Comparative environmental life cycle impact of water-proofing solutions for flat roofs. Application of the studied solutions in the rehabilitation of military infra-structures

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Extended abstract

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1. Introduction

A growing concern with the environment and with how natural resources are used has been noticed in recent times. This concern is partly because it was concluded that the rate of natural resources production is slower than the rate of consumption of those materials. The consequence may be a shortage of some of these resources in the short term.

This study intends to evaluate the environmental and economic impacts of the production and use of construction materials, in particular materials used in the waterproofing of flat roofs. The waterproofing of flat roofs is one of the most important factors to take into account in its execution, because the water tightness of the roof depends on the performance of this layer.

This dissertation intends to compare the impact of the life cycle of several current solutions of waterproofing of flat roofs. This assessment covers the production and use stages, as well as the most relevant features of each solution. The result will be a comparative table of the various solutions of waterproofing in terms of life cycle cost and environmental impacts, for each type of flat roof defined.

2. State of the art

Man has discovered in the beginning of evolution that, to survive, it is not sufficient to hunt and to defend him from animals. After the appearance of the first "houses", meteorological factors led to the development of building roofs, not yet similar to those used nowadays, but with the same function (OLIVEIRA, 2009).

However, human needs evolved, and today there are roofs with the most varied forms and constitutions (OLIVEIRA, 2009). "A flat roof of a building includes all the elements, not only the structural elements, from the ceiling of the underneath space to the surface exposed to the weather, arranged in horizontal layers or close to this position, which, by their very nature, allow it to comply with the main requirements demanded from roofs" (ALVES, 2013).

Flat roofs may have the following components, with the following location sequence: slab, lightweight concrete, vapour barrier, agglomerate of expanded cork, waterproofing layer, geotextile mat, and screed and cladding materials. In this study, the emphasis will be only in one of the components of flat roofs: the waterproofing layer.

3. Environmental life cycle assessment of waterproofing solutions

The main materials used in waterproofing of flat roofs in Portugal are: bituminous membranes (APP and SBS), synthetic membranes (PVC, TPO, HDPE and EPDM), liquid materials (bituminous, acrylic, epoxy and polyurethane) and cement-based membranes (single and two-component) (POMBO, 2014).

One way of dealing with the need of quantifying the environmental impacts of products was the development of the Life Cycle Assessment (LCA) Methodology. According to NP EN ISO 14040:2007, an LCA is the "compilation and evaluation of the inputs, outputs and potential environmental impacts of a product throughout its life cycle." In this work, only the product stage is considered (A1-A3).

To obtain information related to the performance of these materials, databases (Ecoinvent, PlasticsEurope2005 and the ELCD) and Environmental Product Declaration (EPD) databases (IBU, BRE, Norwegian EPD Foundation, INIES, Environdec and DAPc) were searched for. An EPD is considered to be "the most complete and credible environmental labelling" (CAPETILO, 2010).

After excluding the databases that did not contain EPD for waterproofing materials, an exhaustive search was performed of the remaining ones. Finally, EPD were found only for bituminous (without distinction between polymer APP and SBS), bituminous with SBS, and synthetic membranes (PVC, FPO/TPO and EPDM). In Table 1, available data sets are summarized.

Table 1 - Summary of available LCA data sets

Waterproofing solution	Product	IBU	INIES	Norwegian EPD Foundation	Environdec	Ecoinvent
Bituminous membranes	APP/SBS	0	0	5	1	6
Synthetic membranes	PVC	4	3	6	3	0
	TPO/FPO	7	0	2	0	0
	HDPE	0	0	0	0	0
	EPDM	1	0	0	0	0
Liquid membranes	Bituminous	0	0	0	0	0
	Acrylic	0	0	0	0	0
	Epoxy	0	0	0	0	0
	Polyurethane	0	0	0	0	0
Cement-based membranes	Single component	0	0	0	0	0
	Two-component	0	0	0	0	0

Based on the data collected, a relationship between the environmental impacts of each of the solutions will be determined, in order to allow the comparison of several alternatives for the waterproofing of flat roofs.

3.1. Environmental impact categories

The environmental impact categories used were: global warming potential (GWP), acidification potential (PA), eutrophication potential (PE), ozone layer depletion potential (PDCO), abiotic resources depletion potential (PDA), photochemical ozone creation potential (PCFO), and consumption of renewable (CRE-R) and non-renewable (CRE-NR) primary energy resources.

In each database, not all necessary information was available. In Table 2, it is possible to observe the environmental impact categories considered in each of the databases.

Table 2 - Environmental Impact categories considered in each data base

Data base	PAG	PA	PE	PDCO	PDA	PCFO	CRE-R	CRE-NR
IBU	x	x	x	x	x		x	x
INIES	x	x	x	x	x	x	x	x
Norwegian	x	x	x	x		x	x	x
Environdec	x	x	x	x	x	x	x	x
Ecoinvent	x	x	x	x	x	x	x	x

3.2. Environmental performance of waterproofing products

The application of the NativeLCA methodology enables the selection of consistent LCA data sets to be used as generic to represent waterproofing materials in the national context. According to this methodology, the first step is to define the scope and aim. The scope of the methodology is defined by (SILVESTRE et al, 2015):

- The functional unit of the study: the production of a square meter of membrane;
- The characterization of the construction material that will be the object of this study: different types of waterproofing materials available in the European market;
- The LCI and LCIA parameters that will be considered: it was decided to do a standardisation of environmental impacts from the Ecoinvent database, in particular of bituminous membrane sealing V60. It was concluded that the three more relevant categories are: acidification, global warming and abiotic depletion (the CRE-NR category was selected instead of PDA because it is present in all EPD).

Table 3 has the results of the application of NativeLCA methodology to each type of membrane. In the bituminous case, the generic database Ecoinvent has been excluded from the calculation of the average value, as it does not has enough geographical or temporal representativeness.

4. Economic life cycle assessment of waterproofing solutions

4.1. Life cycle cost methodology

The economic impact of a waterproofing solution is calculated using the Life Cycle Cost (LCC) methodology, which is a process that allows the evaluation of the economic performance of a product during its life cycle (REIDY, 2005). The functional unit considered for each type of membrane is "one square meter of waterproofing, during 50 years".

The life cycle cost of each waterproofing solution must be calculated for a period of 50 years, taking into account their different durability values, to make them comparable. To compare the solutions under study, the concept of Net Present Value (NPV) was used through the application of equation (1).

$$NPV = \frac{C_n}{(1+t)^n} \quad (1)$$

In which:

C_n - economic cost of the solution in year n;

t - annual discount rate (without risk) applied (2%).

Table 3 - Summary of the decisions taken at each step of the application of NativeLCA for the membranes in study

Waterproof-ing solution	Consistency and representativeness	Suitability to be used in the quantification of mean values (MeVa)	Selection of a coherent LCA data set to be used as generic for a national context: NativeLCA
Bituminous membrane	Eliminated data sets: two Ecoinvent data sets referring to bituminous membranes with aluminium self-protection	Calculation of total European mean value (MeVa) without packaging	European MeVa for the production of one kilogram of bituminous membrane without packaging (A1-A3.1)
Synthetic membrane - PVC	All data sets were considered valid	Calculation of total European MeVa, with and without packaging	European MeVa for the production of one kilogram of PVC membrane with and without packaging (A1-A3 and A1-A3.1)
Synthetic membrane - TPO/FPO	All data sets were considered valid	Calculation of European MeVa, with and without packaging	European MeVa for the production of one kilogram of TPO/FPO membrane with and without packaging (A1-A3 and A1-A3.1)
Synthetic membrane - EPDM	All data sets were considered valid	Calculation of European MeVa, with packaging	European MeVa for the production of one kilogram of EPDM membrane with packaging (A1-A3.1)

In the determination of the LCC, some simplifications were considered, since they do not have a significant influence on the results:

- The cost of punctual repairs were not considered due to the uncertainty and unpredictability of their occurrence;
- Only whole removals of the waterproofing system were considered;
- The removal cost of the existing waterproofing was not considered, because it can be negligible (in the case of synthetic membranes - PVC, TPO/FPO and EPDM) or it does not even exist (case of bituminous membranes);
- The demolition cost was not considered because it is admitted that it will happen in the year 50, and will be similar for every solutions.

4.2. Life cycle cost of each waterproofing solution

The durability of the membranes was defined as: 15 years for the top layer and 30 years for the bottom layer (system composed by two layers) of the bituminous membranes self-protected or with light protection in traditional systems, and 25 years when they are applied with heavy protection; 15 years for the synthetic - PVC without protection and 30 with heavy protection; 20 years for the synthetic - TPO/FPO without protection and 35 years with heavy protection; and 20 years for the synthetic - EPDM without protection and 40 years with heavy protection. Tables 4, 5, 6 and 7 present the characteristics of each of these types of membranes, including the life cycle cost (cost of acquisition, application and maintenance), updated to year 0.

Table 4 - Characteristics and life cycle cost of the bituminous waterproofing solutions (Imperalum, 2015)

Type of waterproofing solution	Type of accessibility	Type of flat roof	Self-protection	Additional protection	Life cycle cost (€/m²)
B1 - Bituminous membrane - polymer APP	Limited access	Inverted	No	Yes	15.87
B2 - Bituminous membrane - polymer APP	Limited access	Traditional	Yes	No	26.57
B3 - Bituminous membrane - polymer SBS	Limited access	Traditional	Yes	No	23.72
B4 - Bituminous membrane - polymer APP	Accessible to people	Inverted	No	Yes	19.64
B5 - Bituminous membrane - polymer APP	Accessible to people	Traditional	No	Yes	19.64
B6 - Bituminous membrane - polymer SBS	Accessible to people	Not specified	No	Yes	21.31

Table 5 - Characteristics and life cycle cost of the PVC waterproofing solutions (Imperalum, 2015; SIKA, 2015)

Type of waterproofing solution	Type of accessibility	Type of flat roof	Self-protection	Additional protection	Life cycle cost (€/m²)
PVC1 - PVC membrane	Accessible to people	Not specified	No	Yes	24.65
PVC2.1 - PVC membrane	Limited access	Inverted	Yes	Yes	25.47
PVC2.2 - PVC membrane	Limited access	Traditional	Yes	No	44.39
PVC3 - Plasticised PVC membrane	Limited access	Traditional	Yes	No	44.31

Table 6 - Characteristics and life cycle cost of the TPO/FPO waterproofing solutions (Danosa, 2015; Liners, 2015)

Type of waterproofing solution	Type of accessibility	Type of flat roof	Self-protection	Additional protection	Life cycle cost (€/m²)
TPO1.1 - TPO membrane - 1,14 mm thickness	Limited access	Traditional	No	No	36.56
TPO1.2 - TPO membrane - 1,14 mm thickness	Limited access	Inverted	No	Yes	26.58
TPO2 - TPO membrane - 1,5 mm thickness	Accessible to people	Not specified	No	No need	29.91

Table 7 - Characteristics and life cycle cost of the EPDM waterproofing solutions (Imperalum, 2015)

Type of waterproofing solution	Type of accessibility	Type of flat roof	Self-protection	Additional protection	Life cycle cost (€/m²)
EPDM1.1 - EPDM membrane - 1.14 mm thickness	Limited access	Traditional	No	No	43.71
EPDM1.2 - EPDM membrane - 1.14 mm thickness	Limited access	Inverted	No	Yes	29.87
EPDM2 - EPDM membrane - 1.5 mm thickness	Accessible to people	Not specified	No	No need	33.90

5. Economic and environmental life cycle assessment of waterproofing solutions

5.1. Economic and environmental life cycle assessment

To compare the solutions studied, only the environmental factors with more significance (CRE-NR and PAG) were chosen. The life cycle environmental impacts depend on the number of replacements of each membrane during the study period. After all the necessary results to perform the comparison of environmental and economic life cycle of membranes were obtained, comparable waterproofing solutions were defined. Thus, four groups of waterproofing solutions were defined, in accordance to the intended use: non-accessible flat roof (or limited access), traditional or inverted; flat roof accessible to people, traditional or inverted.

In the solution for the non-accessible flat roof, of the traditional type, the thermal insulation layer is located underneath the waterproofing layer. It corresponds to a roof that does not require heavy protection so, generally, the waterproofing membrane includes self-protection.

In the non-accessible roof, of inverted type, the thermal insulation layer is placed on the top of the waterproofing layer and an external protection of the thermal insulation is needed. A flat roof that is accessible to people, of both the traditional and the inverted type, always requires heavy protection. Tables 8, 9, 10 and 11, present the life cycle cost and environmental impacts (PAG and CRE-NR) for each type of waterproofing solution to be used in each type of flat roof considered in this study.

Table 8 - Life cycle cost and environmental impacts of waterproofing solutions used in limited access roofs, of the traditional type

Type of solution	Life cycle cost (€/m^2)	PAG (kg eq CO_2)	CRE-NR (MJ)
B2	26.57	13.40	623.55
B3	23.72	13.40	623.55
PVC2.2	44.39	26.33	608.40
PVC3	44.31	20.25	468.00
TPO1.1	36.56	7.13	189.21
EPDM1.1	43.71	23.04	467.49

Table 9 - Life cycle cost and environmental impacts of waterproofing solutions used in limited access roofs, of the inverted type

Type of solution	Life cycle cost (€/m^2)	PAG (kg eq CO_2)	CRE-NR (MJ)
B1	15.87	8.94	415.70
PVC2.1	25.47	13.16	304.20
TPO1.2	26.58	4.75	126.14
EPDM1.2	29.87	15.36	311.66

Table 10 - Life cycle cost and environmental impacts of waterproofing solutions used in roofs accessible to people, of the traditional type

Type of solution	Life cycle cost (€/m^2)	PAG (kg eq CO_2)	CRE-NR (MJ)
B5	19.64	8.94	415.70
B6	21.31	8.94	415.70
PVC1	24.65	13.50	312.00
TPO2	29.91	5.96	158.23
EPDM2	33.90	20.84	422.97

Table 11 - Life cycle cost and environmental impacts of waterproofing solutions used in roofs accessible to people, of the inverted type

Type of solution	Life cycle cost (€/m^2)	PAG (kg eq CO_2)	CRE-NR (MJ)
B4	19.64	8.94	415.70
B6	21.31	8.94	415.70
PVC1	24.65	13.50	312.00
TPO2	29.91	5.96	158.23
EPDM2	33.90	20.84	422.97

5.2. Case study - selection of the most adequate solution for the rehabilitation of military infrastructures

For the case study, the option was to consider the most appropriate waterproofing solutions to be used in the rehabilitation of military infrastructures instead of solutions for new construction. This decision results from the current context in Portugal, in which rehabilitation interventions are more frequent than new construction. Nevertheless, the analysis and the results achieved would be identical if the focus were in new construction.

Based on sub-section 5.1, the selection of the membrane to be used in the rehabilitation of a flat roof, can be based on three main parameters: life cycle cost, PAG and CRE-NR. To aid this decision, a multi-criteria analysis was used. The weights considered for each parameter were based on common sense. Considering current project practices in Portugal, more importance was given to the life cycle cost, because it is usually the only factor considered, and a lower and similar importance was given to each environmental impact category (embodied energy and carbon footprint), which are not usually considered by the designer: 70% for the total cost, 15% for the PAG and 15% for the CRE-NR. Summing up the value of the parameters in each category multiplied by the respective weights, a single indicator was calculated, which expresses the results related with the three categories. This method reveals the options with better and worse performance in economic and environmental terms. In Tables 12, 13, 14 and 15 the values obtained through the application of this multi-criteria analysis can be observed, for each type of flat roof.

Table 12 - Multi-criteria analysis for limited access roof, of the traditional type

Type of solution	Life cycle cost	PAG	CRE-NR	Multi-criteria indicator	Order of solutions
B2	0.60	0.51	1.00	0.65	3rd option
B3	0.53	0.51	1.00	0.60	1st option
PVC2.2	1.00	1.00	0.73	0.96	6th option
PVC3	1.00	0.77	0.56	0.90	4th option
TPO1.1	0.82	0.27	0.23	0.65	2nd option
EPDM1.1	0.98	0.88	0.56	0.90	5th option

Table 13 - Multi-criteria analysis for limited access roof, of the inverted type

Type of solution	Life cycle cost	PAG	CRE-NR	Multi-criteria indicator	Order of solutions
B1	0.36	0.34	0.50	0.38	1st option
PVC2.1	0.57	1.00	0.73	0.66	3rd option
TPO1.2	0.60	0.27	0.23	0.49	2nd option
EPDM1.2	0.67	0.79	0.51	0.67	4th option

Table 14 - Multi-criteria analysis for roof accessible to people, of the traditional type

Type of solution	Life cycle cost	PAG	CRE-NR	Multi-criteria indicator	Order of solutions
B5	0.44	0.34	0.50	0.44	1st option
B6	0.48	0.34	0.50	0.46	2nd option
PVC1	0.56	0.51	0.38	0.52	3rd option
TPO2	0.67	0.23	0.19	0.53	4th option
EPDM2	0.76	0.88	0.56	0.75	5th option

Table 15 - Multi-criteria analysis for roof accessible to people, of the inverted type

Type of solution	Life cycle cost	PAG	CRE-NR	Multi-criteria indicator	Order of solutions
B4	0.44	0.34	0.50	0.44	1st option
B6	0.48	0.34	0.50	0.46	2nd option
PVC1	0.56	0.51	0.38	0.52	3rd option
TPO2	0.67	0.23	0.19	0.53	4th option
EPDM2	0.76	0.88	0.56	0.75	5th option

6. Conclusions

This work intended to compare the environmental and economic life cycle of several waterproofing solutions, currently used. The proposed result would be a comparative table between the various solutions in terms of life cycle cost and environmental impacts.

In the case of the environmental performance of waterproofing solutions, NativeLCA methodology was used to select consistent data sets from LCA databases to be used as generic in national context. For each type of membrane, the values for three environmental impact categories were compared, and the consistency of the values obtained from each database was verified. Only in the case of bituminous membranes it was necessary to eliminate two data sets, because they include aluminium protection. For the bituminous and synthetic (PVC membranes) materials, the European MeVa was chosen for the production of one kilogram of membrane with and without packaging. In the case of synthetic membrane - TPO/FPO and EPDM, the European MeVa was chosen for the production of one kilogram of membrane with packaging.

To provide a consistent comparison, it was chosen to divide the membranes according to their intended use: limited access, traditional or inverted flat roofs, and accessible to people, traditional and inverted flat roofs. For each type of roof, several waterproofing solutions were compared in what concerns environmental impacts (global warming potential and consumption of non-renewable energy resources) and the cost of acquisition, application and replacement, over a 50 years period.

In the case study, the waterproofing solutions more appropriate for the rehabilitation of military infrastructures were selected, since this type of construction works is now more frequent than new construction.

For each type of flat roof, a multi-criteria analysis was used to allow the ranking of waterproofing solutions, from best to worst. By comparing the life cycle consumption of non-renewable energy resources, global warming potential and costs, it was concluded that, for all types of flat roofs in study, bituminous membranes are the best option, and the synthetic EPDM are those that present higher values.

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