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Urban planning and agriculture. Methodology for assessing rooftop greenhouse potential of non-residential areas using airborne sensors

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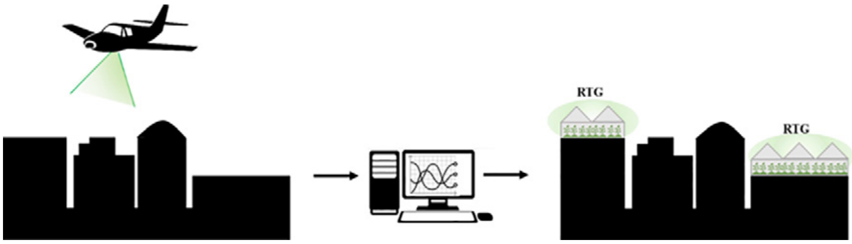
HIGHLIGHTS

- An automated methodology is proposed for urban planning RTG implementation.
- All roofs' characteristics of a city are acquired by airborne sensors in real-time.
- LIDAR and LWIR data allow roof's parameters to determine the potential for a RTG.
- Rubí's industrial area can produce vegetables for about 50% of total population.
- Airborne sensors open a new study area in green urbanism & construction industry.

GRAPHICAL ABSTRACT



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ABSTRACT

The integration of rooftop greenhouses (RTGs) in urban buildings is a practice that is becoming increasingly important in the world for their contribution to food security and sustainable development. However, the supply of tools and procedures to facilitate their implementation at the city scale is limited and laborious. This work aims to develop a specific and automated methodology for identifying the feasibility of implementation of rooftop greenhouses in non-residential urban areas, using airborne sensors. The use of Light Detection and Ranging (LIDAR) and Long Wave Infrared (LWIR) data and the Leica ALS50-II and TASI-600 sensors allow for the identification of some building roof parameters (area, slope, materials, and solar radiation) to determine the potential for constructing a RTG. This development represents an improvement in time and accuracy with respect to previous methodology, where all the relevant information must be acquired manually.

The methodology has been applied and validated in a case study corresponding to a non-residential urban area in the industrial municipality of Rubí, Barcelona (Spain). Based on this practical application, an area of 36,312 m^2 out of a total area of 1,243,540 m^2 of roofs with ideal characteristics for the construction of RTGs was identified. This area can produce approximately 600 tons of tomatoes per year, which represents the average yearly consumption for about 50% of Rubí total population.

Abbreviations: DTM, Digital Terrain Model; DSM, Digital Surface Model; GIS, Geographic Information Systems; GNSS, Global Navigation Satellite System; GE, Google Earth; LED, Light-Emitting Diode; LIDAR, Light Detection and Ranging; LWIR, Long Wave Infrared; UA, Urban agriculture; RTGs, Rooftop Greenhouses.

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The use of this methodology also facilitates the decision making process in urban agriculture, allowing a quick identification of optimal surfaces for the future implementation of urban agriculture in housing. It also opens new avenues for the use of airborne technology in environmental topics in cities.

1. Introduction

The development of humanity is closely linked to the formation of cities (Rossi, 1966). For decades, the rural population migrated to cities in search of new opportunities, but the increase in population, rapid urbanization and high population mobility significantly increased the generation of unwanted problems (Nadal et al., 2015). It is estimated that 7 out of 10 people will dwell in urban areas by 2050 (UN Habitat, 2012). One outcome is that consumption of resources within cities will continually increase and couple with modern consumerism habits resulting in high dependence of big amounts of resources that poses serious threats to the environment (Girardet, 2010).

In this sense, urban environments have proven to be unsustainable because their environmental footprint exceeds their natural bio-capacity and they rely heavily on imported resources (Doughty and Hammond, 2004). They are characterized by requiring large inputs from outside and generating a large amount of organic and inorganic waste (Wadel et al., 2010), resulting in the high consumption of energy resources and large CO_2 emissions per food unit (kg) throughout its life cycle (EEA, 2010). It is necessary to transform modern cities into more sustainable environments and develop a more circular metabolism where more resources are recycled, food is produced in situ and cleaner energy is consumed, among other factors (Doughty and Hammond, 2004). Therefore, it is vital to preserve the balance between the environment and humans (Deelstra and Girardet, 2000); in other words, it is advisable to implement a better reuse system for natural resources, a more sustainable infrastructure for greater flexibility in the urban environment and a better balance in relation to the environment (Schuetze and Thomas, 2011). As a current strategy to address these problems, "green urbanism" seeks to benefit to human health and the environment through interdisciplinary processes that promote the circular metabolism of cities (Beatley, 2003; Lehmann, 2010).This includes urban agriculture (UA), which plays a key role in the objectives of a city of the future and helps shape more sustainable cities through the ability to satisfy the demand for food, which has an impact on society, environmental harmonization and economically sustainable development (Berger, 2013).

Reinforcing this idea, the present systems of UA are diverse and allow for a wide range of approaches, models, scales, directions and objectives that do not curtail the urban and peri-urban environment (Junge and Graber, 2014; Nadal et al., 2015). Urban and peri-urban agriculture takes the form of backyard, roof-top and balcony gardening and community gardening in vacant lots and parks. In the urban context, there are various typologies of UA, depending on the production, market orientation or technology used, and can be classified in different ways (Dubbeling et al., 2010). In particular, the integration of the UA in and on buildings has been referred to in different ways (Table 1): Building Integrated Agriculture (BIA) (Caplow, 2009), Zero-acreage Farming (Z Farming) (Specht et al., 2013; Thomaier et al., 2015), Skyfarming (Germer et al., 2011), Sky garden (Ong, 2003), and Vertical Farming (Despommier, 2011).

Converting vacant and unused rooftops to productive space is a recognized strategy towards sustainability among researchers, city planners and developers (Elzeyadi et al., 2009; Carter and Keeler, 2008). Rooftops have an unprecedented potential for exploitation as they occupy 21% to 26% of all built-up areas (Getter and Bradley Rowe, 2006). They can improve the metabolism performance of cities by producing resources such as energy, greening, and food and rainwater harvesting to create productive areas through the revalorization of unused spaces. Rooftop greenhouses (RTGs) are defined as greenhouses that are implemented on top of buildings and aim to produce vegetables and food through soilless culture systems (Sanyé-Mengual et al., 2015a, 2015b). Its implementation can generate many potential benefits: closer production of food, reduction of transportation to ease food impacts and costs, the revaluation of unproductive spaces, reduction of energy demand in buildings and food safety, among others (Cerón-Palma et al., 2012). The use of soil-less systems (hydroponic and aeroponic) aim to reduce the structural load on the buildings, make responsible use of water and, in general, support sovereignty and food security in the urban context. There are several examples of application of greenhouses on the roofs of supermarkets, hospitals, parking lots and shopping malls worldwide (Specht et al., 2013).

1.1. Urban agriculture and airborne hyperspectral sensors

Despite the interest in the integration of UA, there are zones in cities that have not been exploited at the UA level, such as industrial parks (Sanyé-Mengual et al., 2015a, 2015b). These zones are defined as large

Table 1
Different concepts of urban agriculture integration in and on buildings.

Concept	Function (use buildings)	Synergies (buildings-agriculture)	Integration form	Placement	Usual technology	Sources
Building Integrated Agriculture (BIA)	Multifunctional	Yes	Inside and on the surface of the buildings	Green roofs, balcony gardens, rooftop farms, basements	Aquaponics, Light-Emitting Diode (LED, Recirculating hydroponics.	Caplow (2009)
Zero acreage farming (Z Farming)	Multifunctional	Yes	Inside and on the surface of the buildings	Rooftop gardens, edible green walls, indoor farms, vertical greenhouses	Water, energy and waste recycling, hydroponics, soil-based, aquaponics.	Specht et al. (2013); Thomaier et al. (2015)
Skyfarming	Monofunctional	Yes	Inside the buildings	Inside the buildings	Aeroponics, high efficiency lighting, temperature regulation and recovery of transpiration water, phytosanitation.	Germer et al. (2011)
Sky garden	Multifunctional	No	Inside and on the surface of the buildings	Rooftop gardens, podium gardens,	Soil based, rainwater harvesting.	Ong (2003)
Vertical farming	Monofunctional	Yes	In and on buildings	Inside the buildings	Hydroponics, Light-Emitting Diode (LED	Despommier (2011)