an extract of the developed inspection sheet. The first part identifies the buildings general characteristics. The second part identifies the green roofs general characteristics, namely the area, slope, accessibility and type of green roof [9] (intensive, extensive or semi-extensive). In the third part, and considering the information in [9, 10, 15], more specific characteristics of green roofs are identified, as the presence of access paths, irrigation and drainage systems, among others. The fourth part identifies the type of vegetation as defined in [10, 11]. The fifth part consists on the record of the maintenance actions, their frequency and their responsible authorities, important factors, referred in [11]. The last part of inspection sheet summarizes existing anomalies and their probable causes. The methodology developed in this work allows collecting the important information to evaluate the green roof´s state of degradation, namely

intrinsic characteristics (e.g., constitution, slope, type) and external features (e.g., solar exposure, accessibility, maintenance actions).

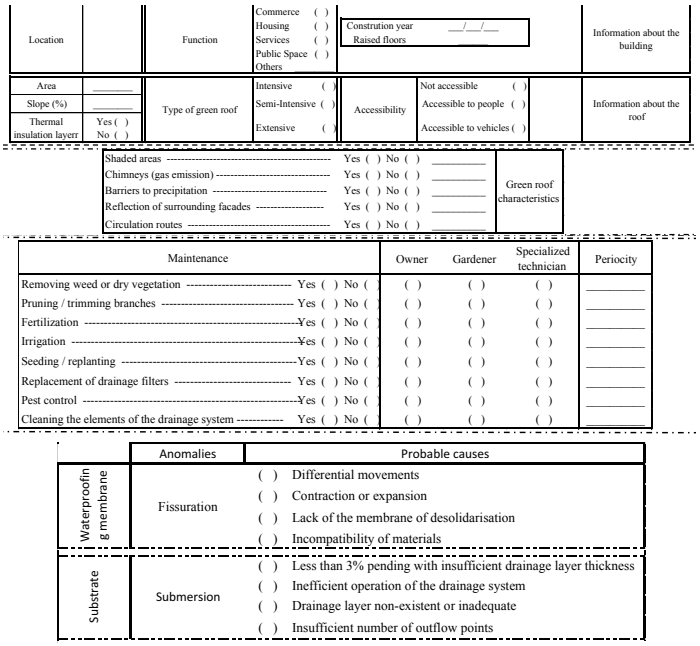

Figure 1. Inspection sheet (extract).

3.3. Case studies

3.3.1. General characterization of the sample

The sample is composed by 10 different case studies, inspected over the period of five months in 2015/2016. All the inspections were carried out whether with the owner's presence or the maintenance teams. There were analysed different types of green roofs: intensive and semi-intensive. Extensive green roofs were not considered. Since it was not inspected any case of extensive green roofs, it has not proposed any maintenance plan for it. It was also taken into account the green roof´s position related to the building. The sample includes flat and slope green roofs. It was also considered in the selection of cases for the sample their accessibility, their age and the type of maintenance implemented. All the ten case studies (figure 2) are described in table 1.

Figure 2. Green roofs of the inspected case studies I, II, III, IV, V, VI, VII, VIII, IX and X (from left to right).

Regarding the type of use, 40% of the case studies are services, 40% are public spaces and only 20% are housing. There were also considered different types of accessibility. Many anomalies observed in green roofs may be associated not only with an incorrect maintenance but also with misuse. Therefore, it is interesting to evaluate their function and accessibility. The sample included non-accessible roofs

(only assessed for maintenance), which represent 50% of the sample, roofs accessible to people, representing 40% of the sample, and roofs accessible to people and vehicles, 10%. It was found that 60% are green roofs with more than 10 years old in-service. The oldest case inspected has 49 years old, showing that green roofs are a concept developed in Portugal in recent decades. As referred in [12], this is important when considering maintenance actions that are included in post-implementation and maturation phases. The sample studied in this work does not include cases of rehabilitation of green roofs. Table 1 shows that 80% of the analysed solutions have dimensions larger than 1000 m^2, while the smallest green roof (case VI) has 50 m^2. As expected, the majority of cases are elevated, as much as 80%. Of those, 60% are terraces and the remaining 20% have slope. It is interesting to assess that the majority of roofs with larger areas are elevated. It was not inspected any green roof on the ground floor without a slope. Cases II and VIII take advantage of the neighbouring terrain´s slope and can be accessed from street level. As shown in table 1, none of the case studies is an extensive one. 70% of coverage are the intensive type, with only 30% of semi extensive type. The type characterization of green roofs presented in the survey is not representative of extensive green roofs.

Table 1. General characteristics of the case studies.

Case studies	Name	Location	Year of construction	Área (m^2)	Type of green roof	Green roof´s position on the building	Accessibility
I	ETAR de Alcântara	Lisboa	2011	37 184			
II	Fundação Calouste Gulbenkian (Cobertura A)	Lisboa	1967	11 000			
III	Fundação Calouste Gulbenkian (Cobertura B)	Lisboa	1967	5 000			
IV	Fundação Calouste Gulbenkian (Cobertura C)	Lisboa	1983	1 000			
V	Edifício Portugal Telecom	Lisboa	1978	3 184			
VI	Sede da MSF	Lisboa	2009	50			
VII	Edifício Soeiro Pereira Gomes	Lisboa	1969	1 550			
VIII	Empreendimento Alto dos Moinhos	Lisboa	2011	3 130			
IX	Empreendimento Azinhaga Galhardas	Lisboa	2008	600			
X	Centro Cultural de Belém	Lisboa	1990	5 700			

Legend:

Intensive
Semi-extensive
Extensive

High / flat
High / slope

Ground floor / flat
Ground floor / slope

Accessible to people
Accessible to people and vehicles
not accessible

3.3.2. Constructive solution

In the presented survey, all constructive roof systems are multi-layer. All the information related to the composition of the roofs was collected from the owners or maintenance teams. All the systems are inverted roofs and have waterproofing membranes, although only 10% of the waterproofing membranes have anti-roots characteristics. Also 50% of the case studies have thermal insulation. Two types of irrigation systems were observed: drip irrigation and spray irrigation. In some cases, there is the installation of both. In 90% of cases the drainage systems were visually inspected, being the exception the case VI. In this case, the solution is capable of collecting and storing rainwater between layers, where valves are installed with a sensor which is activated whenever a layer is full. Regarding the type of substrate, 90% of the case studies have technical substrate. Only the case I has installed a layer of natural substrate.

4. Results discussion and proposal of maintenance plan

In order to develop a maintenance plan proposal, it was taken into account the study by [8] as a term of comparison. It should be noted that the case studies I, VIII and X, inspected in this study were also inspected by [8], although the collected information is different. It was also considered the proposal for a maintenance plan developed in [12]. Both studies served as support to the development of the maintenance plan proposed, allowing to discuss their differences and similarities.

4.1. Pathology

Information was collected regarding superficial elements such as gutter´s clogging, dead/dry vegetation, anomalies in emerging elements, among others (figure 3). All the observed anomalies are shown in table 2. In general, all roofs inspected showed an acceptable in-service performance. Only five system elements show anomalies.

a) b)

Figure 3. Anomalies: (a) dry vegetation in case studies I, V and VI and (b) clogging and accumulation of water in the drainage systems of the case studies III, V and X.

The vegetation layer is the most affected element, followed by the drainage system. All the case studies have infesting vegetation. 41% of the cases have infesting vegetation, due to fungi, pest and diseases. Contrary to what was expectable, stepped vegetation was observed only in non-accessible green roofs.

Table 2. Identification of the anomalies in each case study.

	Case studies	I	II	III	IV	V	VI	VII	VIII	IX	X
Support	Cracking			▶	▼	▶	▶	▶	▶		▶
	Deformation			▶		▶	▶	▶	▶		▶
	Located crushes			▶		▶	▶	▶	▶		▶
	Disaggregation			▶		▶	▶	▶	▶		▶
	Corrosion			▶	▼	▶	▶	▶	▶		▶
	Lack of strength, bracing or stiffn			▶		▶	▶	▶	▶		▶
	Damp patches	▼	▼	▶	▼	▶	▶	▶	▶		▶
	Collapse			▶	▼	▶	▶	▶	▶		▶
	Infiltrations				▼	▶	▶	▶	▶		▶
Susbtrate	Floodings		▼		▼						
	Sliding and erosion	▼			▼	▼	▼		▼		
	Excessive ontraction/retraction					▼				▼	
	Compaction										
Vegetation	Dry vegetation	▼	▼		▼	▼	▼		▼		▼
	Infesting vegetation	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼
	Injuries, freezing and death of vegetation	▼			▼			▼			
	Fallen vegetation				▼		▼				

	Case studies	I	II	III	IV	V	VI	VII	VIII	IX	X
Drainage system	Clogged drains	▼		▼	▼	▼	▶				▼
	Accumulation of dirt and debris	▼	▼	▼	▼	▼	▶	▼	▼		▼
	Gutter´s cracking				▼		▶				
	Cracking of the gutter´s joints						▶				
	Perforation				▼	▼	▶				▼
	Corrosion		▼				▶				
	Water accumulation in downpipes and guttering	▼			▼	▼	▶				▼
Trim system	Cracking of vertical trim			▼	▼	▼		▼			
	Cracking of trim´s expansion joints					▼					
	Trim´s fluency or slip										
	Displacements				▼	▼		▼			

Legend: ▼ Anomalia detetada ▶ Não acessível

The accessible roofs generally have appropriate paths, which prevents damage to vegetation due to the presence of people. The three case studies without paths have stepped vegetation. Accumulation of dirt and debris on the drains were observed in 35% of cases, while 46% had clogging and accumulation of water. Anomalies were observed in the substrate in 13% of case studies inspected, the most common being sliding and erosion of the substrate. There were also observed anomalies in the trims, 11% of the sample. It was possible to visualize the support of seven case studies, of which 8% showed anomalies.

4.2. Maintenance techniques applied

The maintenance actions with their respective priorities and responsible entities are shown in table 3. All inspected green roofs have regular maintenance actions, scheduled by the owners. Yet,

maintenance planning shows a large variability, both in terms of scheduling and actions. Case studies I, VIII and IX have maintenance teams present all working days. 20% of the case studies have maintenance teams four times per week. Most maintenance actions are related to gardening operations. All case studies with available information predict elimination of infesting or dry plants and most inspected green roofs also control pests, diseases, fertilization, pruning, cleaning and dry plants removal. Most of the maintenance actions are the responsibility of the gardening team.

Table 3. Characterization of maintenance actions, entities responsible and frequency of visits (days per moth).

	Case studies	I			II			III			IV			V			VI			VII			VIII			IX			X		
	Responsible entities	O	G	E	O	G	E	O	G	E	O	G	E	O	G	E	O	G	E	O	G	E	O	G	E	O	G	E	O	G	E
Maintenance actions	Infesting/dry vegetation removal		●			16			16						1			1			2			●			●			12	
	Pruning tips		●			16			16						1			1			2			●			●			12	
	Pruning tips		●			16			16						1			1			2			●			●			12	
	Harvest		●			16			16									1			2			●			●			12	
	Irrigation		●			●			●			●			●			●			●			●			●			●	
	Fertilization		12			16			16						1			1			2			●			●			12	
	Fillings		●			16			16						1			1			2			●			●			12	
	Soil ventilation		●			16			16						1			1			2			●			●			12	
	Filling with substrate (erosion)		12			16			16						1			1			2			●			●			12	
	Vegetation control in specific areas (perimeters, gutters, access paths...)		●			16			16						1						2			●			●			12	
	Cleaning consruction elements (gutters, walls, skylights...)	12				8			8						1		8				2		●			●			12		
	Cleaning of drainage systems		12			8			8										x		2				x		●			x	
	Cleaning of ventilation systems	12				x			x										x				x							x	
	Pest control					x			x						x			x			x			x			x			x	
	Anchoring bushes or trees		●			x			x															x			●			x	
	General cleaning	12			16			16							1		8			1			●			●			12		
	Drain filter substitution			x			x			x						x			x			x			x			x			x
	Carbonates cleaning accumulated in gutters			x			x			x						x			x		2						●			x	
	Mastic trims replacement			x			x			x						x			x			x			x			x			x
	Asphaltic membranes trim replacement			x			x			x						x			x			x			x			x			x
	Bituminous membranes and metal trims replacement			x			x			x						x			x			x			x			x			x
	Irrigation system repair			x			x			x			x			x			x			x			x			x			x

Legend: O = Owners G = Gardeners S = Specialized technicians ● = Every day

The owners are responsible for general cleaning of the roofs. Contrary to what would be expected, 50% of the case studies inspected have no maintenance actions planned for cleaning drainage systems. In many cases they resort to a specialist when needed, which indicates that maintenance actions only occur in these systems when there already are anomalies.

Irrigation systems are particularly important in Mediterranean areas, since watering is vital to ensure the correct development of vegetation species during the hot dry summer months. Regarding the frequency of maintenance actions, each case study presents different periodicities. In table 3 the frequencies are referred in days per month. It is important to refer also the entities responsible for implementing the various maintenance actions.

The actions described in table 3 are generally more frequent than in the exposed in COELHO (2014). Only case studies VI and VIII inspected by COELHO (2014), which coincide with the case studies inspected in this dissertation (VIII and X respectively), have daily interventions. It was also collected

information regarding who was responsible for which interventions, unlike COELHO (2014). Note that some of the actions carried out in the inspected case studies are not referred to by COELHO (2014).

4.3. Results treatment

First it was related the age of the inspected green roofs with the amount of detected anomalies. It was possible to realize that the relationship was not linear. Oldest green roofs with frequent and proper maintenance may present the same state of degradation that newer green roofs. Another factor that can be decisive in the performance of green roofs is the frequency of maintenance actions. With some exceptions, it was possible to conclude that there was a proportionality between the frequency of maintenance and the number of anomalies. One of the anomalies detected in many of the cases inspected was the presence of stepped vegetation. Curiously, only 30% of the cases in which the green roof is accessible to people was detected stepped vegetation, while the same anomaly was detected in 40% of cases in which the accessibility is restricted to maintenance teams. The fact that the green roofs are accessible to the public does not mean that the vegetation is found more damaged than in the case of not being accessible. Regarding the drainage system, in many cases there was not implemented any planned maintenance, and interventions were performed only when necessary. Often interventions to drainage systems occur only when there are already accumulations of water in the green roof. This reactive maintenance leads to greater likelihood of serious deficiencies, which means the necessity of early replacements and costs that could be avoided.

4.4. Proposal of a maintenance plan

Based on all the information obtained with the analysis of the various case studies, and having as a support the studies developed by [8] and [12], a proposal for a maintenance plan of green roofs in Mediterranean climate was developed (table 4,5 and 6). This plan consists on the description of all maintenance actions, monitoring and inspection, with the frequency that they should be carried out and those responsible for their implementation.

Table 4. Maintenance plan proposed for intensive green roofs, Participant – Owner.

Type of actions	Code	Maintenance actions	Specifications	Frequency			
				1º Phase	2º Phase	3º Phase	
I	I01P	Inspection of drainage systems	✓Check if the elements are cleaned. ✓Check if the elements are unclogged. ✓Check if there are accumulations of water. ✓Check the physical integrity of the elements.	2 in 2 months ✖	2 in 2 months ✖	1/month ✖	Owner
	I02P	Inspection of trims	✓Check if there are detachments, displacements or cracks.	1/year	1/year	2/year	
	I03P	Inspection of masonry elements	✓Check the physical integrity of the elements.	1/year	1/year	2/year	
	I04P	Inspection of paths	✓Check for cracks or broken elements. ✓Check for cleanliness.	2 in 2 months	2 in 2 months	1/month	
	I05P	Visual inspection of the vegetation´s general state	✓Check for presence of dead vegetation. ✓Check if the vegetation is away from the singular points.	2 in 2 months	2 in 2 months	1/month	
	I06P	Inspection of automatic irrigation systems	✓check if they are functioning	2 in 2 months	2 in 2 months	1/month	
P	P01P	General cleaning	✓Keep the green roof clean and without garbage	1/month	1/month	2/month	
	P02P	Cleaning of vertical elements	✓Kepp the vertical elements such as perimeter walls, skylights, ventilation systems and acceses clean.	1/month	1/month	2/month	
	P03P	Cleaning of paths	✓Keep paths clean and unobstructed	1/month	1/month	2/month	

LEGEND:
I&M Inspection and Monitoring actions
P Prventive actions
✖ After bad weather and periods of intensive rain
✦ Whenever necessary
(⌘) If windy area

There were distinguished two types of maintenance actions: preventive actions (A) and the inspection and monitoring actions (I&M). In order to make it intuitive, it is proposed the division of the plan according to inspection and monitoring actions, which refers to all the actions of control and verification of the state of degradation of the green roof´s elements (does not involve physical interventions), and preventive actions, which refer to all operations to be implemented in the green roof to ensure its correct performance in-service and to prevent the onset of anomalies. Maintenance actions and their frequencies are closely related to the type of vegetation and the constructive solution.

Table 5. Maintenance plan proposed for intensive green roofs, Participant – Gardening teams.

Type of actions	Code	Maintenance actions	Specifications	Frequency			
				1º Phase	2º Phase	3º Phase	
I	I01J	Inspection and regulation of drainage systems	✓Check if all the elements are functioning properly. ✓Check if the system is properly regulated.	2/month ✖	1/week ✖	1/week ✖	Gardening teams
	I02J	Vegetation control	✓Check if the vegetation is outside their perimeters. ✓check if the clearances between vegetation and the singular points are respected.	2/month	1/week	1/week	
	I03J	Pests and infesting vegetation control	✓Check if there is any infesting vegetation	2/month	1/week	1/week	
	I04J	Inspection of the vegetation	✓Track the state of vegetation. ✓Track the state of the substrate.	2/month ✖	1/week ✖	1/week ✖	
	I05J	Large vegetation control	✓Check if the vegetation is anchored. ✓Check the integrity of anchors.	-	1/month (⌘)	1/month (⌘)	
	I06J	Control of plants and anti-slip systems	✓Check the physical integrity of the elements.	2/year	4/year	4/year	
P	P01J	Cleaning the drainage systems	✓Cleaning all the water collection elements. ✓Clearance of drains	1/month ✖	2/month ✖	2/month ✖	
	P02J	Irrigation	✓In the case of manual irrigation, ensure that all roof is sufficiently irrigated. ✓Ensure that the automatic irrigation system covers the entire roof area.	Every day	Every day	Every day	
	P03J	Fertilization	✓Ensure fertilization in adequate quantity.	✦	✦	✦	
	P04J	Plantation		✦	✦	✦	
	P05J	Pruning	✓Pruning the vegetation.	-	3/week	3/week	
	P06J	Infesting vegetation´s removal		✦	✦	✦	
	P07J	Soil Aeration		-	2/month	2/moth	
	P08J	Disposal and vegetation control	✓Keep vegetation within the desired perimeters. ✓Vegetation removal on paths. ✓vegetation removal along the vertical elements and singular points. ✓Ensure spacing between vegetation and water collection elements.	1/month	1/week	1/week	
	P09J	Treatment of the vegetation	✓Treating damaged vegetation.	✦	✦	✦	
	P10J	Removal of dry or dead vegetation		✦	✦	✦	
	P11J	Addition of substrate		-	✦	✦	
	P12J	Large vegetation anchoring	✓Anchoring vegetation at risk of falling. ✓Fix damaged existing anchors.	-	✦ (⌘)	✦ (⌘)	

LEGEND:
I&M Inspection and Monitoring actions
P Prventive actions
✖ After bad weather and periods of intensive rain
✦ Whenever necessary
(⌘) If windy area

Thus, it has been defined two separate maintenance plans with different maintenance actions and different frequencies, depending if it is an intensive or semi-extensive green roof. Note that the classification of the green roof´s types is according to [9] and [10]. The actions of inspection and monitoring were defined in the maintenance plan in order to allow identification of the pre-condition signals of anomalies. Compared to the proposal developed in [12], there were added some maintenance actions in order to avoid the appearance of some of the anomalies detected in the inspected case studies. Among others, it was added the collection of waters and path's cleaning. Since there have been detected anomalies in the inspected roofs, in which the maintenance actions are relatively frequent, and

considering the needs exposed by its responsibles, the plan proposed monthly and daily frequencies, quite distinct from those proposed by [12].

Table 6. Maintenance plan proposed for intensive green roofs, Participant – Specialized technicians

Type of actions	Code	Maintenance actions	Specifications	Frequency 1º Phase	2º Phase	3º Phase	
I	I01E	Inspection of waterproofing elements	✓Check the condition of the exposed sealing elements.	2/year	2/year	2/year	Specialized technicians
	I02E	Inspection of drainage systems	✓Check the physical integrity of all components. ✓Check whether there is a need for replace elements.	1/year	2/year	2/year	
	I03E	Control of gutters	✓Check accumulations of carbonates. ✓Check for elements with corrosion. ✓Check if there is need for replacement elements.	-	2/year	2/year	
	I04E	Control skylights and ventilation systems		1/year	2/year	2/year	
	I05E	Control and regulation of anti-fall safety measures		1/year	2/year	2/year	
	I06E	Deep inspecting of waterproofing membrane		5 in 5 years			
	I07E	Deep inspections of thermal insulation		5 in 5 years			
	I08E	Inspections of the support		2 in 2 years			
P	P01E	Conservation of masonry elements	✓ Any interventions necessary to ensure the physical integrity of the masonry elements.	1/year	1/year	1/year	
	P02E	Technical cleaning of drainage systems	✓More specialized cleaning actions such as the removal of carbonates.	-	1/year	1/year	
	P03E	Replacement of drainage filters	✓Only if necessary	-	-	✦	
	P04E	Replacement of mastic trims	✓Only if necessary	6 em 6 years			
	P05E	Replacement of asphalt membrane´s trims	✓Only if necessary	12 in 12 years			
	P06E	Replacement of metalic trims	✓Only if necessary	15 in 15 years			
	P07E	Replacement and repair of thermal insulation	✓Only if necessary	✦	✦	✦	
	P08E	Substitution of bituminous membranes	✓Only if necessary	15 in 15 years			
	P09E	Substitution of the drainage system´s elements	✓Only if necessary	-	-	✦	
	P10E	Unplanned interventions	✓Any necessary measures whenever it is detected any anomalies such as stains, infiltrations, cracks or detachments in the support or any other element.	✦	✦	✦	

LEGEND: I&M Inspection and Monitoring actions; P Prventive actions; ✖ After bad weather and periods of intensive rain; ✦ Whenever necessary; (⌘) If windy area

5. Conclusions and future work

Several factors can contribute to the correct performance of green roofs, with the correct specification by the designers and the correct maintenance as key factors. This paper analyses the in-service performance of ten green roofs, representative of the Mediterranean climate, and the respective maintenance actions implemented. All inspected green roofs have regular maintenance, mainly concerning gardening operations. In-situ surveys are a key instrument to portray the real in-service requirements. It was presented a systematization of the information collected using visual inspections and data collection from designers, owners, installers and/or gardeners. As shown in the in situ survey, there is a general concern in maintaining the vegetation layer, but in most cases the maintenance of other key elements is ignored. This maintenance plan is intended to serve as a contribution to the subject of green roof´s maintenance. To do so, and based on the results obtained previously, the following aspects have been incorporated:

- ➢ It was considered necessary to distinguish between maintenance plan for intensive green roofs and semi-intensive green roofs. No plan for extensive green roofs was proposed, for not having been inspected a representative case.
- ✓ It was considered important to organize the plan, making it easy to read and apply. Therefore, the plan is divided according to the responsible entity. Each entity has a list of actions that is responsible, in which are distinguished the inspection and monitoring actions from the preventive actions.

- ✓ There are proposed frequent inspections to the drainage systems. In order to prevent the appearance of anomalies in drainage systems and, consequently, other elements of the roof, the maintenance plan proposes that these inspections are carried out by the owner, the gardening team and technical experts. The owner is responsible for carrying out many of the maintenance actions proposed. Since he has easy access to the roof and can represent no additional costs, it is proposed that the owner may be more involved, particularly with regard to conducting visual inspections and cleaning actions.
- ✓ It was suggested that interventions are more frequent, thus increase the ability to predict and prevent the appearance of anomalies.
- ✓ Inspections and monitoring to all the green roof´s elements should be conducted by different actors. However, in order to increase the capacity to prevent future anomalies, it is proposed that the specialized technicians conduct inspections of all the elements, as they have a deeper knowledge.

Future work includes additional inspections for green roofs in other locations and also with extensive typology. It may be also interesting to study more deeply the relation between frequency and maintenance costs, developing a maintenance plan that is adequate to green roofs in Mediterranean climate with minimum costs possible.

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