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Probabilistic social cost-benefit analysis for green roofs: A lifecycle approach

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ABSTRACT

Green roofs have been used as an environmentally friendly product for many centuries and considered as a sustainable construction practice. Economic and environmental benefits of green roofs are already proven by many researchers. However, a lifecycle net benefit-cost analysis, with the social dimension, is still missing. Sustainable development requires quantitative estimates of the costs and benefits of current green technologies to encourage their use. This paper is based on an extensive literature review in multiple fields and reasonable assumptions for unavailable data. The Net Present Value (NPV) per unit of area of a green roof was assessed by considering the social-cost benefits that green roofs generate over their lifecycle. Two main types of green roofs – i.e. extensive and intensive – were analyzed. Additionally, an experimental extensive green roof, which replaced roof layers with construction and demolition waste (C&D), was assessed. A probabilistic analysis was performed to estimate the personal and social NPV and payback period of green roofs. Additionally, a sensitivity analysis was also conducted. The analysis demonstrated that green roofs are short-term investments in terms of net returns. In general, installing green roofs is a low risk investment. Furthermore, the probability of profits out of this technology is much higher than the potential financial losses. It is evident that the inclusion of social costs and benefits of green roofs improves their value.

1. Introduction

The construction industry is responsible to satisfy human development needs, but it is, in general, destroying the environment simultaneously. It is recognized that construction practices are one of the major contributors of environmental problems, particularly due to the utilization of non-renewable materials [48]. The United States Green Building Council (USGBC) estimated that commercial and residential buildings release 30% of the greenhouse gases and consumes 65% of electricity in USA [57]. To reduce the damage created by the construction industry, environmentally friendly practices that contributes in energy saving, reduction of emissions, and re-use and recycle of materials have been introduced [50].

Green roofs have been used as an environmentally friendly product to encourage sustainable construction. Their popularity is increasing due to their multiple environmental benefits; nevertheless, their cost and weight disadvantages have been a challenge to the industry [12,31]. Green roofs are classified as intensive and extensive according to their purpose and characteristics [19,61]. Intensive roofs are associated with roof gardens; need a reasonable depth of soil and require constant maintenance [30]. Extensive roofs have a relatively thin layer of soil, and are designed to be virtually self-sustaining, therefore require low maintenance [30]. Environmental benefits of a green roof vary with the type of green roof; however, all types provide positive environmental benefits. Installation cost, maintenance, and construction time depend on the type of the green roof. Compared to the intensive type, extensive green roofs are lighter and require lower maintenance cost [58]. However, other benefits such as retention and delay of storm water, temperature control, and agricultural space effects can also be relatively lower.

Environmental and operational social-cost benefits of vegetated roofs are several and can be listed as; reduction of energy demand for heating and cooling, mitigation of urban heat island effect, 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 [18,19,30,34,35,44,61].

There are different green roof systems available in the market to cater for different weather conditions and user expectations. Usually, green roofs have, from bottom to top, a root barrier, drainage, filter, growing medium, and vegetation [19,36,49].

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Manufacturers use worldwide-produced polymers, like low-density polyethylene (LDPE) and polypropylene (PP), due to their easy installation, high strength, durability and low production cost [4]. Generally, recycled LDPE is used to manufacture the root barrier, and recycled PP is used to manufacture the water retention and drainage layers. These plastics improve the performance of green roof systems, reduce cost and overall weight of the system; however, their use as green roof layers has a socio-environmental cost. Green roofs take on average 25 years to balance the pollution released to air due to the production process of polymers [4]. Thereby, reusing waste materials can reduce the green footprint of vegetative roofs.

Responsible construction management requires quantitative estimates of costs and benefits of the alternative uses of the environment [6]. Kosareo and Ries [27], Clark et al. [12], and Carter and Keeler [7] have proven the economic advantages of green roofs. However, a lifecycle benefit-cost value representing a unit of area of a green roof is still not available. This paper focuses on filling the gap with best available data based on reasonable assumptions. Data related to lifecycle social-cost benefits of green roofs is extremely rare and mostly qualitative (difficult to quantify). The analysis presented in this paper is based on an extensive literature review in multiple fields, such as forestry, engineering, and plant biology.

This paper estimates the present value of a green roof, by assigning a monetary value to the social-cost benefits that standard commercial green roofs generate, over their lifecycle. Furthermore, results of commercial green roofs are compared with the Net Present Value (NPV) of an extensive, construction and demolition (C&D) waste based, experimental green roof. A probabilistic analysis was performed to estimate personal and societal costs/benefits. Additionally, a sensitivity analysis was conducted to calculate the payback period.

2. Materials and methods

Many studies have already been conducted to estimate the costs and benefits of green roofs in urban scenarios. Kosareo and Ries [27], Clark et al. [12], and Carter and Keeler [7] focused their research on analyzing specific benefits of green roofs. They compared the initial construction cost, energy reduction, storm water management, and air quality of green roofs over conventional flat roofs, by estimating the net present value (NPV). Costs and benefits of green roofs vary depending on many characteristics such as: green roof type, weather conditions, or location of the structure. The location of a green roof in a building is also a factor that affects the NPV. Inflation, discount rate, labor, green roof efficiency, cost of materials, and energy consumption/savings are factors that vary between countries and regions. A generic methodology that takes into consideration these uncertainties (of green roofs), within an acceptable confidence level, is required to estimate lifecycle cost-benefits. Hence, a Monte Carlo simulation was conducted [56].

The analysis was conducted for three main green roof types: (1) extensive green roof, (2) intensive green roof, and (3) C&D waste based extensive green roof. Cost and benefits of green roofs are divided in two categories in this paper: i.e. (1) personal and (2) social. Moreover, the functional unit used in the NPV analysis was dollar per square meter ($/m^2). Personal costs and benefits of green roofs are those that obtained just by the owner or developer of the system. Consequently, social benefits are those that are obtained by society. Three analysis scenarios were performed to calculate NPV investment for each green roof type:

(1) NPV by considering only personal costs and benefits,
(2) NPV by considering only social costs and benefits, and
(3) NPV by considering both, personal and social costs and benefits

The three analyses considered the same variability of discount rate and inflation. The discount rate was assumed to vary from 2% to 8% [51]. Similarly, based on Statistics Canada [51], inflation has varied in the last decade from 1% to 4%. The maximum lifespan of a green roof is about 55 years [1]; while, the minimum has been estimated as about 40 years [12]. Hence, time variance in the Monte Carlo simulations was considered between 40 years and 55 years. In some cases a uniform distribution was assumed. Table 1 summarizes the economic input for the analysis.

3. Theory and calculation

Economic analysis conducted in this paper considered variations in green roof performance related to: rainwater retention, air pollution removal, and energy reduction. Additionally, the input prices were gathered from different published and reliable sources, as noted in the following section. All dollar amounts have been converted to year 2012 valuations using the consumer price index [52].

As described in Table 1, uniform and triangular functions were used to model the analyzed parameters. Uniform distribution was used, when data within the same range have the same probability. For instance, air quality improvement varies depending on many conditions. Thus, green roof air pollution removal cannot be described as a deterministic value. Further, the landfill cost is related to the weight of the polymeric layers. The plastic layers weight of an intensive green roof varies depending on the thickness of each layer; however, one specific thickness is often repeated in many intensive green roofs. Therefore, a triangular distribution was used.

3.1. Personal costs and benefits

Many environmental benefits of green roofs can be taken as personal benefits. Retention and delay of storm water or energy consumption reduction are characteristics that may modify the structural and mechanical design of any building [8,29]. Nevertheless, in order to take advantage of these benefits, an initial investment is required to install a green roof.

3.1.1. Initial construction cost

There is a significant difference between green roof prices. The current costs 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) [4]. Installation price depends on many factors such as labor and equipment costs. This study considers a uniform distribution that varies from $165/m^2 to $540/m^2 for intensive green roofs, while for extensive and C&D waste based extensive green roofs vary between $130/m^2 and $165/m^2.

3.1.2. Property value

Natural landscapes benefit homeowners and investors by increasing the market value of properties. There is no direct literature to note property value increase due to green roofs. The value of an average house could increase by 7.1%, if it is close to

Table 1
Economic data input for the probabilistic analyses.

		Value		Function
Economic	Year	40	55	Uniform
	Discount rate (%)	2	8	Uniform
	Inflation (%)	1	4	Uniform