Green Roof Technical Performance Assessment

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1 Introduction

Throughout the nineteenth and twentieth centuries, the world population grew at a rapid pace resulting in a strong expansion of the cities. Given this growth and multiplication of the cities, there has been an increase in environmental risks (destruction of natural habitats), the climate has suffered many changes showing some extreme weather events, and there has also been the creation and evolution of less ecological mass construction. Therefore, and to mitigate and control the effects of this mass construction, there was a need to stimulate the development of green roof systems. This type of construction has been strongly adopted in developed countries, even though in Portugal the use of this type of roof has not been very used, due to the lack of information and the lack of incentives for its implementation.

Due to the growing use of this type of construction in more developed countries, there was the need to regulate and create technical guidelines in order to certify it. The first norm to be established was in 1989, referred to as FLL (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V), in Germany [1].

This German guideline was the base for all other technical guidelines used in different countries, such as Malaysia, Spain, England, among others.

2 Green Roof Technology

Green roofs are classified in relation to their typology, as they can be characterised in three major groups: extensive, semi-intensive and intensive.

The extensive roof is characterised for requiring a lower maintenance and essentially consists of perennial plants, in other words, self-regenerative. The plants used in this type of roof are somewhat evasive ([2] and [3]).

The semi-intensive type of roof is considered an intermediate point between the other two groups, which is characterised by being able to have small shrubs in its composition and, therefore, the roots in this type of roof are slightly deeper than in the extensive type ([2] and [4]).

The intensive type of roof requires a special maintenance, because it may contain small trees and most of the plants used in this type have a deeper root, in such a way that the minimum thickness recommended for the substrate layer is 30cm [3]. Due to the increased probability of visiting this roof, is the layers of the system need to be dimensioned for this fact [5].

The objective of creating incentive measures for the construction of Green Roofs is to change society's behaviour. There are many measures that can be taken, and so, many countries and cities have adopted various incentive or mandatory measures so as to increase the use of green roofs [6].

The most common measures have been, respectively, the implementation of taxes, subsidy programmes, loans, reduction or increase of council taxes and obligation measures.

The tax is a type of programme that involves the implementation of a reduced tax when the user applies a specific product or system, which in this case is the use of green roofs [7].

The subsidy programme aims to help with the start-up costs for the construction of the roof ([7] and [8]).

When a measure, such as a loan, is implemented, the user may use up to a certain monetary amount with a lower interest rate than the current rate in the market ([7] and [3]).

The implementation of a reduction/increase in council taxes is usually connected to costs or reduction of costs, depending on whether or not a certain measure is applied. For example, in the case where a green roof is used, the area concerning that space is not considered construction area. If this measure is not applied, the user will be subject to a surcharge on that same area ([7] and [3]).

In a situation where there is an obligation measure, all citizens must apply the new measure, and if they do not comply with this, they may incur a penalty or the non-validation of the project may occur ([9] and [10]).

It is observed that the adoption of these measures is common in countries that seek to mitigate actions such as flood peaks, heat-island effect, among others.

The technological progress in the implementation of green roofs has been steady, thus making it possible to obtain better performance from green roofs. Currently there are four types (three traditional and one inverted) of green roofs prescribed under the FLL norm (2008) [2], which are the following:

- Unvented roof without thermal insulation (Figure 1) – It is characterised for being able to hold any type of roof. The use of this technology requires special attention regarding the type of climate existing in that area, because if they are applied in areas with temperatures that are usually lower than zero degrees Celsius, protection measures must be taken against the formation of frost in the lower layers of the roof;

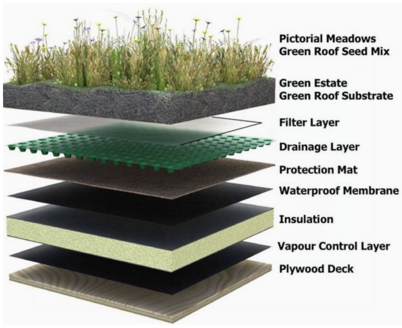

Figure 1 – Traditional roof (http://www.minimalisti.com)

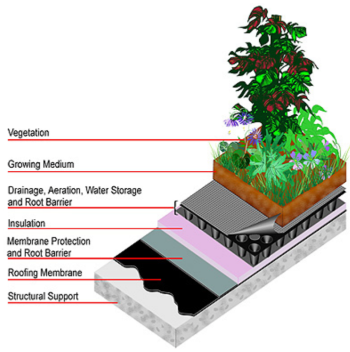

Figure 2 – Inverted roof (http://www.lid-stormwater.net/greenroofs_specs.htm)

- Unvented roof with thermal insulation – it is not conditioned by the typology of the roof used, however, due to the use of thermal insulation, the roof should be previously dimensioned considering the weight it must bear. In the case where this previous dimensioning does not take place, degradation or even rupture of the roof may occur;
- Vented roof with thermal insulation – this type of technology requires special care in relation to its thermal insulation resistance, due to its inability to withhold the pressure exerted by the vegetation and also due to the possibility of its permanent deformation.
- Inverted roof (Figure 2) – The arrangement of the layers is different from traditional roofs, because the thermal insulation is located under the waterproof layer. Due to the abovementioned factor, water resistance should be its basic requirement.

Concerning the technology of the multi-layer system, it consists of several layers, which are: support layer or slab, shape layer, waterproof layer, anti-roots protection layer, thermal insulation, drainage layer, filter layer and substrate.

The support layer is a structural element of the building whose function is to sustain the roof and it should meet the regulations in force. In Portugal the previous regulation in force was the RGEU (General Regulation of Urban Construction), but due to globalization, the roofs began to respect the dimension and requirements prescribed in the Euro Codes Regulation. The support layer should be dimensioned taking into account three types of loads: Dead Load, Live Load and Transient Load. These loads include their own structural actions, occasional actions such as snow and wind, and actions that result from visits and maintenance to the roof [11]. Another criterion that the designer should keep in mind is the load variation due to soil saturation, where a saturation of 65-70% should be considered.

The shape layer creates a slope in order to facilitate roof drainage in which the minimum value indicated in RGEU is 2% [3]. For high slopes (> 15%) adjacent measures should be taken to ensure a good technical quality of the roof.

The waterproof layer is generally characterized by a bituminous membrane whose function is to withstand the hydraulic pressure and ensure the sealing of the roof. This layer should have an additive with anti-root properties.

The root barrier layer is intended to protect the bituminous layer against the actions of the roots from the roof plants, and may be of a physical or chemical nature [12]. This layer can be applied directly on the waterproof layer (chemical) or by applying an independent membrane (physical) [13].

The purpose of thermal insulation is to improve the thermal performance, increase thermal comfort and prevent condensation during periods of lower temperature. It should be water-resistant in the inverted roofs and in traditional roofs any type of insulation may be used, however, a vapour control layer is required ([14] and [15]).

The drainage layer has the function of draining excess water from the roof [5]. This may consist of a geotextile or a plate that is similar (aesthetically) to a carton of eggs, as shown in Figure 3. This layer is directly related to the drainage system of the roof.

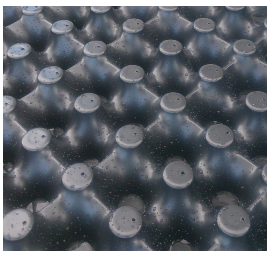

Figure 3- Drainage Layer

The filter layer is intended to hold the fines or residues from the roof, thus enabling a good performance of the next layer (drainage layer) [5]. The material used for this purpose is the geotextile, which should withstand the mechanical actions of the roof, ensure a good permeability and remain unchanged in its composition when in the presence of the substrate [3].

In terms of the substrate, it can be divided into three types, a mixture of soils, substrate boards and substrate mats [2].

2.1 Green Roof Performance

The green roof technical performance meets the minimum requirements that the designer and the builder should consider at the time of its design and construction. Based on the most common international norms and technical guidelines (FLL (2008), NTJ 11C (2012) and GRO (2014)), an analysis was drawn up of those minimum requirements, differentiating them among the different typologies.

It was observed that concerning the extensive roof, the waterproof layer (bituminous layer), should have a minimum thickness of 6mm, and it should have a minimum tension resistance higher than 1kN, in order to support the other layers. Regarding the drainage layer, it should allow the drainage of excess water and in the case of choosing a granular drainage, it should have a minimum thickness of 10 cm, and the diameter should be lower than 0.68cm or 6.8mm. The minimum slope to be used in this type of roof is 2%, yet it is advisable to use 5%.

It was observed that regarding the semi-intensive roof (Table 1), the information for this typology is not exact as it is at an intermediate point between the other typologies. However, the waterproof layer should have a minimum thickness of 12mm, if it is a bituminous layer. Concerning the drainage layer, it should have a minimum thickness of 3cm and the filter layer, which is formed by a geotextile should have a density of 200g/mm2, a traction resistance of 2kN and a penetration resistance of 4kN. The substrate should have a minimum thickness of 15cm.

It was observed that in the case of an intensive roof, the minimum requirements were higher, due to the increased weight of the roof. Thus, it was found that the waterproof layer (bituminous membrane) should have a minimum thickness of 20mm and should be able to resist to a simple compression of 3kN. The drainage layer should have a minimum thickness of 8cm and have a minimum slope of 5%. The filter layer should have a density equal to or higher than 200g/mm2, a traction resistance of 3kN and a penetration resistance of 4kN. The height of the substrate should be at least 50cm. For this type of roof, it is advisable to choose an intermediate granular layer, which is placed between geotextiles after the drainage layer.

Table 1- Pre-requisites for a Semi-Intensive Roof

Technical Guidelines	Layers	Pre-selection or pre-dimensioning requirements
FLL, 2008	Waterproof layer	Used in the extensive roof
	Drainage Layer	
	Filter layer	Used in the extensive roof
	Substrate and vegetation	• Higher than 12 cm; • Due to the diversity of roof plants, the mixture of substrate in the roof may be variable
NTJ 11C, 2012	Waterproof layer	Ability to resist loads of value: [150-350] N/m^2
	Drainage Layer	
	Filter layer	Ability to support a hydraulic load of 10cm
	Substrate and vegetation	• Thickness between [10–25] cm; • Low growing vegetation or short in height.
GRO, 2014	Waterproof layer	
	Drainage Layer	
	Filter layer	
	Substrate and vegetation	Thickness between [10 and 20] cm

3 Market Analysis

The market analysis focused on the analysis of the waterproof, drainage and filter layers, where 53 products, 11 products and 30 products were analysed, respectively.

The analysed products are produced by the following companies: ALWITRA, BARRETT ROOFS, DANOSA, FIRESTONE, IMPERALIUM, OPTIGREEN, PROTAN, RENOLIT WATERPROOF, RESITRIX, SIKA, SOTECNISOL and TEXSA.

The root barrier layer was not assessed, as one of the factors that was supposed to be assessed was the waterproof layer's resistance capacity to root penetration. The thermal insulation was also not evaluated as it does not represent a critical situation for the good functioning of the system. The substrate was also not analysed due to its composition variation and the possibility to select different types of substrates. These were classified according to the technical guidelines FLL and NTJ 11C, and some of these products also had, as criteria, the pre-requisites obtained in the roof technical performance analysis.

3.1 Waterproof Layer

The waterproof layer had, as a method, the analysis and norm distinction present in the FLL, 2008 and NTJ 11C of 2012, as well as the "CE" certification.

In this analysis, it was possible to verify that 45.3% of the analysed products complied with the root penetration resistance norm, prescribed in the technical guidelines NTJ 11C. It is possible to state that all the products that complied with the norms prescribed in the FLL, complied directly with the NTJ 11C norms [16].

Products from North America were also analysed, but these will not be applied in Europe for the time being. After analysing the products of this typology, it was possible to observe that some of the products that obtained the approval of "applicable" were ALWITRA Evalon V, Firestone UltraPly™ TPO roofing membrane, IMPERALUM POLYS R 40 GARDEN, among others.

3.2 Drainage Layer

The drainage layer was analysed based on the pre-requisites prescribed in the assessment of "Green Roof Performance" and, according to more common international norms prescribed in the products. From these criteria tables were created, which are similar to Table 2.

As the assessed product is recent in the market, it was verified that norms used to analyse it, are not the most adequate, given that these are used to analyse geotextile products. From the sample of 11 products, 63.6% obtained the classification of "applicable". Products such as OPTIGREEN FKD 60 UK-BU and IMPERALUM PLATON DE 25 obtained the approval of "applicable".

Table 2- Table of drainage layer product assessment (example)

	Product	Relevant Criteria		Proposal		CE Brand	Applicable
Company		DIN EN ISO 25619	DIN EN 13252	Thickness >30mm	Resistance to compression >2kN		
SOTECNISOL	DANODREN H15	✖	✖	✖	✖	○	No
OPTIGREEN	BOARD FKD 60 BO (G)	✔	✖	✔	✔	○	Yes
IMPERALUM	PLATON DE 25	✖	✔	✔	✔	✔	Yes
DANOSA	DANODREN JARDÍN	✖	✖	✖	✔	✔	Yes

Key: ✖ (does not comply/not applicable), ✔ (complies), ○ (no information)

3.3 Filter Layer

The assessment of the filter layer was based on the pre-requisites of the FLL, 2008 and NTJ 11C of 2012. It is noteworthy that the German norm FLL states that these should be in accordance with the "FGSV" (Road and Transportation Research Association).

It was observed that only 13.3% of the total products analysed (30) obtained the classification of applicable. Some of these products were OPTIGREEN SSV 800 and IMPERALUM IMPERSEP 300.

3.4 Products produced as a group ("kit")

The products certified as a group, referred to as kit, are assessed as a group and currently there are 3 certified kits. The certification is referred to as ETA, and thus the existing ETAs are the 13/0534, 13/0557 and the 13/0668, in which case the first two belong to the company OptiGreen and the last one belongs to Zinco. ETA 13/0668 was the first product certification as a group [17].

These products have advantages and disadvantages in relation to the multilayer system. The main advantage is the fact that the whole group is certified, but there are layers that do not belong to the kits and as such, may create incompatibilities with the kit.

3.5 Results obtained from the market analysis and the analysis between the multilayer system and the "kit"

Through the market analysis, it was observed that not all the products are in accordance with the technical guidelines. The waterproof layer is the multilayer system layer that complies most with the norms prescribed in the technical guidelines. The drainage layer which had its recent products in the market analysed, indicated that there are no norms referring to this type of material yet. The filter layer, being one of the layers in the system that may limit the performance of the subsequent layers, showed through the sample that it does not comply with all the requirements prescribed in the technical guidelines. It was also observed that none of the products being analysed complied with the "DIN EN 12225" prescribed in the technical guideline FLL [2].

When comparing the use of the "kit" with the multilayer system, there is a layer (waterproof) that is still not included in the analysis at the moment of certification. Therefore, there is the risk of causing damage due to the incompatibility of the two products. The multilayer system is a slow process, in relation to the "kit", but it allows the designer to carry out an analysis of the products and select the products in accordance with the intended objective.

4 Case Study: "Expansion of the Santander Totta Headquarters"

The case study focused on a recent work performed during the dissertation. Thus, it was possible to observe several factors, including the precautions to be taken when placing the different layers so as to not cause initial anomalies.

It is located in Lisbon, more specifically in Rua da Mesquita 6/6A.

The company FV architects was responsible for directing and coordinating the project, and the VHM company was responsible for the inspection. PROAP was the company responsible for the landscaping project of the contract.

This work has, in its composition (green roofs), two typologies of different roofs, an initial one that corresponds to the roof, where small slopes were made and covered with small shrubs, and inner courtyards areas which contain different species of herbaceous. The placement of this type of roof intended to join the green corridor of Monsanto, as well as allow atmospheric contact of the lower floors.

The green roof, with a total area of 3840m2., used up only about 1% of the total cost of the work, which had the total cost of about 15 million and 350 thousand euros.

The work began on 4 December 2015, with an initial deadline of 16 months, which was extended to 20 months.

This work also includes an additional system of grey water recycling, intended for the use of roof irrigation, flushing system, urinals and washing faucets in the waste room and garage. The water recycling system consists of a water treatment plant and two reservoirs which add up to 35m3. If the system does not meet the building requirements, there is, as an alternative, an additional network of cold water from the public network.

For the watering system of the roof and patios, different types of systems, such as sprinkling and drop-by-drop irrigation, were used.

4.1 Construction concerns

While performing the work we observed that a special care was given, in order to eliminate the anomalies arising from construction errors or dimensioning with less care. The most common anomalies in the support layer are splitting / cracking, deformation, collapse, breaking apart, humidity and infiltrations. In order to mitigate these potential anomalies, various materials were used, such as geocells, non-calcareous stone, suction drainage systems (which allows the roof to have a constant water level in the whole roof).

The geocells were filled with expanded clay so as to reduce the load on the support layer, thus preventing the appearance of anomalies due to excessive load. In the waterproof layer the most frequent anomalies are cracking or fabric tearing, piercing, blistering or air pockets, decomposition of singular points of water accumulation and appearance of corrosion. Leakage tests were performed (Figure 4) to the various roofs, suction drainage systems (Figure 5) and metal profiles with corrosion treatment were used, among other methods and materials, in order to assess its proper implementation.

In the remaining layers system and substrate, the most common anomalies are sliding and erosion contraction / retraction / cracking and therefore drop-by-drop systems were used, which are only active depending on the soil moisture and on the creation of small separated slopes.

Figure 4- Leakage Test

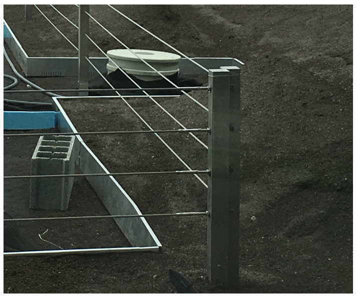

Figure 5 Drainage system

4.2 Alterations

During the work there were changes regarding the green roof installation company, and the inspection company adopted a more viable proposal (economically) for the solution proposed in the project. Consequently, the installation company was the company Ferrovial, using products from the company Diadem. The inspection, represented by the company VHM, elaborated a comparative study (Table 2) for the two proposed options, the solution defined in the project, belonging to the company ZINDO and an alternative solution belonging to the company Ferrovial.

The parameters, such as compliance with the regulations present in the FLL technical guidelines, the ETA certification, a system proposed by BST (Banco Santander Totta) certified by an ETA or EOTA, CE marking for all the proposed components, compliance with guidelines defined in the NTJ 11c technical guidelines and the guarantee given for the work, were assessed.

Table 3 - Comparison of solutions for the roof [18]

Components	**Solution defined in project - Zinco**	**Alternative project Ferrovial – Diadem**	**Observations/ Comparison**
Waterproof Layer	POPLYPLAS 30 + POLYXIS R50	POPLYPLAS 30 + POLYXIS R50	There is no alteration in the product (production company Imperalum)
Thermal insulation	ROOFMATE DOW	ROOFMATE DOW	There is no alteration in the product
Seperating layer	TGV 21	VTL 100	The alternative company had a higher traction resistance.
Drainage layer	FLORADRAIN FD 40 E	DIADRAIN 60	The alternative product had a higher drainage capacity and higher water holding capacity.
Modelling of land	Terracell 350/100 + Brita	Substrate Compound	The product “substrate compound” has a lower weight and as such is a most advantageous solution
Filter layer	TG	VLF 200	The product VLF 200 showed higher permeability

Table 3 - Comparison of solutions for the roof (Continuation)

Soil with compound	Manufactured using mineral based components	Mixture composed of sand, clay, organic matter with low biodegradability and coarse minerals	The composition of the substrate is similar
Vegetation	Defined in the Landscaping Project	Defined in the Landscaping Project	It has no influence in the assessment of the solutions as it depends on the landscaping project.

Concerning the analysis of the parameters analysed, it was observed that one of the company's products defined in the project did not comply with the CE norm.

It was possible to observe that the guarantee proposed by the alternative company is higher than the guarantee proposed by the company defined in the project, and this difference is of 5 years.

4.3 Maintenance and guarantees

The maintenance of the roof and green areas are under the responsibility of the contractor, with some limitations in their activities, such as pruning. This can only be carried out if the work inspection company allows it [19].

The guarantee of the plants and trees are, respectively, for 1 and 3 years.

5 Conclusion and future developments

The increase in mass construction of new buildings has not only been destroying habitats but also reducing green spaces within cities.

The use of green roofs is a solution that aims to reduce the several adjacent effects of this growth, and as such, the need for the products to be in accordance with the technical guidelines is essential. This need has to do with the fact that it creates guarantees for its different intervenors and its users, respectively, the designer, the owner of the construction work, the builder and user.

The international market, mainly northern Europe, has had a very high growth in relation to the other countries of the world. Nevertheless, there are several cities spread out throughout the world which find that the use of this construction method has advantages, not only for the city but also for the citizen.

Through market analysis, it was possible to observe that not all products in the market can be used, however, this is an emerging market. It was possible to observe that the technical guidelines are references for the choice of products as well as for their certification, even though some existing products in the market are not in accordance therewith. In Portugal, it appears that the lack of information on the subject and the lack of incentives as to their use, limits its use, and this is a new market within the borders.

Being this a recent and possibly emerging market in Portugal, it would be advantageous to carry out the survey of the specific requirements to be applied as well as the creation of a specific technical guideline for Portugal. It would therefore be possible to use products with national certification and proven quality.

By conducting the case study it was possible to analyse not only the market analysis, but also the possibility of using additional systems to the roof. The use of grey water treatment systems is an advantage in the adoption of this type of construction method. Thus, it would be advantageous to conduct an assessment of this system in relation to the water cost savings, as well as an assessment of the electricity cost reduction, due to the green roof.

The major limitation when carrying out this dissertation, was due to the lack of national legislation on the topic discussed, as well as the reduced implementation of this method.

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