Urban Forestry & Urban Greening 25 (2017) 120–129

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

Original article

Step-by-step approach to ranking green roof retrofit potential in urban areas: A case study of Lisbon, Portugal

Cristina Matos Silva*, Inês Flores-Colen, Maria Antunes

CERIS, Department of Civil Engineering and Architecture and Georesources, Instituto Superior Técnico, University of Lisbon, Av. Rovisco Pais, 1049-001 Lisbon, Portugal

ARTICLE INFO

Keywords:
Case study
Green roofs
Rating system
Urban planning
Urban resiliency

ABSTRACT

In the last years, green roofs have become increasingly popular to improve urban life and help overcome environmental challenges. This paper presents a methodology to rank existing built areas when planning green roofs installation on existing buildings. First, the methodology identifies neighborhoods with real possibilities of receiving green roofs. A further refinement uses urban indexes to estimate the green needs of each selected area. The proposed model was successfully applied to Lisbon, Portugal. Old city areas are discharged while neighborhoods with lack of green spaces appear as priority zones to initiate green roofs urban policies. The results identify 79% of Lisbon with real possibilities of incorporating green roofs and 52% with high potential for green roofs retrofit.

1. Introduction

Most large urban centers face several environmental challenges, often associated with the number of inhabitants, resource consumption, building density, available technology, lack of green spaces and climate changes. For instance, air quality, local air temperature or water management are key issues that should be tackled when planning smarter and more resilient cities. Introducing additional green surfaces in urban centers helps minimizing some negative effects of dense cities (Oliveira et al., 2011). However, in most cases, current urban zones show few available areas for greening. In this context, green roofs can provide additional green spaces without affecting essential services to citizens or daily life while improving resilience at the building and city level (Berardi, 2014; Kosareo and Ries, 2007; Bowler et al., 2010; Jungels et al., 2013). For instance, green roofs provide outdoor microclimate benefits and energy savings (Ascione et al., 2013; Silva et al., 2016; Berardi, 2016; La Roche and Berardi, 2014; Gagliano et al., 2016), reduce CO_2 emissions (Rowe, 2011) and contribute to sound absorption (Connelly and Hodgson, 2015; Van Renterghem and Botteldooren, 2011) and water retention (Fioretti et al., 2010; Hashemi et al., 2015).

Decision making about green roof retrofit should take into account (FLL, 2008; NTJ, 2012; Maurer, 2013; TGRCS, 2010; Silva et al., 2015; LUCGRC, 2010) that:

- Existing buildings may have limited structural capacity to incorporate green roof solutions. This problem is less important for new construction designed to support their weight;
- Public buildings can be chosen as benchmark cases for green roofs, becoming an added value for municipality entities and residents;
- Commercial and industrial buildings often have large rooftop areas. If greened, these rooftops will introduce several environmental, economical and technical benefits;
- Green roofs at ground level (e.g., covering underground parking areas) are typically more attractive to use than building rooftops because they can be easily accessed;
- Roofs steeper than 20° are not adequate for green roofs (special semi-intensive and intensive green roofs) and require extra fixing measures;
- Built areas with low green indexes should have priority.

This work adopts existing rooftop areas as the most interesting available surfaces for installing green roofs in a city. Public infrastructures, such as roads or pedestrian accesses, are not considered in this study. Also, the type of building (e.g., commercial, industrial, public) is not taken into account. A sequential rating system is defined based on a limited number of indexes that characterize the existing built environment. At first, a test is made to evaluate the possibility of installing green roofs in existing built areas. Then, a further refinement is done by evaluating the green needs of each area. The final result corresponds to the selection of the neighborhoods with both higher possibilities and needs of green roofs. These maps, designated as green space maps, are the output of the proposed methodology.

The present study follows principles of other approaches, namely

* Corresponding author.
E-mail addresses: cristina.matos.silva@tecnico.ulisboa.pt (C.M. Silva), ines.flores.colen@tecnico.ulisboa.pt (I. Flores-Colen).

http://dx.doi.org/10.1016/j.ufug.2017.04.018
Received 6 July 2016; Received in revised form 12 April 2017; Accepted 28 April 2017
Available online 15 May 2017
1618-8667/

Table 1
Definition of building and urban indexes (Maurer, 2013; LUCGRC, 2010; Leandro, 2011; Stevanovic, 2010; Zhang et al., 2012; Wiginton et al., 2010; Izquierdo et al., 2008; Theodoridou et al., 2012; Filogamo et al., 2014; Alcoforado et al., 2009; Almeida, 2006).

Index designation	Units	Description	
Year of construction (YC)	un	Number of years of building	Building characteristics
Floor area ratio (FAR)	m^2/m^2	Ratio between total area of all floors and total plot area	
Number of floors (NF)	un	number of elevated floors	
Green quality (GQ)	qualitative	Evaluation of plants larger than 1 meter within the total plot area	
Roof type (RT)	qualitative	Evaluation of roof constructive solution (e.g., thermal insulation)	
Green roof type (GRT)	qualitative	Green roof solution to be installed (extensive to intensive)	
Roof slope (RS)	° or %	Roof slope classification	
Building load capacity (BLC)	kN/m^2	Building structural safety levels	
Roof load capacity (RLC)	kN/m^2	Roof structural safety levels	
Solar orientation (SO)	qualitative	Building/roof solar orientation	
Building use (BU)	qualitative	Residential, commercial, industrial, services, among others	
Roof-top available area (RAA)	m^2	Amount of total roof-top available area for additional applications	
Built density (BD)	%	Classification of land cover (built-up areas)[a]	Urban environment
Green urban areas (GUA)	%	Classification of land cover (green spaces)	
Census data (CD)	qualitative	Statistical data relating land area to population	
Population density (PD)	qualitative	Population data obtained from geographical units within the region	
Site coverage (SC)	m^2/m^2	Ratio between built area on ground floor and total plot area	
Green surface area (GSA)	m^2/m^2	Ratio between total green area and total surrounding urban area	
Urban trees (UT)	un or un/km^2	Total number of trees in the surrounding urban area	

[a] E.g., high density stands for urban areas where buildings occupy circa 50% of the total floor area.

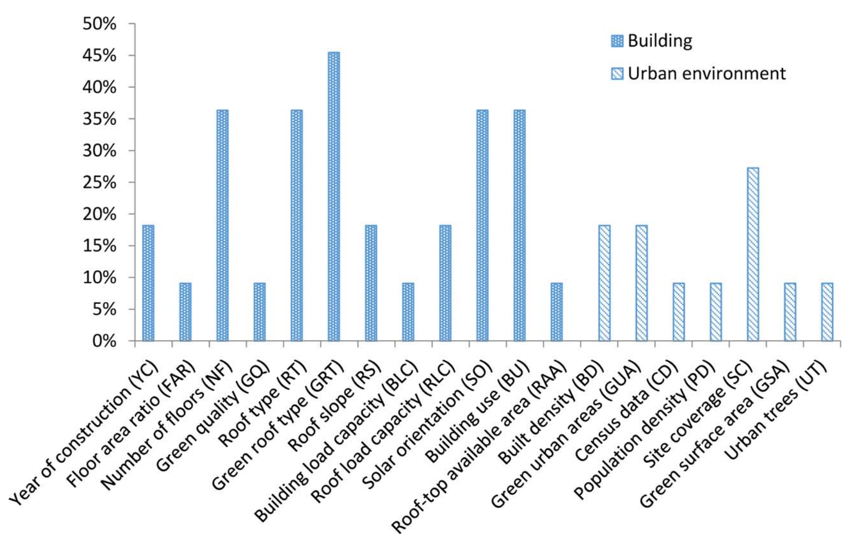

Fig. 1. Occurrence (in percentage) of indexes characterizing the built environment in previous studies.

Maurer (2013) and Gedge (2010). The approach of Maurer (2013) for the city of Linz, Austria, adopted compulsory building plans for new buildings (larger than 500 m^2) and focused on green level evaluation. Also London recognized it needs to retrofit green roofs by the structural capacity of existing buildings (Gedge, 2010). The proposed methodology is a step forward because it combines buildings characteristics to assure the feasibility of green roof retrofit with information of urban environment, namely green needs. This unique approach can help decision-makers identify neighborhoods in existing cities where roofs can be retrofitted with green roofs and define effective policies. The model is applied to Lisbon, Portugal.

2. Methodology

2.1. Adequate indexes to evaluate green roofs potential in urban areas

When evaluating the green roof retrofit potential in urban areas, it is necessary to verify if these green ecosystems are viable and needed in the existing built environment. Indexes are used for quantitative assessments. Several authors (Maurer, 2013; LUCGRC, 2010; Gedge, 2010; Leandro, 2011; Stevanovic, 2010; Zhang et al., 2012; Wiginton et al., 2010; Izquierdo et al., 2008; Theodoridou et al., 2012; Filogamo et al., 2014; Alcoforado et al., 2009) identify different indexes to characterize the built environment. These studies identify a total of 19 indexes (Table 1) divided into two groups: (i) indexes typifying building characteristics and (ii) indexes representing urban environment. Some indexes are correlated. For instance, building load capacity (BLC) and roof load capacity (RLC) give similar information and are directly related to the number of years of construction (YC), number of floors (NF), roof type (RT) or green roof type (GRT). Other characteristics not stated in Table 1, such as the thermal insulation of buildings, can indirectly be estimated by the roof type (RT) and the number of years of construction (YC). Some indexes are more frequently used than others, depending on the scope of the study. Fig. 1 summarizes the occurrence (in percentage) of each index in the following eleven references: (i) green roofs (Maurer, 2013; LUCGRC, 2010; Leandro, 2011; Stevanovic, 2010; Zhang et al., 2012); (ii) photovoltaic panels (Wiginton et al., 2010; Izquierdo et al., 2008); (iii) energy management (Theodoridou et al., 2012; Filogamo et al., 2014); (iv) sustainability of built environment (Alcoforado et al., 2009; Almeida, 2006). E.g., NF (Number of Floors) was used in four of the eleven studies ($4/11 \times 100 = 36\%$).