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Research article

# Optimal location selection for the installation of urban green roofs considering honeybee habitats along with socio-economic and environmental effects

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ABSTRACT

This study proposes a new framework for the selection of optimal locations for green roofs to achieve a sustainable urban ecosystem. The proposed framework selects building sites that can maximize the benefits of green roofs, based not only on the socio-economic and environmental benefits to urban residents, but also on the provision of urban foraging sites for honeybees. The framework comprises three steps. First, building candidates for green roofs are selected considering the building type. Second, the selected building candidates are ranked in terms of their expected socio-economic and environmental effects. The benefits of green roofs are improved energy efficiency and air quality, reduction of urban flood risk and infrastructure improvement costs, reuse of storm water, and creation of space for education and leisure. Furthermore, the estimated cost of installing green roofs is also considered. We employ spatial data to determine the expected effects of green roofs on each building unit, because the benefits and costs may vary depending on the location of the building. This is due to the heterogeneous spatial conditions. In the third step, the final building sites are proposed by solving the maximal covering location problem (MCLP) to determine the optimal locations for green roofs as urban honeybee foraging sites. As an illustrative example, we apply the proposed framework in Seoul, Korea. This new framework is expected to contribute to sustainable urban ecosystems.



## 1. Introduction

Honeybees play an important role in the conservation of natural ecosystems because they help in pollinating a diverse range of crops, fruits, and plants (McGregor, 1976; Klein et al., 2007; Bradbear, 2009). Nevertheless, the population of honeybees is gradually decreasing globally because of diverse reasons such as expansion of urban areas, use of pesticides for agriculture, climate change, and competition from non-native species (Kluser and Peduzzi, 2007). In particular, honeybee habitats in urban areas have sharply declined due to urban sprawl (Murray et al., 2009; Winfree et al., 2009; Grixti et al., 2009). However, honeybee foraging activities are also an important part of food production and ecosystems in urban areas (Quistberg et al., 2016). In such a scenario, green roofs have received attention as an ecological engineering technique to increase green coverage in urban areas (Tonietto et al., 2011; Mitsch, 2012; MacIvor and Ksiazek, 2015).

The development of green roofs in urban areas is known to have positive effects on the maintenance or improvement of the diversity of species such as birds and certain arthropods, including bees and butterflies (Baumann, 2006; Colla et al., 2009; Madre et al., 2013; Lee and Lin, 2015). Consistent with this reasoning, green roofs offer alternative foraging sites for honeybees in urban areas (Colla et al., 2009; Tonietto et al., 2011). This is especially desirable because the extinction of honeybees in urban areas is caused by the limited foraging range in this environment (Osborne et al., 1999; Greenleaf et al., 2007). Green roofs can serve as effective alternatives to natural foraging sites when the locations of green roofs are selected based on the foraging behavior of honeybees (Danner et al., 2016).

The plant diversity and plant-community composition in green roofs are also considerably important for the foraging sites of honeybees (Tonietto et al., 2011). Although plant community is an important factor for the foraging of honeybees, we focused on

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selecting suitable locations for honeybees considering the foraging range of honeybees, rather than the plant community.

Not only the ecological, but also the socio-economic and environmental advantages of green roofs for urban residents also need to be considered when selecting the locations for green roofs. Previous studies have verified the diverse benefits of green roofs in terms of socio-economic and environmental aspects. In relation to socio-economic benefits, green roofs provide space for education and leisure, because of their similarities with public parks, if they are designed for public use (Molineux et al., 2009). Green roofs can also raise market values of buildings by providing natural landscapes and offering aesthetic scenes to urban residents. Furthermore, if a green roof is installed on their building in some cities, building owners can benefit from a tax reduction based on the area of the green roof (Bianchini and Hewage, 2012). Finally, green roofs can increase the lifespan of roofs by maintaining suitable temperature levels and reducing temperature fluctuations (Ouldboukhitine et al., 2014).

In terms of environmental benefits, green roofs play an important role in relieving issues of air pollution, heat island, and water management in the urban environment. First, green roofs can be used to relieve air pollution in urban areas (Yang et al., 2008; Currie and Bass, 2008). Yang et al. (2008) quantified the removal effect of air pollutants in Chicago and showed the amount of air pollutants removed by green roofs during one year. Currie and Bass (2008) composed six scenarios through combination of trees, shrubs, green roofs, and green walls, and analyzed how large the purifying effect of each scenario is in respect of the air pollutants, $NO_2$, $O_3$, PM10, and $SO_2$, and verified the effect of green roofs in reducing air pollutants.

In addition, green roofs can alleviate heat island issues in urban areas, and reduce energy use related to cooling and heating of buildings (Wong et al., 2003a; Jaffal et al., 2012; Sun et al., 2012). Sun et al. (2012) analyzed the effect of vegetation on the thermal environment in Taipei and verified the cooling effect of green roofs. Wong et al. (2003a) showed that the degree of the insulating effect is greater if a green roof is constructed, rather than not, and verified that there is an effect of reduced heat flow through green roofs.

Furthermore, green roofs can offer three benefits related to urban water management. First, the ability of green roofs to retain storm water has been emphasized. Storm water retention can prevent urban flood from heavy rain events and reduce the rainwater flow through public sewers (Carter and Jackson, 2007; Getter et al., 2007). Second, green roofs can harvest rainwater (Thomas, 1998; Wong et al., 2003b). The structure of green roofs helps to store and filter the rainwater for domestic uses such as water for toilet flushing (Christova-Boal et al., 1996). Using the water from rainwater harvesting schemes is expected to reduce water consumption between approximately 3% and 30%, depending on the climate in the individual home (Rozos et al., 2009). Lastly, the potential for green roofs to improve the quality of storm water by removing nutrients and pollutants in rainwater has been proposed recently (Hathaway et al., 2008; Czemiel Berndtsson et al., 2009). However, some empirical studies found that green roofs can act as the source of metals and nutrients. Czemiel Berndtsson et al. (2006) measured higher levels of nutrients, such as Cd, Mn, TN and TP, in runoff from green roofs, while Hathaway et al. (2008) also found similar results, in that the level of TP was shown to be higher in runoff from green roofs than from conventional roofs.

Such potential benefits of green roofs may vary depending on the spatial conditions, such as temperature, air quality, and rainfall. Therefore, if construction of green roofs is considered as an alternative for sustainable urban growth by certain local governments, they need to construct the green roofs in locations that maximize the benefits of green roofs, considering such spatial conditions within the limitations of the budget.

Thus, this study proposes a new framework for selecting the optimal locations for green roofs to harness the diverse positive effects for a sustainable urban ecosystem. The framework suggests selecting building sites that can maximize the benefits of green roofs based on the socio-economic and environmental effects on urban residents and the provision of urban foraging sites for honeybees. The proposed framework comprises three steps. First, possible locations for the construction of green roofs are selected considering the purpose of the building. Second, the total monetary value of green roofs in relation to their main benefits and the costs incurred over their lifecycle are calculated. The main benefits and costs, including the reduction in cooling and heating energy costs, improvement of air quality, reduction of flood risk and infrastructure improvement costs, reuse of storm water, provision of educational and leisure spaces, and initial construction costs, are compared. Third, building sites for green roofs are finally proposed considering the foraging patterns of honeybees, by solving the maximal covering location problem (MCLP). We then illustrate the application of this framework to urban areas in Seoul, Korea.

This research paper is organized as follows: Section 2 presents a framework for selecting the optimal building sites for green roofs. Section 3 describes the results of applying the proposed framework to Seoul. Section 4 suggests possible developments related to the proposed framework.

## 2. Framework

This study proposes a new framework for selecting the optimal locations for green roofs in urban areas (Fig. 1). The framework includes three steps to identify places that can maximize the socio-economic and environmental benefits of green roofs and their advantages as foraging sites for honeybees. Fig. 1 presents the three steps involved in the framework.

### 2.1. Step 1: types of buildings

There are certain conditions to be considered in order to select suitable locations for green roofs, such as the applicability of operating a green roof in terms of building use, and the environmental requirements for the growth of plants. Regarding conditions related to environmental requirements, previous studies have covered the relationship between air pollution and growth of plants (Gostin, 2016; Jäger, 2016), and these researchers verified the negative influences of diverse air pollutants on the metabolism of plants. Therefore, when such conditions are considered, for example, it might be difficult for people to operate a green roof in a small private business facility, because the building use is focused on the business, and factories also may be not suitable for green roofs because of high levels of air pollution. As such, in step 1, the suitable types of buildings that meet such conditions are selected for installing green roofs.

### 2.2. Step 2: socio-economic and environmental benefits and costs

In step 2, building sites are selected based on the socio-economic and environmental benefits and costs of green roofs. The benefits of constructing green roofs can vary based on heterogeneous spatial characteristics such as temperature, air pollution, and flood damage. We consider the heterogeneous spatial characteristics by cost–benefit analysis.

Net-cost–benefit analyses of green roofs over their lifecycle have been conducted in previous studies (Banting et al., 2005; Carter and Keeler, 2008; Bianchini and Hewage, 2012). Bianchini and Hewage (2012) categorized the diverse benefits and costs of