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Biodiversity assessment of green roofs for green building design

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ABSTRACT

Green roofs can provide several environmental benefits in urban cities and can also create habitat for living organisms thus help to enhance biodiversity. At present, many green building assessment methods have considered green roofs as a desirable sustainable design feature, however, the approach to assess the biodiversity aspect in these methods is not clear and effective. This research aims to investigate how green roofs can enhance biodiversity in an urban environment and to develop an effective system to assess the green roofs. Firstly, the basic concepts and significance of biodiversity conservation were studied. Secondly, the important factors and considerations for using biodiversity as a criterion for assessing green roofs were evaluated. Thirdly, a systematic method to assess the biodiversity effects was established. Finally, the design strategies to maximise urban biodiversity of green roofs were discussed.

It is found that building development in the urban areas will destroy the habitats and result in biodiversity loss; the built environment created by green roofs is one of the mitigation methods for biodiversity conservation. Some urban cities in Europe and North America are developing research studies and government policies on biodiversity and green roofs. After reviewing the existing green roof guidelines and green building assessment methods, useful information was obtained to develop a systematic method for assessing the biodiversity effects. The method comprises of six major factors: (a) species diversity and richness, (b) substrate type and depth, (c) plant species selection, (d) connectivity to natural environment, (e) green roof ratio and (f) ecologically responsible development.

Keywords: Biodiversity assessment, green roofs, green building design.

1. INTRODUCTION

Biological resources of the Earth are vital to human economic and social development (Dirzo and Mendoza, 2008). As a result, there is a growing concern that biological diversity (or biodiversity) is a global asset of tremendous value to present and future generations (ETWB and AFCD, 2003; Miller, 2005). The United Nations (UN) has designated 2010 as the International Year of Biodiversity and also declared 2011-2020 the UN Decade on Biodiversity, with the goal of significantly reducing biodiversity loss (Convention on Biological Diversity, www.cbd.int).

Urban areas development inevitably destroys the habitats and results in biodiversity loss. To reduce the adverse impact on biodiversity, it is important to promote greening in the built environment (GRHC, 2009). As green roofs can provide ecosystem services in urban areas (Oberndorfer, *et al.*, 2007), many countries in the world are developing research, projects and policies on using green roofs to enhance biodiversity (Coffman and Waite, 2011; Currie and Bass, 2010; Dunnett, 2006; Gedge, 2005; Gedge and Kadas, 2005; Grant, Engleback and Nicholson, 2003).

Green roofs can provide several environmental benefits in urban cities (Hui, 2006) and can also create habitat for living organisms in the nature in order to enhance biodiversity which is an important issue of sustainability (Dunnett and Kingsbury, 2008; Luckett, 2009). At present, many green building assessment methods (BEAM Society, 2010; Fowler and Rauch, 2006; USGBC, 2009) have considered green roofs as a desirable sustainable design feature, however, the approach to assess the biodiversity aspect in these methods is not clear and effective. There is an urgent need to examine the biodiversity effects of green roofs and develop a systematic way to evaluate the performance.

This research aims to investigate how green roofs can enhance biodiversity in an urban environment and to develop an effective system to assess the green roofs. Firstly, the basic concepts and significance of biodiversity conservation were studied. Secondly, the important factors and considerations for using biodiversity as a criterion for assessing green roofs were evaluated. Thirdly, a systematic method to assess the biodiversity effects was established. Finally, the design strategies to maximise urban biodiversity of green roofs were discussed.

2. BIODIVERSITY AND GREEN ROOFS

The meaning of biodiversity and the potential of green roofs for biodiversity conservation in urban areas are explained. The biodiversity of wildlife, plants and their habitats is a vital component of healthy, well-functioning ecosystems, which in turn sustain all life on the planet (UK-GBC, 2009).

2.1 Biodiversity

Biodiversity is the degree of variation of life forms within a given ecosystem. It is a measure of the health of ecosystems. It is believed that biodiversity contributes to a relentless and often invisible ecosystem service that is provided within atmospheric, hydrologic and biogeochemical life cycles where air and water and living and dead elements are cycled and recycled in a continuous circle of life (Currie and Bass, 2010).

Biodiversity can have many interpretations. For example, geneticists define it as the diversity of genes and organisms; biologists define it as the sum total of all of the plants, animals, fungi, and microorganisms on Earth; their genetic and phenotypic variation; and the communities and ecosystems of which they are a part (Dirzo and Mendoza, 2008). To describe it clearly, three levels of biological variety are identified:

- Genetic diversity
- Species diversity (or richness)
- Ecosystem diversity

Biodiversity loss is a matter of great concern among conservation scientists (Miller, 2005). It includes diversity within species, as well as between species of ecosystems. GRHC (2009) pointed out that biodiversity is not just about counting the number of species on a roof or in any other landscape; it is composed of both structure and function. The complex, interconnected community of living organisms in an ecosystem affects the level of biodiversity (Currie and Bass, 2010).

2.2 Green Roofs

Green roofs are living vegetation installed on the roofs and can provide many environmental and social benefits (Hui, 2010; Hui, 2006). They could provide green spaces, mitigate urban heat island, reduce air quality problem, contribute to stormwater management and enhance biodiversity. Roof greening has two main approaches: intensive (depth 150 to 1000 mm) and extensive (depth 50 to 150 mm). Intensive green roofs (including roof gardens) have a greater depth of growing medium to support a wider range of planting, and often include shrubs and trees. Extensive green roofs are systems with low growing plants, such as sedums, with no access other than for occasional maintenance; this type of roof is intended to be self sustaining and more economical. Figure 1 shows the typical structure of extensive green roof (Hui, 2009). It is composed of a waterproof membrane, followed by a root barrier, a layer of insulation, a drainage layer, the growing medium or soil substrate, and the plant material.

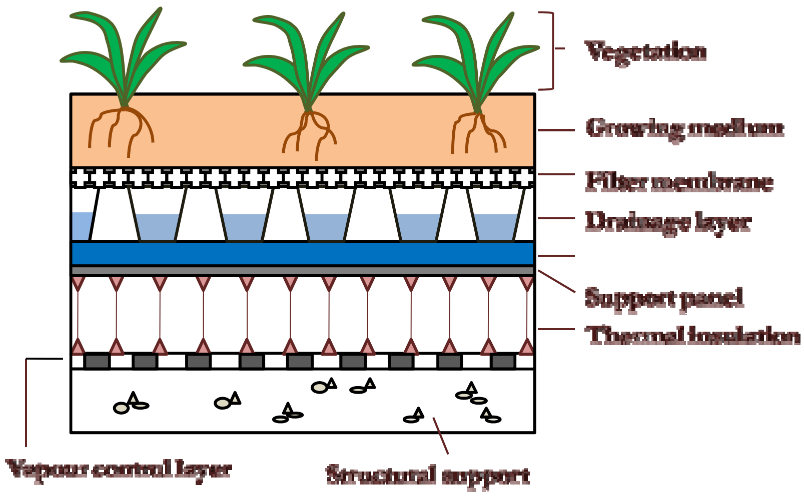

Figure 1. Structure of extensive green roof

Schrader and Böning (2006) indicated that in urban areas, green roofs are part of the environmental green lung that provides important environmental, economic and technical advantages compared to conventional flat roofs. Moreover, green roofs may be part of a larger system of wildlife corridors in urban and suburban areas, including park areas and gardens, offering an environment for plants, birds and invertebrates. As a result, green roofs can be used to promote urban biodiversity by connecting isolated habitat pockets when installed in aggregation especially if located near fragmented ground-level habitats.

In UK, people are interested in using green roofs as a mitigation measure for habitats lost during urban regeneration, especially on brownfield or abandoned sites (Grant, Engleback and Nicholson, 2003; SLBAP, 2010). They have identified five potential benefits of green roof to urban ecology and biodiversity:

- Provision of new wildlife habitat
- Replacement of habitat lost through development
- Provision of quiet refuges
- Providing links or stepping stones in greenspace networks
- Acting as the only available green space in inner urban core

2.3 Urban Ecosystem

In an urban area, biodiversity is a concept that involves not only the quantification of available habitat areas, but also the description of species diversity within these spaces (Currie and Bass, 2010). Green roofs may help restore the imbalance of the urban ecosystem by providing habitat within the urban environment for the coexistence of plants, vertebrates and invertebrate animal species, some of which may be rare or endangered (GRHC, 2009). In fact, green roofs are often inhabited by various insects, spiders and birds (Coffman and Waite, 2011; Fernandez-Canero and Gonzalez-Redondo, 2010).

Oberndorfer, *et al.* (2007) has reviewed the green roof benefits and examined the biotic and abiotic components that contribute to overall ecosystem services. They found that green roofs represent a distinct type of urban habitat and can be designed to mimic natural ecosystems and/or ground-level vegetation. It is especially important for high density urban development which has very limited green space (Hui and Chan, 2008). In some urban cities in Europe, the main driver for implementation of green roofs is their habitat value; a particular type of green roofs, known as biodiversity, biodiverse or brown roofs, has emerged to represent the concepts of restoration ecology (Dunnett, 2006). Basically, a brown roof is a non-seeded green roof system that undergoes natural colonization with little human interaction. This approach allows local plant species to populate the roof over time, thus harmonising its appearance with its immediate surroundings. A brown roof permits the conservation of urban biodiversity when redeveloping a brownfield or abandoned site.

As more and more people live in cities, restoration, preservation and enhancement of biodiversity in urban areas become critical (Savard, Clergeau and Mennechez, 2000). Enhancement of biodiversity in urban ecosystems can have a positive impact on the quality of life and education of urban dwellers and thus facilitate the preservation of biodiversity in natural ecosystems. Francis and Lorimer (2011) pointed out that green roofs and living walls are just one aspect of urban reconciliation ecology, but are particularly important ‘bottom-up’ techniques for improving urban biodiversity that can be performed directly by the citizenry. Concepts related to biodiversity management such as scale, hierarchy, species identity, species values, habitat fragmentation and habitat quality can be used to manage urban biodiversity (Savard, Clergeau and Mennechez, 2000).

3. GREEN BUILDING ASSESSMENT

With growing interest of green and sustainable buildings, green building assessment methods are becoming more and more important in the world (Fowler and Rauch, 2006). At present, many green building assessment methods have considered green roofs as a desirable sustainable design feature and certain credit points can be obtained for the building project (Hui, 2010). In some countries, awarding these credits for ecological enhancement is partially responsible for the increased prevalence of green roofs on new buildings. However, the approach to assess the biodiversity aspect in the green building assessment methods is not clear and effective. There is an urgent need to examine the biodiversity effects of green roofs and develop a systematic way to evaluate the performance. To illustrate how the current methods assess the biodiversity effects of green roofs, two examples are given below.

3.1 BEAM Plus in Hong Kong

The Building Environmental Assessment Method (BEAM) was established in Hong Kong in 1996 (BEAM Society, 2010). The latest version, BEAM-Plus, has one credit point on ecological impact as shown in Table 1. Although it aims to assess the ecological value of sites by using habitat and biodiversity criteria (ETWB and AFCD, 2003), it is difficult to determine how adding green roofs will affect the score. It is also unclear what parameters should be used to evaluate green roofs on the habitat and biodiversity criteria. The structure and function of the ecosystem as well as the potential benefits of green roof to urban ecology are not addressed here.

Table 1. Credit point on ecological impact under BEAM Plus*

<table>
<tr><td>2 Site Aspects</td><td>2.2 Site Planning and Design</td></tr>
<tr><td></td><td>SA 5: Ecological Impact</td></tr>
<tr><td>Objective</td><td>To conserve and enhance the natural environment by protecting the ecological value of the site in terms of habitat and biodiversity and using Brownfield site.</td></tr>
<tr><td>Credit requirement</td><td>1 BONUS credit for meeting a value less than 30% of score obtained in Habitat Section of Nature Outlook Assessment and for meeting a value less than 20% of score obtained in Biodiversity Section of Nature Outlook, or demonstrating that appropriate design measures have been implemented to contribute positively to the ecological value of the site.</td></tr>
<tr><td>Assessment</td><td>Scoring system for assessing ecological value of sites:
<table>
<tr><td>Habitat Criteria</td><td>Weighting (%)</td></tr>
<tr><td>Naturalness</td><td>15</td></tr>
<tr><td>Habitat diversity</td><td>15</td></tr>
<tr><td>Size</td><td>10</td></tr>
<tr><td>Non-recreatability</td><td>10</td></tr>
<tr><td>Degree of disturbances</td><td>10</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Biodiversity Criteria</td><td></td></tr>
<tr><td>Species diversity & richness</td><td>20</td></tr>
<tr><td>Species rarity / endemism</td><td>20</td></tr>
<tr><td>Total</td><td>100</td></tr>
</table>
Relevant site survey and assessment report for Habitat and Biodiversity section shall be provided to demonstrate compliance with the bonus credit requirement.</td></tr>
</table>

* Adapted from (BEAM Society, 2010) and (ETWB and AFCD, 2003).

3.2 LEED in USA

The Leadership in Energy and Environmental Design (LEED) is a certification rating system developed by the US Green Building Council (USGBC, 2009). At present, it has two credit points related to biodiversity which is under the Sustainable Sites (SS) category. Table 2 describes the two credit points. Vegetated roof is considered in order to provide habitat value and promote biodiversity. However, it is unclear what parameters should be used to evaluate green roofs on biodiversity. The site disturbance, habitat restoration and open space are not helpful to evaluating green roof projects. Since vegetated roof areas can contribute to credit compliance, it is important to have a systematic way to assess the green roofs.

Table 2. Credit point on habitat and biodiversity under LEED**

Sustainable Sites	SS Credit 5.1: Site Development -- Protect or Restore Habitat
	1 Point
Intent	To conserve existing natural areas and restore damaged areas to provide habitat and promote biodiversity.
Requirements	1. For greenfield sites, limit all site disturbance. 2. For previously developed sites, restore a minimum of 50% of the site (excluding the building footprint) or 20% of the total site area (including building footprint), whichever is greater, with native or adapted vegetation. Projects earning SS Credit 2: Development Density and Community Connectivity may include vegetated roof surface in this calculation if the plants are native or adapted, provide habitat, and promote biodiversity.
Sustainable Sites	SS Credit 5.2: Site Development -- Maximize Open Space
	1 Point
Intent	To promote biodiversity by providing a high ratio of open space to development footprint.
Requirements	1. Sites with Local Zoning Open Space Requirements: Reduce the development footprint and/or provide vegetated open space within the project boundary such that the amount of open space exceeds local zoning requirements by 25%. 2. Sites with No Local Zoning Requirements (e.g. some university campuses, military bases): Provide a vegetated open space area adjacent to the building that is equal in area to the building footprint. 3. Sites with Zoning Ordinances but No Open Space Requirements: Provide vegetated open space equal to 20% of the project site area. 4. For all 3 cases above: a) For projects in urban areas that earn SS Credit 2: Development Density and Community Connectivity, vegetated roof areas can contribute to credit compliance. b) For projects in urban areas that earn SS Credit 2: Development Density and Community Connectivity, pedestrian-oriented hardscape areas can contribute to credit compliance. For such projects, a minimum of 25% of the open space counted must be vegetated. c) Wetlands or naturally designed ponds may count as open space and the side slope gradients average 1:4 (vertical: horizontal) or less and are vegetated.

** Adapted from (USGBC, 2009).

4. BIODIVERSITY ASSESSMENT FOR GREEN ROOFS

The key factors affecting biodiversity on green roofs are identified and an assessment system with six major factors is proposed. The design features, different substrates and planting regimes are considered in the proposed system.

4.1 Key Factors

The important design parameters and characteristics of green roofs have been studied and how they affect biodiversity conservation is evaluated. The key factors affecting species richness and urban biodiversity are summarised below.

(a) Substrate type, depth and composition

Substrate or growing media is crucial for green roof plants. Green roof systems with a variety of substrate depths and vegetation types tend to have higher spider, beetle, and bird diversity. The use of natural, local soils and substrate can assist biodiversity, as well as benefit regional and endangered species because local species have already adapted to that particular soil environment (Currie and Bass, 2010). The substrate depth is often a good indicator of future successes in biodiversity for green roofs. Other factors such as pH value and organic constituents for substrate will affect the growth of green roof plants and thus the colonization of various vertebrates and invertebrates.

(b) Plant species (native or non-native)

Calcareous and sedum species are the common plant species for extensive green roofs (Snodgrass and Snodgrass, 2006). Native plant species is preferred in particular region as the roof can mimic the regional habitat environment and thus attract the species to colonize based on the naturalness. For the non-native plant species, they are selected for building up intensive green roofs which may attract some rare species. Selection of the plant species for green roofs depends on which target species of vertebrates and invertebrates are expected to attract to the site of interest, and is very important to determining whether biodiversity enhancement is achieved.

(c) Proximity to existing urban landscape (habitat connectivity)

It is believed that proximity of green roofs to the nearby naturalized zones or landscape can contribute a positive influence on biodiversity. Good habitat connectivity can overcome the adverse effects (species extinction) brought by the habitat fragmentation and modification during the urban development.

4.2 Proposed Assessment System

After studying the important issues, a simple system is proposed for the biodiversity assessment of green roofs. The system consists of 6 major factors as shown in Table 3 and the respective criteria for the score are described. The overall scoring is the sum of the credit marks and a proposed rating is given at the end of Table 3. This assessment system is useful to building designers and developers who would like to evaluate green roof projects.

Table 3. Proposed assessment system on biodiversity of green roofs

1	Species diversity and richness	Extensive green roof (EGR): 1 mark Intensive green roof (IGR) : 2 marks Brown/Biodiverse (BF): 3 marks
2	Substrate type and depth	Extensive (E): 150 mm or less: 1 mark Semi-intensive (S): Above and below 150 mm: 2 marks Intensive (I): More than 150 mm Substrate: 3 marks
3	Plant species selection	Exotic species: 1 mark Native species: 2 marks Both: 3 marks
4	Connectivity to natural vegetation	Connection of the green roof to urban landscape? Yes: 1 mark, No: 0 mark
5	Green roof ratio	Ratio of green roof area to building (footprint) area: 1:1 (1 mark) 2:1 (2 mark) 3:1 or above (3 marks)
6	Ecologically responsible development	Programme to promote awareness, training and proper roof maintenance? Yes: 1 mark, No: 0 mark

Total score: 4-7 Fair; 8-10 Good; 11-14 Excellent

5. DISCUSSIONS

The properties of the roof, the type of vegetation used, and the overall design will combine to affect biodiversity (Coffman and Waite, 2011). It is essential to understand the design object and constraints in order to maximise biodiversity.

5.1 Extensive Green Roofs with Sedum

Extensive green roofs with sedum mats are often not viewed as the optimal substrate for biodiversity (GRHC, 2009). The scores of the first two factors in Table 3 also reflect this. In general, substrate-based green roofs could maximise biodiversity by encouraging plant species diversity, whereas sedum mat systems comprise only stonecrop plant species (Molineuxa, Fentiman and Gange, 2009). Schrader and Böning (2006) pointed out that extensive roof greening promotes urban biodiversity but does not replace nature.

Nevertheless, extensive green roofs with sedum is still the most effective way of providing greening to buildings having design constraints such as structural loading and accessibility. They represent an opportunity to create green space in areas that are otherwise unsuitable for natural restoration. Butler and Orians (2011) have found that sedum can cool soil and improve neighboring plant performance during water deficit; the palette of green roof plants can be expanded by using sedum species as nurse plants. Suitable application of sedum can also create optimum outcome.

5.2 Design Strategies to Maximise Biodiversity

Currie and Bass (2010) has established design strategies to enhance biodiversity and natural colonization on green roofs in Toronto. A summary of them is given below. They can serve as useful hints for other urban cities.

(a) Planting

• Emphasize native species
• Any non-native species used should be noninvasive
• Review suitable plant species including end points and life cycle needs for targeted species
• Select grasses and herbaceous plants that produce numerous seed heads that can provide invaluable energy sources for migratory birds

(b) Substrate

• Position substrate near building sites before elevating to the roof if practical (species can inoculate substrate at grade level)
• Incorporate local materials in substrate blends (compost/porous materials)
• Use compost liberally where practical
• Vary substrate depths and drainage regimes to create a mosaic of microhabitats on and below the soil surface that can facilitate colonization by a more diverse flora and fauna
• Vary substrate depths by adding berms/mounds, bare areas, and physical substrate connections to enhance species movement (promotes heterogeneity)

(c) Structure

• Add bird boxes, bat boxes, and trap nests for bees as desired
• Add snags (tree limbs) and stones for terrain variation and moisture retention
• Add depressions to collect rain water for short periods

5.3 Other Considerations

Some green roofs were designed to create habitat for birds by considering the habitat components of birds, namely, food, cover, water and space (Fernandez-Canero and Gonzalez-Redondo, 2010). The substrate and vegetation layers of a green roof can be designed to promote habitat creation (Currie and Bass, 2010). Variation in substrate topography and composition, as well as the addition of other materials can produce niche spaces for organisms, creating “microhabitats”. Where technically feasible, green roofs should be designed to protect sensitive biological communities and avoid aggressive species. By designing green roofs that include important habitat forming, it is possible to encourage biodiversity across urban green roofs. In some situations, green roofs can also be used for supplying goods and services, such as rooftop urban farming to grow herbs and vegetables or other crops (Hui, 2011).

Snep, Van Ierland and Opdam (2009) found that implementing measures to enhance biodiversity may be acceptable only if combined with other urban green functions (like recreation and health and well-being) and if tailored to the required functional appearance of the business site environment (in terms of external appearance and tidiness). Therefore, the biodiversity criteria should be fully integrated with other important design factors for a green roof project.

Grant, Engleback and Nicholson (2003) indicated that although individual green roofs offer local environmental benefits, any significant contribution to wider environmental quality is only likely to become apparent when a more substantial area of town and city roof space has been greened. Such a programme will require political commitment and concerted action underpinned by science, technical expertise and good design.

6. CONCLUSIONS

Green roofs have the potential to function as islands of biodiversity within urban and suburban environments. They will become an important component of urban sustainability in the coming future, provided that favourable public policy measures encourage and enable their construction. A systematic method was developed for assessing the biodiversity effects of green roofs. The method comprises of six major factors: (a) species diversity and richness, (b) substrate type and depth, (c) plant species selection, (d) connectivity to natural environment, (e) green roof ratio and (f) ecologically responsible development.

It is hoped that green roofs can be integrated effectively for promoting green building design and the biodiversity effects of green roofs can be maximised in most situations.

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