



Review

Green roof vegetation for North American ecoregions: A literature review

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ABSTRACT

A green roof is a vegetated roof or deck designed to provide urban greening for buildings, people, or the environment. Made popular across Europe over the past few decades, green roofs are now becoming more familiar to North Americans as some cities have built green roof pilot projects and adopted incentives for using green roofs or even require their use. Green roof standards and guidelines are also emerging to be used for governance and project specification. Although much is known about the application of green roofs across Europe, much less is known about their application across North America's diverse ecological regions. When considering the many decisions required in applying green roof technology to a specific place, there are few choices more critical to their success than the selection of appropriate vegetation. We conducted a review of green roof research to investigate what is known about the application of plants on green roofs across North America and their ecological implications. Results indicate that investigation sites across ecoregions begin to reveal differences in plant survival. Although ecological investigations are limited, their results show improved plant performance and ecological services with diverse green roofs. We conclude that as green roofs continue to become regulated and adopted in policy, further development of standards and guidelines is needed. To date, there is no common ground for reporting of green roof research, and we make recommendations for facilitating such efforts for improved research, policy development and their management across North America's diverse ecological regions.

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1. Introduction

A green roof is a flat or sloped rooftop designed to support vegetation. Soil depths can range from a few centimeters for a dense mat of succulent plants to 20 cm to 1 m or even deeper for more intensively managed roof gardens. Green roof systems have been shown to provide many ecosystem services such as improved stormwater management, reduced energy usage for cooling, reduced urban heat island effects, and wildlife habitat (Oberndorfer et al., 2007). Europe has more than three decades of green roof research and product development to support its flourishing green roof industry. Much of Europe's early green roof research took place in Germany, Switzerland, and Scandinavia, and was written in languages other than English (Köhler, 2007; Mentens et al., 2006). Europe's broad experiences with the technology eventually led to guidelines and standards that were supported by university-led research, field observations, and product or component development.

One of the most well-known set of guidelines for green roofs throughout Europe is the FLL Guidelines (FLL refers to the Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau [the German Landscape Research, Development and Construction Society]). They are formally known as the *Guidelines for the Planning, Execution and Upkeep of Green Roof Sites*, and are used for green roof design, specification, maintenance, and testing (FLL, 2002). The FLL members began to develop the guidelines in 1975, and first published them in German in 1982 and in English in 2002. The FLL guidelines correspond to findings from empirical green roof research and application throughout Germany. In the Preface to the 2002 edition of FLL, it clearly states its connection to research and application, "It is in line with state-of-the-art technology and scientific research and takes account of practical experience so that it can be seen as a set of "recognized rules of technique" in the sense of the Standard Building Contract Terms" (FLL, 2002, p.3). The review of green roof literature presented in this paper makes frequent references to the FLL Guidelines, as they are recognized as a source of authority regarding the design, construction and maintenance of green roofs in Europe and throughout the world.

In North America, over the past decade, there has been an expansion of green roof research that is beginning to support the development of national standards, guidelines and tests, but currently there is no document comparable to the FLL Guidelines, and the future growth of the green roof industry may well be dependent upon the establishment of such guidelines (Miller and Narejo, 2005; Philippi, 2005).

The Association of Standards and Testing Materials (ASTM) has produced several documents that describe design characteristics for green roofs including determination of structural loads (ASTM E 2397, 2005; ASTM E 2399, 2005), permeability tests for drainage and growth media (ASTM E 2396, 2005; ASTM E 2398, 2005), and a guide for selecting and maintaining plant material (ASTM E 2400, 2006). There is a new ASTM green roof document titled ASTM WK 14283 under review that is a comprehensive guide to be used to address green roof terminology, design considerations and benefits.

2. Aims and objectives

Prior to the 1990s, there were occasional articles and specifications that describe roof gardens and earth sheltered structures (Osmundson, 1999), but they do not accurately represent the

lightweight green roof systems used today. Although these new green roof technologies are becoming used across North America, there is no well-established knowledge system in place to guide their application (Miller and Narejo, 2005). Guidance on plant selection is one of the most critical areas of knowledge needed to design successful green roofs. In the FLL Guidelines, significant coverage is dedicated to the design and specification of an underlying substrate that is designed to sustain plants. To better understand what is known about green roof plants in North America, their relationships to substrate characteristics and some of the ecological implications of maintaining these systems, we conducted a literature review of North American green roof research.

North America encompasses a wide range of climatic conditions from sub-tropical regions in Southern Florida where vegetation rarely is exposed to freezing temperatures, to desert areas with extremely low annual rainfall, to mountainous areas with extreme radiative, temperature and wind conditions. Thus, environmental conditions experienced by plants on green roofs can vary widely across the continent. As a way of understanding and identifying natural ecosystems, scientists have subdivided the continent into several hundred ecoregions. An ecoregion is a geographical area that encompasses similarly functioning ecosystems (Bailey, 1976, 1983; McNab et al., 2005). The delineation of ecoregions is based on broad prevailing climatic conditions and localized knowledge of other conditions such as altitude, soil type, topography and climax vegetation (Bailey, 1983). Our aims are to use "ecoregion" as a reference to reveal which plants were found to perform well on green roofs across ecoregions, and their ecological implications. Green roof plants are subjected to similar environmental conditions as those species that are endemic to the ecoregions, and thus we would expect that green roof plant success is partially dependent on the similarity between the ecoregion and the green roof plant native habitat. However, as green roof soil conditions are entirely different from normal soil conditions, the probability of success in a given ecoregion is likely modified by the ability of the green roof substrate to mimic natural hydrological conditions as well as cycling of nutrients and providing enough depth for adequate rooting.

We recognize that the European based green roof technology has only emerged in North America over the past decade, and as an emerging technology it has not yet been explored in most of North America's ecoregions. Considering the role that research played in establishing standards in Europe, and the fact that some North American cities are already requiring (Peck, 2009) or regulating (Miller and Narejo, 2005) green roofs, we conducted this investigation in order to document what is known about green roof vegetation in order to make recommendations for guidance and efficiencies for future research and application.

3. Methods

3.1. Criteria for selection of articles

This review of green roof technology research scans a time-frame from when original research on extensive green roofs was first published in academic papers in 1998 through March 2010. To be included in this review, a paper had to meet the following criteria: (1) the research took place in North America, (2) the findings apply directly to green roof technology, (3) the paper was published in a peer-reviewed journal or an influential refereed conference

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