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How “green” are the green roofs? Lifecycle analysis of green roof materials

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A R T I C L E I N F O

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A B S T R A C T

Green roofs can be classified as intensive and extensive roofs based on their purpose and characteristics. Green roofs are built with different layers and variable thicknesses depending on the roof type and/or weather conditions. Basic layers, from bottom to top, of green roof systems usually consists of a root barrier, drainage, filter, growing medium, and vegetation layer. There are many environmental and operational benefits of vegetated roofs. New technology enabled the use of low density polyethylene and polypropylene (polymers) materials with reduced weight on green roofs. This paper evaluates the environmental benefits of green roofs by comparing emissions of NO_2, SO_2, O_3 and PM_{10} in green roof material manufacturing process, such as polymers, with the green roof's pollution removal capacity. The analysis demonstrated that green roofs are sustainable products in long-term basis. In general, air pollution due to the polymer production process can be balanced by green roofs in 13–32 years. However, the manufacturing process of low density polyethylene and polypropylene has many other negative impacts to the environment than air pollution. It was evident that the current green roof materials needed to be replaced by more environmentally friendly and sustainable products.

1. Introduction

The construction industry is vital to provide the necessary infrastructure to satisfy human development needs. This professional sector provides multiple products to enhance the quality of life [42]. Importance of the construction industry is seen in its economic significance to the society and its direct social and environmental impacts [35]. It is recognized that construction practices are one of the major contributors of environmental problems, particularly due to the utilization of non-renewable materials. United States Green Building Council (USGBC) [46] estimated that commercial and residential construction buildings release 30% of green houses gases and consumes 65% of electricity in USA. Due to the well-known environmental issues (i.e. global warming, deforestation, waste generation, etc.), the concept of sustainability has been introduced to the construction sector.

Green construction aims to develop environmentally friendly construction practices that contribute in energy saving, reduction of emissions, re-use, and recycle of materials [39]. These concepts are used in different construction applications such as green roofs, ventilation systems, waste management policies, and recycled materials [52].

Green roofs can be classified by their purpose and characteristics in to two major types: intensive roofs and extensive roofs [8,51]. Intensive roofs need a reasonable depth of soil and require skilled labor, irrigation, and constant maintenance. They are usually associated with roof gardens [20]. Extensive roofs have a relatively thin layer of soil, grow sedums and moss and are designed to be virtually self-sustaining and require minimum maintenance [20]. There is a third type of green roofs called semi-intensive. Semi-intensive green roof is a combination of extensive and intensive, however the extensive type must represent 25% or less of the total green roof's area [51].

Over time, green roofs became popular construction product due to their environmental benefits; nevertheless, their cost disadvantage has been a challenge to the industry [21]. In general, green roof's experts agree that the reasons for these higher costs are usually due to materials lifting with cranes to the roof tops, expensive labor cost, and high insurance premiums. In addition, green roofs add more weight to the roof, which leads to changes of the structural design where columns, beams, and slabs must be modified, resulting a more expensive structure [5]. Green roof's experts justify the need to introduce materials like plastics into the market because it can reduce the overall weight and improve the performance of waterproofing layers without compromising the benefits of green roofs.

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Green roofs layers and materials are similar among manufacturers; however each manufacturer has developed its own system. General data about green roofs systems is available; however, specific content of substances, production process, installation process, and engineering technical information is kept as trade secrets in most cases. Usually manufacturers keep this information confidential to achieve competitive advantage.

This paper has two main objectives:

1. Discuss the importance of different layers of green roof with related materials properties.
2. Discuss the amount of pollution released to the air due to the production process of polypropylene and polyethylene (in green roof materials) and compare with Yang et al. [51] green roof's air pollution removal results.

The importance of this paper relays in determining the sustainability of green roofs, by estimating the number of years that a regular green roof takes to balance the pollution released in its' material production, with the pollution removed by the green roof's plants in the operation phase. The analysis was performed for the polymers, since all the layers, except for the growing medium and vegetation, are generally made out of polymer materials.

2. Research methodology

The data published in this paper was collected through published literature, one-to-one interviews, workshops, and questionnaire surveys.

2.1. Literature review

A comprehensive literature review was conducted to understand the present body of knowledge related to green roofs focusing on the following subjects: 1) environmental benefits, 2) materials, 3) design, and 4) installation.

2.2. Interviews

Open ended interviews were held with green roof's experts in different fields. Experts in installation, designing, and manufacturing provided practical industrial information which was not available in published literature.

2.3. Workshops

The researcher attended industrial workshops on green roofs to understand characteristics, designing, and installation processes of green roofs. Valuable information from the attendees' and informal conversations with presenters were recorded.

2.4. Questionnaire surveys

Formal and structured questionnaire surveys were distributed among green roof experts in Canada. The survey included design, constructability, operation, and market questions.

2.5. SimaPro modeling

The main tool used to determine the environmental impact of green roof's materials was SimaPro. The software's results were used to perform the lifecycle analysis presented in this paper.

3. Environmental benefits of green roofs

Environmental and operational cost-benefits of vegetated roofs are several and can be listed as follows: reduction of energy demand for heating and cooling, mitigation of urban heat island, reduction and delay of storm water runoff, improvement in air quality, replacement of displaced landscape, enhancement of biodiversity, provision of recreational and agricultural spaces, and insulation of a building for sound [7,8,20,31,51].

3.1. Comparison of green roof types

Environmental benefits can be maximized by building one type of green roof or the other; however all three types provide positive environmental benefits. Nevertheless, the installation cost, maintenance, and construction time are depended on the type of the green roof type. Compared to the other two types, extensive green roofs are lighter and require lower maintenance cost. However retention and delay of storm water, temperature control, and agricultural space effects can be lesser as well.

There is a substantial difference of price between the different types of green roofs. While the current cost in British Columbia, Canada for a standard extensive green roof varies from \$130/m^2–\$165/m^2 (\$12/ft^2–\$15/ft^2); the cost of a standard intensive green roof starts around \$540/m^2 (\$50/ft^2). This fact is one of the major reasons that influence owners decisions to build one type or the other [50].

3.2. Heat island effect

The heat island effect explains why urban areas have a higher temperature than rural areas. The reason for this effect is mainly due to dark colors of the buildings' roof tops [21]. Roofs with dark colors absorb energy from the sun and can reach temperatures higher than the ambient temperature. High temperatures on the roof result in increases of energy demand, higher air conditioning costs, and heat-related illnesses [44].

Rural areas are not exposed to this problem due to vegetation. Trees and plants help to control the ambient temperature by evapotranspiration [29]. In open areas plants use solar energy to control temperature by releasing vapor and contributing to the water cycle, while in urban areas there is not enough vegetation to cool down the environment [22,29].

Heat island effect can be mitigated by installing green roofs in urban areas. Rosenzweig et al. [28] suggested that if New York City covers 50% of roof tops with green roofs, the temperature difference between the city and its surrounding may decrease by 0.8 °C.

3.3. Stormwater runoff

Impermeable surfaces in cities are increasing due to urban developments, resulting in decrease storm water infiltration [8]. Green roofs have a water retention capacity that contributes to control the quantity of runoff water that can go into the city's sewer system [7,8,47]. Compared to regular roofing systems, vegetative roofs drain runoff water at a lower rate allowing the city's storm water sewer system to have enough time to transport runoff to the disposal body of water, which reduces the risk of flooding [27,43,49].

The amount of water that can be harvested from rain is important; however the quality of that water is very important as well [8]. Some research studies noted the effect of the roof's materials over the quality of runoff water. Such studies show that regardless of the roofing system, current roofing materials add chemicals or metal compounds to the runoff water [8,11,18,24,43].