Artículo de Revisión / Review Article / Artigo de Revisão

Producción + Limpia - Julio - Diciembre de 2015. Vol. 10, No. 2 - 173•185

Global research trends in green roofs: benefits, main developments and future needs

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Tendencias globales de investigación en techos verdes: beneficios, lecciones aprendidas, retos y modelos futuros

Tendências mundiais de investigação nos tetos verdes: benefícios, principais acontecimentos e as necessidades futuras

ABSTRACT

Currently, the world faces a critical time with regard to environmentally friendly technologies or green trends whose main objective is to adjust the modern social development to the requirements of environmental protection, conservation of natural resources and adaptation to sustainable development models. In this context, green roofs meet these needs and provide valuable opportunities in environmental, economic and social terms. This article aims to present current trends in research on green roofs globally so as to encourage further research at local and regional levels and facilitate its implementation in the medium and long term by recognizing its benefits, lessons learnt and challenges. The paper first presents an overview of green roofs. The following sections focus on major research topics developed in the last 10 years with regard to green roofs. In these, some relevant aspects are discussed with regard to its implementation worldwide, demonstrating its potential importance and benefits. Next, each of the sections focuses on present challenges and future research needs.

Key words: Green roofs, bioarquitecture, ecourbanism, environment, sustainable development, and green technologies.

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Artículo recibido: 23/06/2015; Artículo aprobado: 11/12/2015

RESUMEN

El mundo actual vive un momento coyuntural en torno a tendencias ambientalmente amigables o tecnologías verdes cuyo objetivo fundamental es ajustar el desarrollo social moderno a las exigencias de protección ambiental, conservación de los recursos naturales y adaptación a los nuevos modelos de desarrollo sostenible que se imponen. En este contexto, los techos verdes se ajustan a estas necesidades y brindan oportunidades valiosas en términos ambientales, económicos y sociales. El presente artículo tiene como objetivo presentar las tendencias actuales de investigación con relación a los techos verdes a nivel global para así fomentar mayor investigación a nivel local y regional y facilitar su implementación en el mediano y largo plazo mediante el reconocimiento de sus beneficios y características. El artículo presenta inicialmente las generalidades sobre los techos verdes. Las secciones siguientes se enfocan en los principales temas de investigación desarrollados en los últimos 10 años. En éstas se presentan además aspectos sobre su implementación a nivel global, lo que demuestra su potencial, importancia y beneficios. Cada sección del artículo, el artículo se concentra en presentar los desafíos y las necesidades futuras de investigación.

Palabras clave: techos verdes, bioarquitectura, ecourbanismo, ambiente, desarrollo sostenible, tecnologías verdes.

RESUMO

O mundo atual vive um momento conjuntural em torno a tendências ambientalmente amigáveis ou tecnologias verdes cujo objetivo fundamental é ajustar o desenvolvimento social moderno às exigências de proteção ambiental, conservação dos recursos naturais e adaptação aos novos modelos de desenvolvimento sustentável que se impõe. Neste contexto, os tetos verdes se ajustam a estas necessidades e brindam oportunidades valiosas em termos ambientais, económicos e sociais. O presente artigo tem como objetivo apresentar as tendências atuais de investigação com relação aos tetos verdes a nível global para assim fomentar maior investigação a nível local e regional e facilitar sua implementação em médio e longo prazo mediante o reconhecimento de seus benefícios e características. O artigo apresenta inicialmente as generalidades sobre os tetos verdes. As secções seguintes se enfocam nos principais assuntos de investigação desenvolvidos nos últimos 10 anos em torno aos tetos verdes. Nestas se apresentam ademais de aspectos sobre sua implementação a nível global, o que demostra seu potencial, importância e benefícios. Seguidamente, o artigo se concentra em apresentar os desafios e as necessidades futuras de investigação.

Palavras chave: tetos verdes, bioarquitetura, ecourbanismo, ambiente, desenvolvimento sustentável, tecnologias verdes.

INTRODUCTION

Green Roofs are sloped or flat rooftop mainly designed to support vegetation (Goddard, Dougill, & Benton, 2009; Henry & Frascaria-Lacoste, 2011). These have several ecological, technological, architectural and environmental characteristics that allowfor applications such as aesthetic and decoration, reduction of heat, minimization of AC systems usage, optimization of energy usage and other uses currently being investigated worldwide as presented in this paper. In terms of design, green roofs are typically composed by several layers of membranes that include waterproofing, barriers to prevent roots to grow excessively and damage underlying layers, drainage and filtration barriers, and vegetative layers that support a wide variety of plant species. Their incorporation into architectural design can have several alternatives as those presented in Figure 1. Green roofs are also called eco-roofs, living-roofs or roof gardens. The importance of this technology is mainly provided by several

environmental benefits that can potentially be used in today's society to face global warming and develop smarter-environmentally friendly cities. In this regard, additional additional and detailed environmental aspects of green roofs are presented in a recent publication by Berardi, Ghaffarian Hoseini, & Ghaffarian Hoseini (2014).

Figure 1. Various awarded configurations of green roofs around the globe (GreenRoofs Org., 2014)

Multiple research studies have been conducted in the last two decades with regard to green roofs involving a wide number of topics that involve not only design and technical aspects, but also environmental, aesthetic, biological and modelling considerations. Nevertheless, there's a lack of a comprehensive study showing the different lines of research mainly studied worldwide along with their main outcomes, as well as the summary of some successful study cases.

Therefore, based on the importance of green roofs in the context of environmental sustainability and climate adaptation, the main objective of this paper is to introduce the main lines of research currently developed with regard to green roofs by introducingthe trending research topics, potential uses and prospective research. Consequently, the second objective of this paper is to promote a deeper understanding of green roofs to facilitate further progress in research as well as implementation of these technologies, mainly in developing countries. Nine sections that will cover the most important topics researched in the last ten years around the globe compose the paper. These sections introduce some of the most relevant lines of research and provide important highlights on the benefits, limitations, challenges, and prospective research. The topics include: *(i)* effects on water management, *(ii)* biological assessments, *(iii)* climatic adaptation and urban planning considerations, *(iv)* performance evaluations and thermal efficiency, *(v)* economic assessments, *(vi)* life cycle assessments, *(vii)* modelling applications and technological developments, *(viii)* aesthetic evaluations, and *(xi)* case studies in the globe.

Effects on Water Management

According to recent research, green roofs influence water management strategies at the local and global levels (Lamera, Becciu, Rulli, & Rosso (2014); Beecham & Razzaghmanesh 2015; Metselaar, 2012; Gregoire & Clausen, 2011; Lee, Moon, Kim, Kim, H. & Han, 2013; Malcolm, Reese, Schaus, Ozmon, & Tran, 2014). For instance, Beecham *et al.* 2015 studied different types of green roofs (i.e., sixteen intensive and extensive green roof beds without maintenance and fertilizers) in terms of the water quantity and quality. The quantity of water was assessed by collecting it via storm water-drainage points during five events of rainfall, whereas the quality was evaluated considering water quality parameters (NO_2, NO_3, NH_4, PO_4, pH, EC, TDS, Turbidity, Na, Ca, Mg and K). Based on the experimental design, the authors concluded on the significant differences found for vegetated versus non-vegetated green roofs in terms of the water quantity and quality, which suggests on the influence of this variable on

water management systems when integrated into building strategies for reducing water consumption and increase its recycling rate (e.g., for non-potable use such as toilet flushing and landscape irrigation). In addition, the ability of green roofs' vegetation to reduce pollutants in runoff and its advantages as water retainers were highlighted by the authors. Similarly, modelling approaches have been used for studying the capacity of green roofs for favoring water management. Lamera *et al.* developed a bucket model to simulate the existing relationship between rainfall and runoff in green roof in order to determine the hydrological influence on a watershed which led to concluding on the importance of this technology for water harvesting. Also, the authors highlighted green roof as valuable systems in today's world to promote Sustainable Urban Drainage Systems. Likewise, Metselaar (2012) used modelling for evaluating the connection between vegetation types in green roofs and the hydrological water retention potential. Some additional recent approaches involved with water management include those developed by Versini, Ramier, Berthier, & De Gouvello (2015), Lee, J., Lee, M., & Han (2015) and Poë, Stovin, & Berretta (2015). The research conducted by these focused on hydrological assessments of green roofs at different levels and scales of analysis, starting from pilot study to building and basin scales. In addition, the authors also included several hydrological, hydraulic and biological considerations, since designing green roofs not only comprise individual components of engineering but also, integrate several criteria simultaneously.

In terms of future research to be conducted in water management, some of the topics suggested by the authors include the information presented in Table 1.

Biological Assessments

This section focuses on some research studies recently conducted about biological assessments of green roofs intended to characterize vegetation types, diversity, growth and effect of substrate type.

Effect of substrate type

The substrate in green roofs plays a key role in several aspects as described by recent research (Bates, Sadler, Greswell, & Mackay, 2015; Zhao, Tabares-Velasco, Srebric, Komarneni, & Berghage, 2014; and Farrell, Mitchell, Szota, Rayner, & Williams, 2012). For instance, use of virgin substrates versus recycled aggregates can have effects on the quality of the vegetation, the aesthetic aspects and the overall performance of the green roofs systems. In fact, Bates *et al.* assessed the influence of using recycled aggregates substrates (i.e., crushed brick, crushed demolition aggregate, solid municipal waste incinerator bottom ash aggregate, and a mix of the previous in two combinations) during a 6-year period. The authors emphasized on the importance of developing multi-year studies to reach relevant conclusions in terms of vegetative development in green roofs. Similarly, Zhao et al. evaluated the effect of substrate and plant type on the thermal performance during the summer season. Conversely, Farrell et al. focused not only on summer climate conditions, but also assessed other seasons' influences on water use and substrates in green roofs. Moreover, Kanechi, Fujiwara, Shintani, Suzuki, & Uno (2014) studied vegetation in relation to irrigation and substrate type that allowed for conclusions on the importance of appropriate selection of plant species and substrates to promote irrigation and facilitate the thermal and water efficiency of green roofs systems.

Vegetation type, diversity and development

Several layers compose green roofs systems, whose main function is supporting vegetation and providing adequate conditions for their development. In this respect, the study of vegetation in green roofs systems has become a major topic for research in the last years globally. Several assessments have been considered that include, but are not limited to: types, diversity, growth, development and other biological and environmental characteristics of interest. For instance, germination and colonizing has been studied by Miller, Heim, & Lundholm (2014). Similarly, green roofs are considered as

Table 1. Further research suggested by current research about water management in green roofs.

Author(s)	Year	Country	Research Topic	Approach	Recommendations for further research
Vijayaraghavan & Raja	2015	India	Runoff quality	Pilot-scale study	Evaluate the suitability of P. grandiflora for other plant species and for stormwater attenuation potential.
Beecham & Razzaghmanesh	2015	Australia	Quantity and quality of water	Sampling and testing of water samples	Studies on the effects of evapotranspiration on water retention in dry climates. Effects of growing media on water chemistry
Yang, Li, Sun, & Ni	2015	China	Saturation and infiltration	Empirical and Numerical-Modelling	Further studies on the relationship between infiltration-excess and saturation-excess to generate runoff.
Vanuytrecht *et al.*	2014	Belgium	Runoff and vegetation stress	Water balance model GreenRoof	Evaluation and selection of plant species for Mediterranean green roofs.
Lee, Moon, Kim, Kim, H. & Han.	2013	South Korea	Urban flood mitigation	Quantitative analysis of extensive green roof systems	Runoff assessments in additional green roof types.
Speak, Rothwell, Lindley, & Smith	2013	United Kingdom	Runoff retention	Empirical measurements of runoff	Assess the effect of organic matter on runoff retention.
Metselaar	2012	The Netherlands	Water retention and evotranspiration	Simulation through the model Soil Water Atmosphere and Plant (SWAP)	Development of laboratory experiments to understand the environmental factors and vegetation relationship.
Gregoire & Clausen	2011	United States	Runoff quality and quantity	Comparison of extensive green roof vs. control by paired watershed study	Further combinations of vegetation and hydrological assessments to compare results.

Source: Authors' own work

important systems for promoting biodiversity, which supports the development of research on this area (Heim & Lundholm, 2014; Madre, Vergnes, Machon, & Clergeau, 2014; Bates, Sadler, & Mackay, 2013; Song et al. 2013). Information on detailed benefits from vegetation diversity can be found elsewhere (Cook-Patton & Bauerle, 2012; Nagase & Dunnett, 2012; Nagase & Dunnett, 2013). Also, considering the relevance of climate change in ecological adaptations and biological development, some additional studies have selected climate change scenarios and climatological conditions as reference points to determine beneficial conditions for vegetation in green roof systems (Vanuytrecht *et al.* 2014; Getter, Rowe, & Cregg, 2009) as well

as highlighted the positive effects of vegetation on thermal efficiency and other global warming related-aspects (Susca, Gaffin, & Dell'Osso, 2011).

Climatic Adaptation and Urban Planning Considerations

Taking into consideration the fact that climate change imposes challenges for ecosystems to adapt to extreme conditions, the evaluation of climatic adaptation processes acquires special relevance in the context of green roof research. For instance, Jim (2015) focused on global warming and urban heat island (UHI) in Hong Kong due to the significance of these in climate adaptation. In particular, by monitoring thermal performance of *Sedum* and *Perennial Peanut* and climatic conditions in summer, the author concluded on some design and management strategies to counteract global warming in compact cities. Additionally, Virk et al. (2015) focused on microclimatic effects from the general and specific outlooks in order to better understand green and cool roofs in London. According to the authors, green roof usage in buildings can have a positive effect on the reduction of energy consumption on an annual basis, especially when summer conditions are prevalent because winter performance tends to lead to energy penalties and lower reduction in energy consumption. By developing a modelling approach set to 2050, it was determined that both cool and green roof produce savings in annual energy use, meaning that these have significant advantages from the economical perspective as well. Nevertheless, the authors concluded on the better performance that can be obtained by using conventional isolation to minimize energy consumption, implying that its combination with neither cool roofs nor green roof is convenient in terms of the effectiveness for these systems.

Some other studies have been undertaken to determine if green roof have the potential for carbon sequestration (Luo *et al.* 2015; Whittinghill, Rowe, Schutzki, & Cregg, 2014). For instance, Luo *et al.* investigated two substrate types that included mixed-sewage-sludge (MSSS) and local natural soil (LNS), from which the former exhibited lower carbon sequestration potential (i.e., 3.89 kg C m^{-2} yr^{-1} vs 3.81 kg C m^{-2} yr^{-1}) whereas the carbon storage followed a reversal trend (13.15 kg C m^{-2} for MSSS and 8.58 kg C m^{-2} for LNS). Similarly, Whittinghill *et al. (*2014) studied nine in ground and three green roof landscape systems in order to better understand their carbon sequestration potential and the main outcomes relate to the higher carbon content found for woody plants. Future research suggest on the need for developing more comprehensive studies focused on evaluating scaled-up systems with several configurations of substrates and vegetation (Luo *et al.* 2015). Also, management practices are to be thoroughly assessed, along with landscaping tools to determine the potential carbon sequestration and allow for improved permanence of it on the systems when considering an equilibrium point.

Performance Evaluations and Thermal Efficiency

In big cities, green roofs are valuable systems for counteracting the effects of global warming, minimize energy consumption and mitigate thermal stress and urban heat (Krüger & Emmanuel, 2013), while contributing with positive aesthetic improvements and environmental benefits (Berardi, Ghaffarian Hoseini, & Ghaffarian Hoseini, 2014). As a result, green roofs performance represents an important source of information for better understanding of the advantages, disadvantages and challenges faced nowadays to achieve higher thermal efficiency, energy savings and biological value while promoting appraisable landscapes for greener cities. Some approaches recently carried out for assessing performance of green roofs and the corresponding recommendations for future research include those presented in Table 2. A comprehensive review on energy aspects of green roofs with relevant findings and topics of future research is available in a recent publication by Saadatian et al. (2013). Future research suggested in terms of performance include the evaluations of energy efficiency and indoors thermal comfort in green roofs when combined with other systems such as nocturnal ventilation (Gagliano et al. 2014).

Table 2. Suggestions for further research in green roofs with regard to performance and thermal efficiency

Author(s)	Year	Country	Research Topic	Recommendations for further research
Klein & Coffman	2015	United States	Performance in extreme climatic conditions	Results for phase II project to be presented with regard to improved performance by means of methodological modifications.
Lamnatou & Chemisana	2015	Spain	Critical review of photovoltaic performance	Further research is needed for the evaluation of large-scale PV-green roofs under different climatic conditions.
Yang, Li, Sun, & Ni.	2015	China and United Kingdom	Comparative study of the thermal performance	Thermal insulation, substrate type and vegetation types are to be assessed under other experimental conditions for more deep understanding.
Dominique, Tiana, Fanomezana, & Ludovic	2014	France	Thermal performance	Assessing the effectiveness of GRO for energy savings, water management, acoustic, biodiversity in Tropical humid climates.
Sun, Bou-Zeid, & Ni	2014	China and United States	Performance of irrigation-integrated green roof system.	Use of appropriate medium layers, irrigation controls to improve green roof efficiencies.
Zhao, Tabares-Velasco, Srebric, Komarneni, & Berghage.	2014	United States	Thermal performance of green roof assemblies	Development of additional and, eventually, more accurate simulations of the heating loads and heating energy consumption for buildings with green roof assemblies.
Coutts, Daly, Beringer, & Tapper	2013	Australia	Comparative assessment of the insulating properties, the radiation budget and surface energy balance	Research and modelling at the micro-scale focused on examining and comparing the evaluated urban configurations and propose the best approaches to be followed.
Lin, Yu, Su, & Lin	2013	Taiwan	Thermal effectiveness of green roofs in different locations	Rainfall influences, rainfall duration, intensity and water accumulation can be further investigated, as well as additional configurations for other climatic conditions.
Moody & Sailor	2013	United States	Thermal performance metrics of green roofs.	Evaluating additional benefits to the building energy performance for characterizing green roofs efficiency.
Jaffal, Ouldboukhitine & Belarbi	2012	France	Model simulation and evaluation of green roof foliage and soil surface temperatures	High performance soils and drainage layers, more detailed green roof models, Detailed parametric studies of different green roof configurations for both new construction and retrofit projects in different climates

Author(s)	Year	Country	Research Topic	Recommendations for further research
Jim & Peng	2012	Hong Kong	Solar radiation, relative humidity, soil moisture and wind speed were explored	More empirical studies in subtropical areas are required to better understand thermal performance.

Source: Authors' own work

Economic Analysis

Economic analysis constitutes an important topic of recent research on green roofs worldwide. In effect, recent publications have studied aspects such as energy savings (La Roche & Berardi, 2014; Castleton, Stovin, Beck, & Davison, 2010), comparison of green roofs types (Sproul, Wan, Mandel, & Rosenfeld, 2014), economic performance (Chan & Chow, 2013), cost benefits assessments for the public and private sectors (Claus & Rousseau, 2012) and effectiveness of green roofs for lower energy consumption (Refahi & Talkhabi, 2015).

Life Cycle Assessments

As a supplement to economic analysis of green roofs, life cycle assessments (LCA) is to be conceived as an essential approach to better understand the environmental, economic, social and technical aspects related to these systems in various conditions that depend upon a wide range of variables such as materials, geographic location, initial costs, period of design, vegetation types, among others. In this context, several current studies are available with respect to LCA (Chenani, Lehvävirta, & Häkkinen, 2015; Rincon *et al.* 2014; Bianchini & Hewage 2012a, 2012b; Kosareo & Ries, 2007).

Modeling Applications and Technological Developments

Research not only has been conducted on real scenarios, but also future or ideal scenarios have been studied in modeling green roofs projects worldwide. This is mainly due to the technological developments currently available and the possibilities of pairing these with real scenarios through experiments and field evaluations. In this line of thinking, Feng, Zheng, Wang, Yu, & Su (2015) developed a non-traditional photovoltaic/thermal/day lighting (PV/T/D) system coupled to optical simulation software to be utilized in green roofs as alternative for greener building design and improved thermal efficiency. This system allowed for improved thermal efficiency and provided excellent light control at noon and other technical advantages as compared to other green roofs systems. Gagliano, Detommaso, Nocera, Patania, & Aneli (2014), carried out a study in south Sicily, Italy, which involved simulation through Design Builder® software to assess building energy performance and dynamic thermal behavior in an extensive green roof. Their results indicated that significant reductions in energy consumption were found for cooling and heating load (i.e., 80% and 34%, respectively), which essentially indicates the benefits of green roofs in greener buildings to allow for thermal efficiency in buildings, while allowing for energy savings and maintain comfort conditions throughout the day. Modeling also has applications in: hydrologic performance, as presented in recent publications by Hakimdavar, Culligan, Finazzi, Barontini, & Ranzi (2014). and Stovin, Poë, & Berretta (2013); economic and energy performance (Chan & Chow, 2013), green roof forecasting and demand (Tsang & Jim, 2013).

Aesthetic Assessments

Contrary to what might be expected, design of green roofs not only involves technical and economic aspects but also biological, environmental and aesthetic deliberations as previously presented, which are mainly intended for providing these structures with the ability to suit both functionality and efficiency, while providing buildings with greener attractiveness. As a result, some recent research around the globe has evaluated green roofs design from a more holistic approach, involving, for instance, studies

regarding novel ecosystem design of green roofs (Van Mechelen, Van Meerbeek, Dutoit, & Hermy 2015) and assessments of user's preferences, attitudes, expectations and reactions with regard to green roofs use in big and small cities (Jungels Rakow, Allred, & Skelly 2013; Fernandez-Cañero, Emilsson, Fernandez-Barba, & Machuca 2013; White & Gatersleben 2011; and Yuen & Hien 2005). In particular, the authors have concluded on the positive influence of green roofs on user's perception when comparing conventional no-green roofs buildings with those having green roofs at any level (i.e., industrial, academic, and domestic, extensive, intensive). Lines for future research are mainly focused on improving functional diversity and other biological-related components as those reported by Van Mechelen *et al.* (2015).

Case Studies in the Globe

The previous sections introduced recent research conducted on several aspects of green roofs around the globe, indicating the current relevance of this topic and the valuable lessons learnt from its implementation. To further supplement this information, this section focuses on some case studies of green roofs in different geographic locations, covering several topics from preceding sections and indicating their main findings and lines for further research.

In a recent study undertaken in Jordan, Goussous, Siam & Alzoubi (2015) assessed the energy and thermal efficiency of green roofs for applications in buildings. Computer simulations developed with Autodesk Ecotect Software were employed to determine the efficiency of heating, ventilating and air conditioning in a four-story residential building located in Amman. Clay and grass were recommended as suitable materials for green roofs. As suggested, future research should include development of new materials and detailed characterization of these for use in green roofs systems in order to facilitate improved efficiency.

Following the approach presented in the aesthetics section, Loder (2014) developed an interesting study case in the United States and Canada territories, covering the cities of Chicago and Toronto, respectively. The experiment involved two vegetation types (i.e. *Prairie* and *Sedum*). As indicated by the author, the perceptions of people with regard to green roofs are mainly based upon aesthetics, past experiences with nature, considerations about progress, modernity and native habitat. Furthermore, cultural components also had an influence on the responses from Chicago and Toronto participants. In general, public acceptation of green roofs depend of several aspects that need to be further studied and considered in other regions to determine which of these have more potential for successful implementation from the aesthetics standpoint. Also, perceptions of comfort, dwelling and place can have an influence when comparing workers of cities where scarce nature is available nearby. Access, scale and distance are also considered as important factors to be considered for further research by considered the importance of nature in human life. Finally, psychological and ecological aspects of green roofs were reinforced by the author, who encouraged more ecological aesthetics assessments.

Comprehensive reviews for specific regional aspects of green roofs are important informational sources for encouraging research that focuses on the gaps found by the authors. In this context, Chen (2013), and Xiao, Lin, Han & Zhang (2014) published state-of-the-art papers covering performance evaluations in Taiwan and research tendencies and development of green roofs in China. Widely available researches carried out in the United States territory can be found in journals with regard to green roofs, such as the study cases by Dvorak & Volder (2013), Dvorak & Volder (2010) and Yang, Yu & Gong (2008). Other studies in additional geographical locations provide additional insights on green roofs research activities in some of the areas covered in this paper, as supported by Italian researchers D'Orazio, Di Perna & Giuseppe (2012), Parizotto & Lamberts (2011) from Brazil, Nagase & Dunnett (2013) from the United Kingdom and Al Ali & Emziane (2013) from Abu Dhabi.

Conclusive Remarks

Based on the literature review presented in this article, it is clear that significant research efforts have been made in the last ten years for deeper understanding of the benefits, implementation, efficiency, challenges and other topics concerning green roofs around the globe. More specifically, the topics covered in the article included water management; biological assessments; climatic adaptation and urban planning; performance evaluations and thermal efficiency; economic analysis; life cycle assessments; modeling applications and technological developments; aesthetics and; some case studies from around the globe. From these, guidelines for topics to be undertaken in the near future were provided in order to contribute to advances in these areas. In fact, additional research outcomes in the coming years are expected as a response to the need of enabling a more massive use of this *environmentally friendly* technology with enormous potential for facing the global challenges with respect to global warming, climatic adaptation, energy efficiency, water management, biological conservation and other interesting fields of study. Nevertheless, research is not the only path to contribute in this area; implementation projects at various levels as well as a cooperative synergy between academy, industry and government can facilitate a more massive use of green roofs, especially in developing countries such as Colombia and other Latin-American counterparts, by using the great human potential and capabilities that these can offer in terms of pertinent technological and innovative developments.

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