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Green roofs: A critical review on the role of components, benefits, limitations and trends

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ABSTRACT

Green roofs have been proposed as an efficient and practical tool to combat urbanisation in many countries. This review paper focuses on various benefits associated with green roofs and research efforts made till date to promote green roofs. Through systematic comparison of literature, this review also emphasises knowledge gap that prevail in green roof technology and highlight the need for local research to install green roofs in developing and under-developed countries. Considering that growth substrate, vegetation and drainage layer determine the success of green roof, efforts were made to consolidate desirable characteristics for each of these components and suggests methodology to construct practical green roofs. This critical review also explores limitations associated with green roofs and recommend strategies to overcome. Apart from stand-alone green roofs, there is a huge scope for hybrid green roof systems with other established techniques, which are presented and discussed. Recommendations for future study are also provided.

Contents

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1. Introduction

As a result of rapid economic growth, many countries have been experiencing increased urbanisation. Due to this amplified urban population, tall buildings and other new developments are made at the expense of green areas. This resulted in the shortage of greenery which in turn causes a decrease in canopy interception and transpiration within the urban area leading to an increased temperature and decreased air humidity [1]. These problems can be partially solved by altering buildings' rooftop properties. The introduction of plants and soil to the unutilized rooftop surfaces are often regarded as a valuable strategy to convert buildings more sustainable [2,3]. Green (vegetated, eco or living) roofs are basically roofs planted with vegetation on top of the growth medium (substrate). The concept was designed and developed to promote the growth of various forms of vegetation on the top of buildings and thereby provide aesthetical as well as environmental and economic benefits. Green roofs generally comprise of several components, including vegetation, substrate, filter fabric, drainage material, root barrier and insulation. The role played by each component is well defined in engineered green roof system and type of each green roof component depends on the geographic location [4].

Green roofs are broadly classified into intensive, semi-intensive and extensive green roofs. Intensive green roofs are characterized with thick substrate layer (20–200 cm), wide variety of plants, high maintenance, high capital cost and greater weight. Due to increased soil depth, the plant selection can be more diverse including shrubs and small trees. Therefore, typically require high maintenance in the form of fertilising, weeding and watering. On the other hand, extensive green roofs are characterized with thin substrate layer (less than 15 cm), low capital cost, low weight and minimal maintenance. Owing to the thin substrate layer, extensive roofs can accommodate only limited type of vegetation types including grasses, moss and few succulents. An extensive green roof system is commonly used in situations where no additional structural support is desired. Semi-intensive green roofs accommodate small herbaceous plants, ground covers, grasses and small shrubs due to moderately thick substrate layer. These roofs require frequent maintenance as well as sustain high capital costs. Of the three types, extensive green roofs are most common around the world due to building weight restrictions, costs and maintenance.

Green roofs present numerous economic and social benefits in addition to more obvious environmental advantages such as storm–water management, decreased energy consumption of buildings, improved water and air quality, decreased noise pollution, extended roof life, reduced heat-island effect and increased green space in urban environments [1,5,6]. Many countries and municipalities understood these benefits and started to implement or even mandate green roofs in buildings. Consequently, more and more green roofs are established. Shortly, commercial green roof products started to appear in the market doing brisk business. However, it should be pointed out that the focus of green roof developers has been limited to achieving basic aesthetical benefits of green roofs [1]. Many other benefits of green roofs are just as achievable, but thus far the green roofs generally are not optimised to meet those [7]. This is generally due to lack of research on different aspects of green roofs and premature introduction of products into the market. Thus, there is a great need for green roof research. The objectives of this review are to understand the current scenario in green roof research, provide suggestions to select different green roof components based on requirements and strategies to develop practical green roofs to meet consumer needs. In addition, this review also summarizes the benefits of green roofs as well as recent trends in green roof technology.

2. History of green roofs

Planting vegetation at the building rooftop is an old technique. The most famous ancient green roofs were the Hanging Gardens of Babylon constructed around 500 BC. In more recent times, peoples tend to cover their rooftops with sod for the purpose of insulation from extreme climates. Modern green roofs, therefore, may acquire their concept from ancient technique; however technological advances have made modern green roofs far more efficient, practical and beneficial than their ancient counterparts.

Modern green roofs, in a larger scale being designed, developed and marketed by Germany [2]. Several investigations have been carried out with emphasis on biodiversity, substrate, roof construction and design guidelines [1]. Unfortunately, most of the early studies on green roofs was written in German and also not readily available to rest of the world [8]. However owing to the first initiative by Germany and subsequently by neighbouring European countries, green roofs became popular in other parts of the world. Recently, green-roof coverage in Germany alone increases by approximately 13.5 million m^2 per year [2]; whereby 10% of its buildings utilise green roof technology [9].

Currently, countries like USA, Canada, Australia, Singapore and Japan are making a strong initiative to install green roofs during construction of new buildings, and are retrofitting old ones so green roofs can be added in the near future. As a result of the regulations for new and renovated flat roofs, 15% of flat roofs in Basel (Switzerland) have been greened [10]. In Toronto (Canada), the green roof by-law mandates all newly established development with a floor area of $\geq 2000\ m^2$ to include green roof on 20–60% of the roof area [11]. Similarly, Tokyo (Japan) accelerated the green roofing process by mandating that all new-construction buildings were to have green roofs. Private buildings larger than 1000 m^2 and public buildings larger than 250 m^2 must green 20% of the rooftop or pay an annual penalty of USD 2000 [11]. All new City-owned buildings in Portland are required to be built with a green roof that covers at least 70% of the roof [10]. There were approximately 2 acres (0.81 ha) of green roofs in Portland (USA) in 2005, with about another 2 acres committed to be built. In Hong Kong, governmental best practices for green and innovative buildings encourage construction of green roofs [12].

Green roof research has been performed in several countries. Blank et al. [13] conducted a survey on green roof publications appeared in ISI Web of Science database and identified that USA contributed 34% of total publications in green roofs, whereas EU and Asian counties contributed 33% and 20%, respectively. The authors also indicated that the pace and number of publications in the field of green roof increased significantly compared to early 2000. Earlier research publications mostly focussed on to evaluate/highlight the benefits of green roofs [14,15]. Only recently it was understood that each countries with different climatic conditions and building characteristics has to do local research to identify components for successful establishment of green roofs. Apart from added cost, it is well known that the commercial green roof systems from Western nations or other countries might not be completely adapted to the local context [16]. For instance, the vegetation or substrate successfully performed in the Scandinavian countries may not perform in tropical climates. The same applied to other green roof components as well. These aspects acted as driving force behind the increase in green roof research, with recent studies focussed onto identify new and low-cost or alternative components for practical implementation of green roofs. Graceson et al. [17] examined different types of locally available crushed bricks and composted green waste as green roof substrate. On the other hand, Vijayaraghavan and Raja [18] prepared green roof substrate using locally available perlite, vermiculite, crushed brick, sand and coco-peat to support *Portulaca*