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Environmental performance of recycled rubber as drainage layer in extensive green roofs. A comparative Life Cycle Assessment

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ABSTRACT

Using recycled rubber crumbs as drainage layer in extensive green roofs have high potential to reduce the heating and cooling loads in buildings over traditional materials used as drainage layer, such as pozzolana gravel. However, the environmental impact due to the life cycle should be analyzed to assess its environmental benefit. This paper evaluates the environmental performance of green roofs in which the drainage layer is made of rubber crumbs, a recycled material the use of which is still experimental for this purpose. In this paper Life Cycle Assessment (LCA) is applied to compare the environmental impact of four constructive systems, two extensive green roofs without insulation layer and with different drainage materials, – a recycled material, rubber crumbs, and a conventional one, pozzolana gravel -, in front of two conventional flat roofs, with and without thermal insulation (polyurethane), built in an experimental set-up consisting of four monitored house-like cubicles, located in Mediterranean continental climate (Lleida, Spain). The LCA considered the production, construction, operational, and disposal phases of the roofs, according to UNE-EN 15643-2. The operational phase was carried out using data measured in the experimental set-up, considering heating and cooling energy consumptions in the winter and summer period, respectively.

1. Introduction

Sustainable construction requires systems and materials that allow the integration of natural environmental processes in construction, such as extensive green roofs. Extensive green roofs have been consolidated in recent years as a construction system that offers interesting environmental advantages over traditional solutions, such as improving the durability of waterproofing materials protecting them from solar radiation [1], the reduction of surface runoff in large cities [2], the improvement of the urban environment [3,4], and energy savings [5–7]. Extensive green roofs are basically formed (from outer to inner layer) by vegetation, substrate, filter, drainage, protection, root barrier, and waterproofing layer [8]. However, their design is still based on conventional materials, in some cases non-environmentally friendly materials, such as polypropylene or polyester geotextile membranes, polyethylene or polystyrene panels, bitumen or PVC membranes [9]. The drainage layer is sometimes composed of aggregates of porous stone materials, e.g. expanded clay or natural pozzolana stone. It has to be taken into consideration that the aggregates extraction is the major extracted non-energy resource in these systems [10]. Moreover, the extraction of these stone materials leads to a large environmental impact, such as landscape destruction, impact associated to waste management, and other impacts arising from its later processing. For this reason, the use of natural stone in the drainage layer of the extensive green roof might be substituted by materials with lower environmental impact, such as recycled materials [11]. In conclusion, there is a need to replace current green roof materials by more environmentally friendly and sustainable products [12].

Nowadays a large volume of waste products, which are difficult to manage, are produced. A clear example is rubber from out use tires that meant the use of 3.2 Mt in 2009 in the EU27. About 2.6 Mt of end of life tires remained on the EU market for recovery and recycling. Alternatives for this problem, such as recycling and reuse of these materials [11] need to be found. The use of rubber crumbs as drainage layer in extensive green roofs can be a good way to reuse a material that is currently considered a waste.

Usually, Tire Derived Aggregate (TDA) is used as foundation for roads and railways, as a draining material replacement for sand and gravels, landfill construction, sub-grade fill and embankments, backfill for walls and bridges, and sub-grade insulation for roads.

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TDA is 30–50% lighter, provides eight times better insulation than gravel, and drains ten times better than well graded soil [13]. Likewise, preliminary studies show that the use of recycled rubber from tires, or rubber crumbs, is not dangerous for human health or for environment [14,15]. Thus, substituting the porous stone materials currently used (such as expanded clay, expanded shale, pumice, natural pozzolana, etc.) and using recycled rubber in drainage layer of extensive green roofs can meet both objectives: reducing aggregates consumption and recovering today's waste.

Previous research has considered the possibility of using rubber crumbs as a drainage layer in extensive green roofs. Vila et al. [8] analysed the study of the functional benefits of green roofs considering the possibility of using rubber crumbs as drainage layer in extensive green roofs instead of porous stone materials. Its results showed that rubber crumbs are a good substitute for stone materials used as drainage layer. Pérez et al. [9] studied the ability of recycled rubber crumbs for draining, and compared its hydraulic conductivity with pozzolana. The new solution was tracked in experimental extensive green roofs in trays in order to analyse the effect of recycled rubber on plants development. Different particulate sizes of recycled rubber crumbs were studied and compared with pozzolana. It was observed that the thermal behaviour of half-particulates and small-particulates rubber crumbs was similar to that of pozzolana. Therefore, they can be used interchangeably from the point of view of the drainage function of the system (substrate and drainage layers).

The environmental benefits of using rubber crumbs in extensive green roofs can be quantified by means of Life Cycle Assessment (LCA). LCA is a tool for evaluating the environmental impact of a product through analysing the corresponding life cycle phases from cradle to grave [16]. LCA has been previously applied to buildings and green roofs [17].

Previous experiences have compared the LCA of green roof systems with conventional flat roofs (insulated and non-insulated). Tselekis [18] compared green roof systems with conventional insulated and non-insulated ones in order to identify the potential energy savings of green roofs and the benefits provided in comparison with the cost of construction. Saiz et al. [19] carried out a comparative LCA of standard and green roofs, were the energy building use was simulated. It found that by replacing the common flat roof with a green roof, the environmental impacts were reduced between 1.0 and 5.3% due to the savings in annual energy use, especially in summer. Likewise, Kosareo and Ries [20] carried out an LCA on green roofs, comparing intensive and extensive green roofs versus conventional roofs. It found that the energy use reduction that is caused by the lower thermal conductivity of the roof, due to the green roof growing medium, is the critical factor in determining the relative magnitude of the environmental impact of the compared alternatives.

Moreover, LCA have been used to evaluate the materials composing green roofs. Some examples of this use is found in Peri et al. [21], which applied LCA methodology to extensive green roofs including the whole life cycle of the substrate, focusing on the role of fertilizers used for the green roof maintenance and on the disposal of substrate, which played a significant role in the whole LCA balance. Moreover, Bianchini and Hewage [12,22] focused on LCA of polymers. They evaluated the socio-environmental benefits of green roofs by comparing emissions of NO_2, SO_2, O_3 and PM_{10} in polymers manufacturing process, with the green roof pollution removal capacity. They demonstrated that green roofs are sustainable products in a long-term basis since they can balance air pollution due to the polymer production process in 25 years. They highlighted that current green roof materials need to be replaced by more environmentally friendly and sustainable products. Furthermore, Rivela et al. [23] applied LCA to quantify the environmental impact of the green roofs materials, showing the high environmental impact associated to the structure, the important contribution of the felt wick irrigation system, and the extruded polystyrene thermal insulation.

Many examples of LCA in green roofs are found in literature. However, there are still no experiences about the LCA of a recycled material such as rubber crumbs and its use as drainage layer in extensive green roofs. Moreover, most literature studies use simulations to estimate the energy consumption of the building during the operational phase, but there is a lack of analysis that are using measured energy consumptions obtained from experimentation in real winter and summer conditions.

The objective of this paper is to evaluate the environmental performance of green roofs in which the drainage layer is made of rubber crumbs, a recycled material the use of which is still experimental for this purpose. The present paper applies the Life Cycle Assessment (LCA) methodology on two constructive systems of extensive green roofs without insulation with different drainage material: a recycled rubber crumbs drainage layer is compared with a natural pozzolana gravel one. In addition, the LCA applied to both green roofs are compared with the LCA applied to two conventional flat roofs, with and without thermal insulation (polyurethane). The operational phase of the LCA is obtained from an experimental set-up consisting of four house-like cubicles with each type of roof, located in a Mediterranean continental climate (Lleida, Spain), where the energy consumptions of the heating and cooling period are measured.

2. Materials: experimental set-up in Puigverd de Lleida (Spain)

The experimental set-up consists of four house-like cubicles (Fig. 1) located in Puigverd de Lleida, Spain. Puigverd de Lleida is located at N 41° 32′, E 0° 44′, with an elevation of 219 m above sea level, and a Mediterranean continental climate. The annual number of heating degree days in Puigverd de Lleida is 1230 and the cooling degree days is 423 [24]. The average summer and winter temperatures are 22.6 and 8 °C, respectively. The annual precipitation is 456 mm.

The house-like cubicles have the same internal dimensions (2.4 × 2.4 × 2.4 m). Their bases consist of a mortar base of 3 × 3 m with crushed stones and reinforcing bars. The walls present the following layers from the inside out: plaster lining, alveolar brick (30 × 19 × 29 cm), and cement mortar coating. No additional insulation was used in these facades.

The only difference between the four cubicles is the construction system of their roofs:

a) Green roof with recycled materials (RB): It consists of a conventional flat roof (precast concrete beams and ceramic floor arch 25 cm), concrete relieved pending formation of 2%, double waterproofing membrane, and 4 cm of recycled

Fig. 1. Experimental set-up in Puigverd de Lleida.