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

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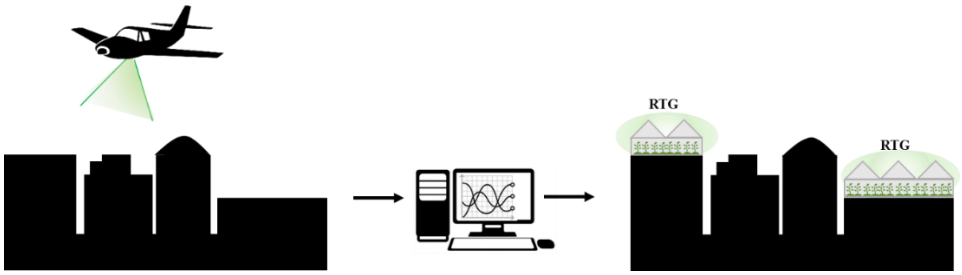
Graphical abstract



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.

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.

Keywords

Cities sustainability, urban agriculture, food security, smart cities, vertical farming, industrial parks

Abbreviations

Digital Terrain Model (DTM)

Digital Surface Model (DSM)

Geographic Information Systems (GIS)

Global Navigation Satellite System (GNSS)

Google Earth (GE)

Light-Emitting Diode (LED)

Light Detection and Ranging (LIDAR)

Long Wave Infrared (LWIR)

Urban agriculture (UA)

Rooftop Greenhouses (RTGs)

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, Avellaneda, and Cuchí 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, Zeeuw, and Veenhuizen 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).

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)

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 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 soil-less culture systems (Sanyé-Mengual et al., 2015). 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., 2015). These zones are defined as large areas of land that are sub-divided and developed for the use of several companies simultaneously and are distinguished by the shareable infrastructure and close proximity of companies (Peddle 1993).

The importance of these areas in the concept of the UA is based on the frequent homogeneous characteristics of buildings that are usually suitable for the development of UA because of their characteristics: the buildings have similar heights and are built at low densities, which prevents buildings from overshadowing nearby rooftops. They are also homogeneous in terms of materials and shapes, having typically much larger floor plans than other type of buildings. All these features facilitate the commercial exploitation of UA. Furthermore, buildings in industrial parks usually belong to an owner, making it easier to overcome management-related barriers and implementation (Sanyé-Mengual et al., 2015).

To quantify the potential of UA in cities, Sanyé-Mengual et al. (2015) developed a pioneering study that consisted of a step-by-step guide for the implementation of agriculture at the urban planning scale. This study confirms that industrial parks are a good option for the implementation of UA. The guide has three steps. First, a definition of criteria to identify feasible rooftops for the implementation of RTGs (based on expert consultations and considering basic economic, legal, and agricultural factors) is conducted. Second, the area of the entire park is accounted for by means of geographic information systems (GIS) — and the criteria defined in Step 1 are applied — to determine the total area of feasible rooftops. Third, the quantification of environmental and self-sufficiency indicators for evaluating the implementation of RTGs is performed. Nevertheless, the process of the acquisition of roof data is complex, laborious and time consuming since a detailed database to analyze the possibilities of the study area in real time is needed.

Apart from this implementation guide, there are various technologies such as remote sensing — onboard aerial or space platforms — that provide information about important parameters and processes in land cover. These data have been used in agriculture since the 1980's, along with weather, topographical and geographical information systems and are a powerful tool for optimizing agriculture management (González Dugo 2006).

Today, there are a large number of sensors such as the USU multispectral digital system (Neale and Crowther 1994), Daedalus sensor scanner (Daedalus Enterprises 2012), and CASI sensor (ITRES© 2016), or Leica sensor (Leica Geosystems © 2016), among others, which provide global coverage at different scales of the earth's surface. These sensors cover different regions of the electromagnetic spectrum, recording both energy reflected by the earth's surface (for quantifying properties of crops and soil as the fraction of vegetation cover, biomass or the delimitation of types of soil) and the energy emitted by the surface in thermal and microwave regions (related to plant transpiration, water stress or soil moisture) (González Dugo 2006; Moran, Inoue, and Barnes 1997).

This can be particularly useful in the case of rural agriculture and specifically in precision agriculture, a management strategy that uses information technologies to collect data from multiple sources to inform decisions associated with crop production (National Research Council 1997). In the same sense, the use of sensors in cities provide information from the Earth's surface and existing covers: the detection of the urban structure, analysis of urban sprawl, general mapping, mapping of transport networks, mapping of urban trees, etc. (Cardozo and Da Silva 2013). This process generates an image where a portion of the earth's surface is represented by the smallest unit of information (pixel). For this, many satellites, such as Quick Bird (Digital Globe Corp 2010), are used. These satellites provide high spatial resolution images of approximately 2.0-2.4 m in a multi-spectral range. Active sensors such as Light Detection and Ranging (LIDAR) technology are also used. However, there is no absolute certainty about the effects of the sensor resolution in detecting urban decks and their architectural composition; optical sensors (Visible + IR) with high spatial resolution are the most widely used devices in urban applications (Cardozo and Da Silva 2013).

1.2. Justification and objectives

Today, earth observation satellites, global positioning and geographic information systems and airborne sensors are consolidated as technological tools for territorial analysis and precision agriculture activities. These technologies have proven to be an important source of information for a large number of applications, among which urban planning, land use analyses, environmental monitoring, crop management, oil and mining exploration and the location of assets roots are included.

In particular, the use of TASI-600 (ITRES© 2016) and Leica ALS50-II (Leica Geosystems © 2016) sensors have been applied to mining and road maintenance. Both sensors provide information on the status and characteristics of the rock surfaces and the wear on asphalt surfaces (ITRES 2010). Therefore, they may have significant potential for identifying built area characteristics in cities.

The foregoing, coupled with growing scientific and technical interest in these issues, makes remote sensing a tool with high potential for the development of UA and, specifically, the use of new technologies that automate the urban planning selection of roof surfaces with properties for RTG implementation.

In this sense, the purposes of this paper are as follows:

- To develop an automated procedure to identify the viability and quantify roof areas for the implementation of greenhouses in non-residential urban areas using airborne sensor (Long Wave Infrared data (LWIR) and LIDAR) data.
- To validate this procedure through a real case application in Barcelona area.
- To identify opportunities and barriers for the application of this procedure in different real cases.

This study is expected to support and streamline decision-making process for planners, designers and other professionals related to urban planning and urban agriculture when performing any interventions in a non-residential urban area to implement professional rooftop greenhouses.

2. METHODS

2.1. Requirements for data acquisition

As a starting basis for this research, the methodology defined by Sanyé-Mengual et al. (2015) has been used as a starting point. The methodology was developed to determine the short-term potential implementation of RTGs in industrial and logistic parks. A Geographic Information System (GIS) is used to manage the information and analyze the potential for the implementation of RTGs in industrial zones. Appendix A.1 details the original method, which is modified in this paper, and can be summarized in the following steps:

Step 1: Definition of Requirements for Implementing RTGs

Five issues are basic to determining the feasibility of implementing RTGs: planning, agriculture, economy, legal requirements, and technical aspects. For the criteria definition corresponding to each of these issues, it is necessary to consider the following requirements: data availability for validating the criteria, logical and understandable criteria for stakeholders, and the representation of the barriers that have been encountered in the study area.

- Planning criteria: Planning must allow for greenhouse installation in rooftops. Planning documentation can be requested from public entities. This criterion is geographically sensitive, and planning conditions vary by city.

- Agriculture criteria: Roofs must be empty and have no other installations, and shady roofs or shady areas must be excluded. The data may be compiled in the rooftop database.

- Economy criteria: Minimum roof area of 500 m² for ensuring economic viability is required. Data might be compiled in the rooftop database. The economic criterion is geographically sensitive.

- Legal criteria: Implement specific technical codes. Legal documents on buildings should be consulted to verify the legal requirements in urban areas. This criterion is geographically sensitive and planning conditions vary between cities.
- Technical criteria: Roofs must ensure stability and accessibility for workers. Flat roofs are technically feasible for implementing RTGs. The material and structure of the rooftop must be resistant to match the load requirements of the greenhouse. Reinforced concrete usually yields more stability for rooftop use and ensures structural strength for implementing RTGs. Usually this Data may be compiled in the rooftop database.

Step 2: Quantification of the Potential Implementation Area

A Geographic Information System (GIS) is used to manage the information by creating a multi-data spatial layer: the rooftop database. This database integrates all criteria from Step 1, which are collected for each rooftop. The rooftops that fulfill the requirements are then identified as short-term potential rooftops for implementing RTGs.

Step 3: Production, Self-Sufficiency, and Environmental Indicators

To assess the implementation of RTGs, three indicators are calculated: potential production, potential consumption and potential self-supply for one product. The latter value is calculated by dividing the potential production (total tons of product) by the average consumption of the product in the study area. Savings associated with the avoided distribution of non-local products are also calculated, as well as greenhouse gases and energy savings.

2.2. Data acquisition

Leica ALS50-II and roof plane detection from LIDAR data

Airborne LIDAR data are acquired with a Leica ALS50-II (Leica Geosystems © 2016). The ALS50-II (Figure 1) is a compact laser-based system for the acquisition of topographic data from a variety of airborne platforms. Range and return signal intensity measurements are recorded in flight along with position and attitude data derived from airborne GNSS and inertial subsystems. The operating principle of the ALS50-II is based on measuring the location (latitude, longitude and altitude) and attitude (roll, pitch and heading) of the aircraft, the slant distance to the target and scan angle, from which the target point position of each laser echo can be determined (Leica Geosystems © 2016).

TASI-600 and roof plane detection from LWIR data

The Thermal Airborne Spectrographic Imager 600 (TASI-600) is a hyperspectral LWIR sensor manufactured by the Canadian company ITRES© (ITRES© 2016) (Figure 1). The system operates in a push broom configuration and provides the user with 32-band hyperspectral data in the 8-11.5 µm spectral range. The nominal Field-Of-View (FOV) is approximately 40°, and it is distributed over 600 spatial pixels. The TASI can measure and retrieve information concerning skin temperature and the emissivity spectrum of the imaged scene. When flown over man-made areas such as an industrial district, TASI-based absolute temperature becomes a reliable descriptor of heat leaks through roof covers, whereas patterns detected within hyperspectral emissivity images usually account for different properties of the cover material.

Figure 1. TASI-600 and Leica ALS50-II sensors by Itres© Company and Leica Geosystems©.

2.3. Data preprocessing

Leica ALS50-II

The system parameters (Appendix A.2) were set to obtain an average point density of 6 points/m^2. With this configuration, the point density for a single strip is 2 points/m^2, but as the side overlap between flight lines is 66.8%, each point in the project area was surveyed with at least 3 strips.

The LIDAR system is calibrated in a flat area as recommended by Leica Geosystems. The LIDAR strips are adjusted in the project area with points measured in the control fields with TerraMatch software from Terrasolid (Burman, Tekniska högskolan i Stockholm, and Institutionen för geodesi och fotogrammetri 2000). The point cloud is then classified as ground, vegetation and buildings with the TerraScan and TerraModeler software, also from Terrasolid. Next, manual editing is performed to correct the mistakes from the automatic classification and to classify points on the powerline wires and towers. From all the points of the point cloud and points on wires, in the air or underground, a DSM of 0.5 m grid step is computed.

TASI-600

TASI-600 sensor is spectrally and radiometrically calibrated by the manufacturer. The process implies a radiometric calibration, spectral alignment and removal of anomalous pixels.

Key parameters for rooftop greenhouse suitability

To develop an effective methodology of RTG implementation, it is necessary to automatically acquire (for the subsequent analysis) a series of key parameters from the use of TASI-600 and Leica ALS50-II sensors. These parameters are presented in Table 2.

Table 2. Key parameters from the use of TASI-600 and Leica ALS50-II sensors.

Variable	Specifications	Sensor used
Rooftop area	500 m^2 (minimum)	Leica ALS50-II
Presence of obstacles	Rooftop free of elements that divide the surface	Leica ALS50-II
Solar radiation	Minimum range of 1900-2000 MJ / m^2/year or 13-14 MJ/m^2 day	
Rooftop slope	No greater than 10%	
Rooftop material	Differentiate surfaces and potential identification of concrete roofs	TASI-600 sensor

2.4. Automated identification

Due to the novelty proposed in this paper in the use of the LIDAR and TASI-600 sensors for the acquisition of information about the characteristics and materials of the roofs, it is necessary to verify that the information supplied is correct. Verification is conducted through site visits in which buildings within the study zone are randomly selected, which represent the most representative roof building systems in the area.

The verification process consists of 2 stages:

a). Hyperspectral data classification

The information provided by the LIDAR sensor was analyzed and classified in the following categories: total roof area, free roof, solar radiation and slope. Information regarding roofing materials and roof system resistance that was provided by the TASI-600 sensor was processed, and the most representative materials of each roof covering were selected.

These materials are classified as gravel, apparent concrete, metal roofing (mainly metal roofing sheet structures or metal sandwich panel roofing), fiber cement and polymeric material -corresponding to the materials that are most commonly used in the roof covering of the buildings in the study area-. They are identified in accordance with the spectral footprint and the wavelength that they present.

b). On-site verification and spectral discrimination

Visits to the buildings roofs were carried out by specialists on structures and construction and the technical personnel of the building owners (maintenance area). Technical information provided by the owners was used to verify the roof characteristics.

During the technical visits, a photographic survey was carried out, a sketch of the roof was made and the characteristics previously selected by the sensors were validated (area, solar radiation, free roof, slope and roofing material as well as construction typology of the roof system). In the case of roofs without sufficient resistance to be walked on, the technical and maintenance information of the owner was used for the verification of the information of the sensors.

Finally, the information collected through the sensors was contrasted with the information collected during the visit to the site. The information provided by the sensors had to match the information collected in the technical visits to be considered valid.

2.5. Case Study

Rubí industrial park

Rubí is a town in the Barcelona metropolitan area located 23 km northwest of Barcelona with a population of 75 167 (Instituto Nacional de Estadística 2016) (Figure 2). The town lies on the left bank of the river Rubí, and it hosts important industrial activity with approximately 11 industrial parks and 51 companies. The most important industrial activity in the municipality is the production of electronic equipment and computer products, a sector that invoices more than 613 million euros per year (Galián 2015).

Additionally, Rubí was identified as a suitable study area for different reasons. First, over the past several years, the population of Rubí has increased as a result of the expansion of its industry and its strategic location. And it is estimated

that 49% of the population are industrial employees (Galián 2015). Second, the industrial zone presents homogeneity in the basic typology of the buildings. Third, the municipality of Rubí and Rubí's companies are explicitly open to sharing experience and collaborating to extend UA and have been working on environmental sustainability issues since the establishment of the Municipal Institute for the Environment (IMMA) in 1996. The Rubí Brilla ("Rubí Shines") project (Ajuntament de Rubí 2011) also aimed to make the city of Rubí a national and international energy efficiency and renewable energy territory for the industrial, commercial and domestic environment. The commitment involves a 20% reduction in CO_2 emissions and an increase of 20% of renewable energy and energy efficiency until 2020 (Ajuntament de Rubí 2015). Due to these early actions, Rubí may be considered a sustainability prototype for small towns located in proximity to dense (or large) urban areas. This medley of conditions make Rubí an interesting and dynamic case study, and this research attempts to propose further actions towards its sustainability goals while creating a model for similar towns in metropolitan city areas.

In addition, Rubí presents an industrial tradition in which the use of fiber cement rooftops (many with asbestos fibers) was very common in the decade of the 50's (Foundation for Occupational Risk Prevention 2001) . Today most of these rooftops have been removed and replaced by metal roofing sheets, because of the danger that asbestos poses to health (BOE 299 – 14.12.2001 2001). However, fiber cement rooftops (with or without asbestos fibers) can still be found today in some industrial buildings in the area.

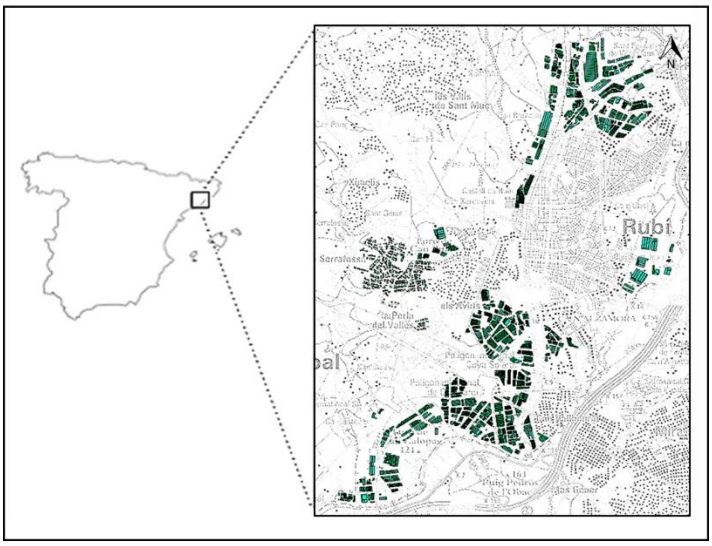


Figure 2. Location of the study case: Rubí and industrial parks (dark green).

3. RESULTS

3.1. Improved guide for assessing RTG implementation

This study uses the first version of an RTG implementation guide (Sanyé-Mengual et al., 2015) and adds some improvements to adapt it for the use of airborne sensors (TASI-600 and Leica ALS50-II). This allows the quantitative

information of the building's characteristics to be automatically expedited. It should be noted that this study focuses only on the development of commercial RTGs, so it requires economic usefulness for the agricultural enterprise. The guide addresses the urban planning implementation of RTGs in non-residential urban areas, though it can be applied to more general contexts. The study posits that the RTG system consists of a soil-less culture system, hydroponics or aquaponics, a way that reduces potential problems of structural overload of the building.

Figure 3 shows the basic differences between the previous guide and the present. In step 1, the previous guide has 5 basic criteria: planning, agriculture, economy, legal and technical. The tool used in the agriculture, economy and technical criteria is the GIS database, which were previously collected in secondary sources; for the remaining criteria, the literature review is used. In the present guide, Phase 1 has quantitative information (unlike the previous guide) for the identification of the basic requirements for the implementation of the RTGs. Phase 1 is divided into 2 stages. The first stage covers economic and legal criteria. LIDAR data are used to assess the economic criteria (free rooftop surface), and the literature review is used to assess legal criteria. The second stage covers the agricultural and technical criteria. LIDAR data are used to assess the agricultural criteria, and the LWIR and LIDAR data are used for the technical criteria.

In step 2, the previous guide uses a compilation of data on the study area, which is applied to determine the total area of feasible roofs through QGIS. In the present guide, LIDAR and LWIR data are treated separately in specific software; afterward, all the information is collated in QGIS to determine the feasible area for the implementation of RTGs. Finally, in step 3, the previous study focuses on quantifying the potential area for the implementation of RTGs, potential food production and potential benefits through a life cycle approach. In this study, Phase 3 covers the quantification of potential food production and the potential for self-sufficiency. Other potential benefits are not calculated explicitly and are left for a specific subsequent analysis because the objective here is to quantify the potential area and productive capacity using real agronomic production data of an RTG located in the study area.

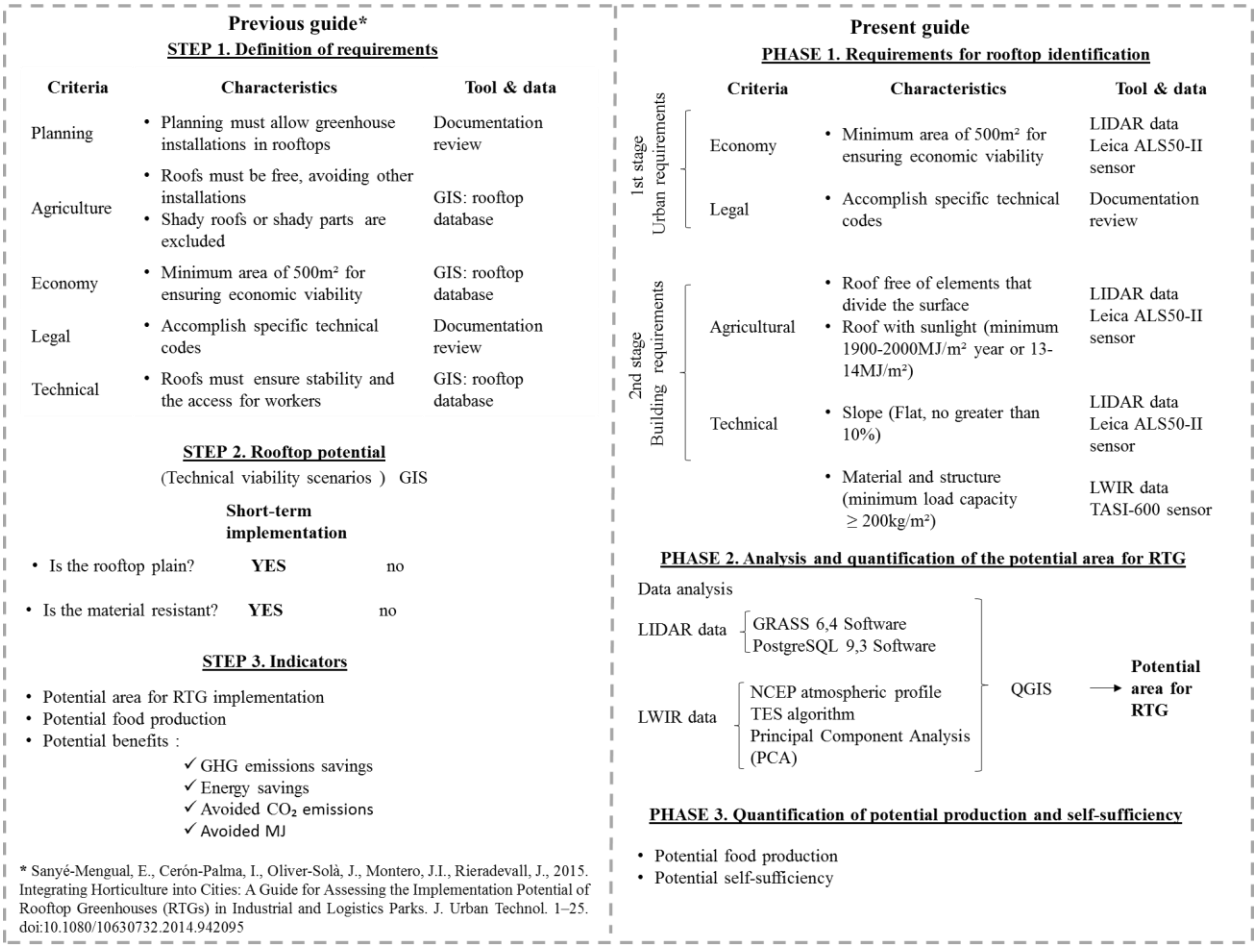


Figure 3. Comparison between guides and improvements in the proposed guide.

In the following, a summary of the three basic phases of the new guide (Figure 4) is presented:

- *Phase 1: Requirements for rooftop identification*

Phase 1 integrates all urban and building requirements that may be related to the implementation of an RTG in an existing building. This phase consists of two general stages. First, the urban requirements for identifying the feasibility of implementing greenhouse roofs are defined. They are based on economic and legal criteria, both of which are essential for the implementation of RTGs because they represent general aspects and are necessary to start the 2nd stage. In this stage, a review of the documentation (buildings and urban codes) and LIDAR data are used to measure the areas.

The second stage relates to the requirements of the building where the RTG is to be implemented. In this stage, LIDAR and LWIR data are used to fulfill agricultural and technical criteria covering aspects of sunlight, slope and roof material (load bearing).

1st stage. Urban requirements

Economic criteria: This guide focuses on the commercial approach to UA. A viable rooftop must have a minimum of 500 m^2 area to be able to recover the economic investment in a short period of time (Berger, 2013; Sanyé-Mengual et al., 2015), but it should be noted that economic criteria are geographically variable. Therefore, it is recommended to perform a review to estimate the minimum area feasible depending on the location. This criterion can be validated through Leica ALS50-II sensor and LIDAR data.

Legal criteria: In legal matters, the construction of an RTG is more closely related to building codes and urban codes than to laws of conventional greenhouse regulations. Any construction of RTGs should follow existing building codes and must ensure, above all, stability and structural safety. Regarding the legal criteria and due to the difficulty of automating these data, there has been no substantial modification regarding the first protocol of departure.

2nd stage. Building requirements

Agricultural criteria: These criteria cover the basic or minimum requirements for agricultural activity: (A) The area of the rooftop must be free and (B) must be sunny.

A. Typically, the rooftops of buildings in industrial areas have HVAC equipment, communication antennas and other elements that divide the surface. For the proper development of an RTG, a free rooftop without elements that may obstruct the maximum exploitation area is advised (Sanyé-Mengual et al., 2015). This criterion can be validated through the Leica ALS50-II sensor and LIDAR data.

   For all agricultural activity in which no use of LEDs (Light-Emitting Diode) is used, sunlight for plants is essential. With sunlight, plants perform photosynthesis and other biological processes that allow the germination, growth, fruiting and ripening of good quality products. The greater the solar radiation is, the larger the crop production is. However, due to the current conditions of cities, tall buildings often deprive low adjacent buildings of sunlight.

   Given this, the most important criterion at the agriculture level is to have a safe and steady supply of solar radiation for most of the year. For this investigation, a minimum range of 1900-2000 MJ/m^2 per year or 13-14 MJ/m^2 per day of solar radiation is required to build an RTG with ideal production. For this reason, shaded roofs are considered unfeasible. This criterion can be validated through the Leica ALS50-II sensor and LIDAR data.

Technical criteria: These criteria encompass all characteristics related to the roof slope (A) and structural load bearing (B) of the building.

A. Slope: To build an RTG, it is necessary to have a flat rooftop with a slope no greater than 10%. If the slope is greater than this value or the building has an inclined, gabled, hipped or convex roof typology, it is

recommended that the roof be used for other applications, such as collecting rainwater or implementing solar panels. This criterion can be validated through the Leica ALS50-II sensor and LIDAR data.

B. Material and load bearing: It is necessary to consider that the roof must support the weight of the structure of the RTG as well as the cultivation and irrigation system, the water tanks and the weight of the users.

All flat roof with a minimum capacity of 200 kg/m^2 is considered as feasible for the implementation of a RTG in a short time. The present guide considers a hydroponics system (80-100 kg/m^2), and a RTG's construction systems of 65 kg/m^2 (Sanyé-Mengual, Oliver-Solà, et al. 2015), resulting in a total weight of 145-165 kg/m^2 per RTG. Therefore, a roof system with a minimum load capacity of 200 kg/m^2 is sufficient for the endurance of RTG; leaving a small margin of safety and variation. Roof systems consisting of a concrete deck supporting a heavy roof covering (e.g. concrete deck with concrete pavers, ceramic tiles or a wearing course as roof covering) are ideal, because they tend to be designed to withstand a minimum load of 200 kg/m2 (in the case of Spanish regulations) (BOE.Orden FOM/1635/2013 2013; BOE 2006). A short time implementation in roofs with metal deck and light or metal covering (e.g. roof sandwich panel systems, metal roofing sheets or fiber cement roofing plates) is feasible, but it is necessary to check their load capacity, status of walkable roof and that they do not pose a risk to users.

It should be noted, that an RTG system is frequently lighter than a green roof. Usually a green roof has a weight of approximately 60-150kg/m^2 for extensive modality, 120-200 kg/m^2 for semi- intensive modality and 180-500 kg/m^2 for intensive modality (Livingroofs Enterprises 2017). Or, for general cases, 450 kg/m^2 in average (Contreras and Castillo 2015).

In the present guide, technical criteria can be preliminarily checked through the TASI-600 sensor and LWIR data (by an analysis of the wavelength of the materials). But, a technical visit to the building can be required. A building structures expert must conduct a study of the roof materials and the state of the building.

In special cases of parallel activities (rainwater harvesting or photovoltaic system) on the same rooftop (without interfering with the requirements for the correct development of the RTG), it is essential to consider a heavier load (an approximate of 12.5 kg/m^2 for a framed module of photovoltaic system (SEAI 2010) while a water tank weight varies according to its capacity). The same as for inclined rooftops (slope greater than 10%) and rooftops with low resistance, a series of renovations and reinforcements may be needed. These cases are displayed as rooftops that are viable for the medium and long term. Within this category, roof systems made with fiber cement siding can be found. As additional data, all cases where the fiber cement siding is reinforced with asbestos (built mainly between 1965 and 1985, and before 2002, when the legal codes prohibited definitively its fabrication and (The Spanish National Institute for Health and Safery at Work 2005) are totally excluded for implementing RTG, because of the risks that they pose to the health of users, as well as because its low load capacity.

- *Phase 2: Analysis and quantification of the potential area for RTG*

The use of airborne sensors facilitates the process of data collection on the roofs of interest. Flying over the city area with the Leica ALS50-II laser scanner and TASI-600 sensors, it is possible to acquire first-hand data of the rooftop: the dimensions if the roof is empty, solar radiation on the surface, slope and the majority of materials on the roof system (mainly those of the roof covering). The data are calculated using intensity measurements and range return signals recorded during the flights, along with the position and attitude data derived from GNSS and inertial navigation subsystems. For this guide, the Leica ALS50-II laser scanner obtains information concerning the size of the roof, whether the roof is empty, the slope and aspect. Solar irradiation on the surface is later computed with GRASS, taking into account the shadowing effects from any object in the surrounding area.

The TASI-600 can measure and retrieve information concerning the surface temperature of the materials and the emissivity spectrum of the imaged scene. Thus, the TASI-600 is a reliable instrument for detecting the leakage of heat through roofs, while the patterns detected in hyperspectral imaging emissivity usually represent different material properties as the cover (Pipia et al. 2010; Pipia et al. 2011).

The DSM obtained from the LIDAR data holds all the geometric information of the terrain and buildings, including the area, slope and aspect. This model also includes the obstacles on the rooftop and objects that can cast shadows. Any object that could cast a shadow over the rooftop has been taken into consideration because it was probably detected by the LIDAR sensor, and the DSM was computed with points belonging to any such objects: buildings, vegetation, towers, poles, air conditioning machines, antennas, etc. The DSM was used to choose the most appropriate buildings for RTG installation, compute the feasible surface available and the average solar irradiation received in an average year. Note that the data acquired by the TASI-600 is the incoming radiance on the sensor TIR spectrum. The incoming radiance contributes to the object surface, the object emissivity and the radiance reflected from other sources, particularly the sun and the interaction with the atmosphere. Once the TASI-600 data are compensated by the sensor calibration; the geocoded image temperature and a hyperspectral emissivity image can be retrieved from each flight trach using the NCEP atmospheric profile (Barsi, Barker, and Schott 2003) tied to ground information provided by a close weather ground station and a version of the TES technique tailored to the TASI-600 spectral properties (Pipia et al. 2010).

- *Phase 3: Quantification of potential*

The production and self-sufficiency (Equations 2 and 3 below) were measured by taking the surface results obtained for the short-term feasible implementation identified (Sanyé-Mengual, Cerón-Palma, et al. 2015). The potential area (m^2) for the implementation of an RTG (Equation 1) and the potential production (kg) for the entire system (Equation 2) are used as indicators to assess the RTG implementation. The potential food for self-sufficiency is calculated by dividing the potential production (kg of product) by the average consumption of the product in the study area (kg • person • year) (Equation 3), resulting in the total number of people whose demand for the agricultural product is satisfied. In Equation 3, using secondary sources for the data of the annual average product intake of a highly demanded vegetable in the study area is recommended.

$$Potential\ area\ (m^2) = \Sigma Area\ of\ feasible\ rooftop\ (ha) \quad (1)$$

$$Potential\ production\ (kg) = Potential\ Area(m^2) \cdot Vegetable\ output\ \left(\frac{kg}{m^2}\right) \quad (2)$$

$$Potential\ selfsufficiency\ (\#persons) = \frac{Production(kg)}{average\ vegetable\ intake\ \left(\frac{kg}{percapita \cdot año}\right)} \quad (3)$$

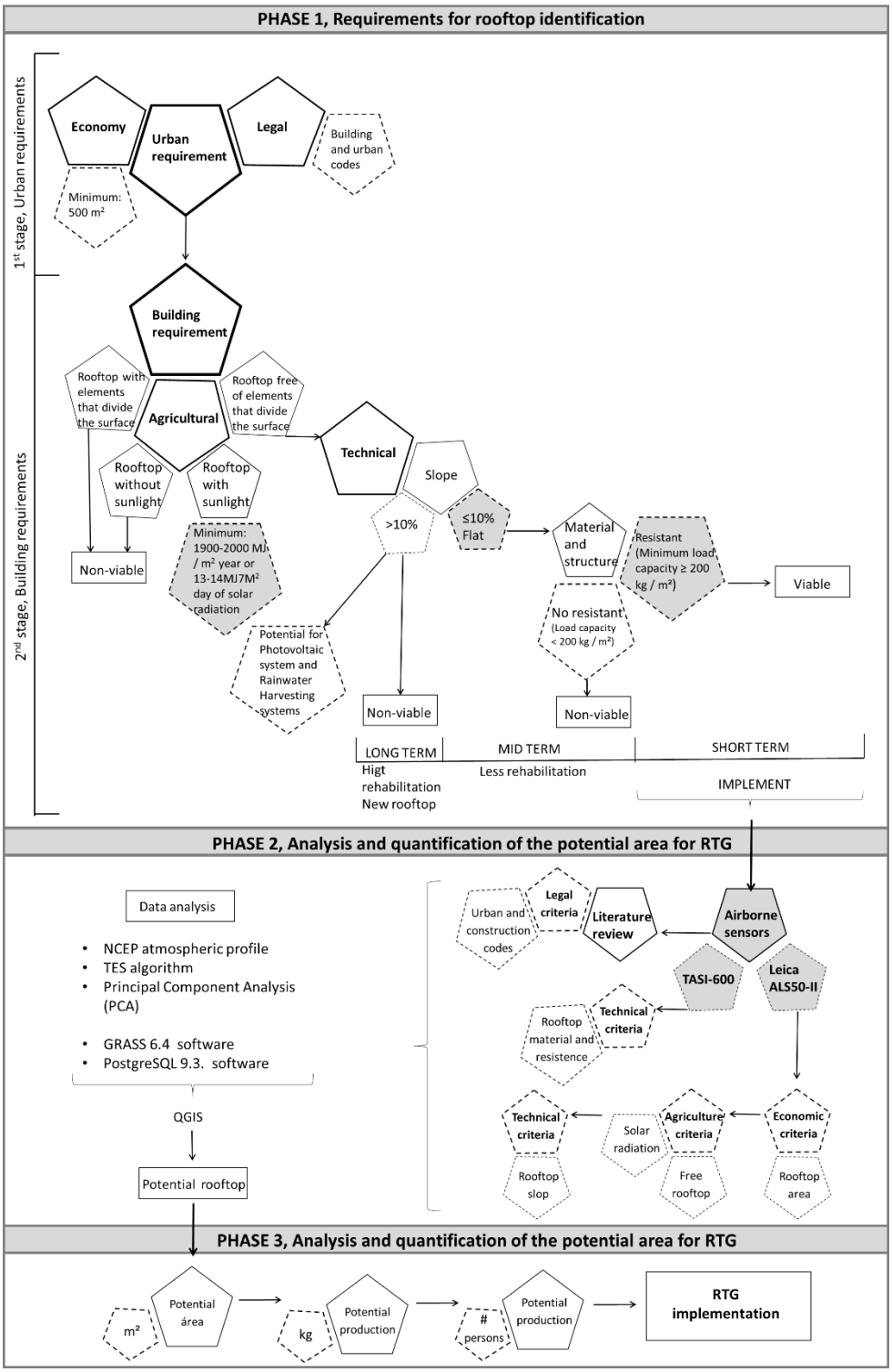


Figure 4. Graphical representation of the methodology (guide) proposed for identifying the feasibility of RTG implementation in non-residential urban areas, using Long Wave Infrared (LWIR) technology and LIDAR data.

3.1.2. Considerations for the application of the guide

For the implementation of an RTG, it is important to understand the characteristics of building context:

- The wind speed increases with the height. It is important to know the average wind speed on the roof of the building and in the area. Additionally, it is necessary to identify local atmospheric phenomena that can damage the greenhouse structure (e.g., hurricanes in the Gulf of Mexico).
- High temperatures (summer) can be a risk for crops in some regions. It will be necessary to create shade with shade nets.
- Due to the work being developed within the greenhouse, it is advisable to perform an analysis of the air quality. It is necessary to know the number of particles in the air and check the emissions from neighboring companies. Air quality should be acceptable and not pose a threat to human health and crops.
- Access to the greenhouse must be direct, safe and be a good location for the transport of the products (from the rooftop to the street level). When the building (in which there are plans to implement an RTG) does not have stairs or an elevator, it is necessary to remodel or annex the building to include stairs or an elevator.

3.2. Flights over the study area

The area over Rubí was flown with TASI-600 in February 2013 by the Cartographic and Geological Institute of Catalonia (ICGC) in the framework of the Rubí Brilla project (Ajuntament de Rubí 2011). Five strips flown N-E to S-W with a nominal overlap of 40% between strips were used to ensure full coverage of the area. Two flights were carried out, at midnight and 6 a.m., to evaluate the energy dynamics, which were potentially caused by energy leaks (Table 3).

Table 3. Main flight parameters over the Rubí area

Flight main parameter	Data
Sensor	TASI-600
Date	5-6 – Feb – 2013
First flight time	12am
Second flight time	6am
Flying height (above ground) [m]	1600
GSD (Ground Sampling Distance) [m]	2
Number of strips	5
Overlap [%]	40
Surface [km^2]	35

3.2.1 Analysis of LIDAR and LWIR data of flights over the study area

LIDAR data

The LIDAR data of the area was available from a previous survey. The flight configuration parameters are shown in Appendix A.2. From the classified point cloud, a DSM of a 0.5 m grid step was computed using the highest LIDAR point in each grid cell.

The average annual solar irradiation was computed with the r.sun module in GRASS using the 0.5 m DSM by adding the contributions of direct and diffuse light for consecutive half-hour time periods for a whole year. The direct and diffuse clear sky coefficients (Hofierka, J., Šúri, M. 2002) were adjusted to match the direct and diffuse solar irradiation for 4 solar stations near Rubí (ICAEN-UPC 2000). The computation time of the solar irradiation can be improved if a horizon is provided. In GRASS, the horizon is represented by a set of grids, each of which correspond to a fixed azimuth, and for each pixel, the angular height of the horizon corresponding to that azimuth. In this case, an azimuth step of 5 degrees was used, and for each, two different horizons were computed: one local horizon was obtained from the DSM with a 0.5 m grid step for the study area, and a topographic horizon was obtained from a DTM with a 15 m grid step covering the study area plus a buffer of 25 km surrounding it. The horizon used in the irradiation computations was the maximum of both the local and the topographic horizons.

The polygons of the building footprints in the area were drawn from the Urban Map of Catalonia (MUC) at a 1:1000 map scale. Because the industrial buildings have simple roofs, it was decided to split the building footprints into two segments at most according to the surface normal vector of the DSM. A maximum likelihood unsupervised classification was performed for the DSM pixels inside each footprint polygon. The variables employed in the classification were the sinus of the slope and the sinus and the cosinus of the DSM aspect. Working with the azimuth sinus and cosinus, a jump of approximately 0 that we would have had if the azimuth angle had been used directly is avoided. Roof segment polygons were obtained with a raster-to-polygon conversion of each of the segments obtained in this classification. The roof segment polygons were generalized with the Douglas-Peucker algorithm (Douglas, D.H. Additionally, Peucker, 1973), and those smaller than 4 m^2 were removed. Afterwards, the 3D area, the 2D projected area, the mean slope, the aspect, the yearly mean total, and the beam and diffuse irradiations were assigned to each roof segment polygon. The irradiation was computed as the aggregation of the pixels' interior to each roof polygon from the irradiation grids. All these operations were performed with GRASS 6.4 and PostgreSQL 9.3.

LWIR data

The TASI-600 data set comprises both flights (at 12 am and 6 am; see Table 3). The goal was to analyze roof temperature anomalies that may indicate heat loss (Pipia et al. 2014). As a result, both flights were carried out at night when the temperature was not influenced by sun activity. Notice that the nocturnal data acquisitions are the most appropriate for temperature analysis. However, nocturnal data sets are not the most appropriate for analyzing the emissivity of roof covers/materials because derived emissivity is noisy due to the low signal level. In a project with the main goal of detecting roofing materials and classifying rooftops, it would be desirable to use the highest

hyperspectrality possible, which means using VNIR and TIR Hyperspectral sensors if they are available and to perform the acquisition during the day instead of at night.

The temperature and emissivity maps corresponding to each flight are retrieved using the NCEP atmospheric profile tied to the ground information, which is provided by the Cerdanyola del Vallès automatic weather station (5 km from downtown Rubí) and the TES algorithm adapted to the TASI-600 spectral. Notice that emissivity is linked to the roof system material features. Afterwards, both thermal maps are compared on a pixel-by-pixel basis to detect changes in the temperature patterns, which can be related to heat-loss fluxes. Similar thermal dynamics will be sought and compared to hyperspectral emissivity information. A Principal Component Analysis (PCA) will be applied to highlight the existence of possible relationships between thermal behaviors and cover materials to analyze the spectral signatures in terms of emissivity for selected roof target areas.

3.3 Results of the case study

3.3.1 Local data

Specific data are needed for the application of the present methodology in the case study. To validate the legal criteria of Phase 1, available legislation, regulations and published work on Rubí were consulted. Legal information that must be considered in the case of Catalonia when implementing RTGs include Act 3/2010 on fire prevention (Spanish Government 2010) and the Technical Building Code (TBC) (BOE.Orden FOM/1635/2013 2013). The economic, agriculture and technical criteria were checked through the mentioned flights over the industrial zone of Rubí using the TASI-600 and Leica ALS50-II sensors. The flights were conducted by the Cartographic and Geologic Institute of Catalonia (ICGC).

In Phase 2, the characteristics of the rooftops collected through the flights are filtered using specific software and algorithms (NCEP atmosphere profile, TES algorithm, Principal Component Analysis PCA, GRASS 6.4 software and PostgreSQL 9.3 software) for each of the two sensors and are then integrated into a single GIS layer on the Urban Map of Catalonia (MUC) (orthophoto map, 1:5000 - OF-5 M - v6.0, from the ICGC).

Phase 3 discusses the potential area, production and self-sufficiency parameters, which are calculated based on tomato, the agricultural product selected. The tomato is the second most consumed vegetable in the region of Barcelona (Sanyé-Mengual et al., 2015), and it can be produced with hydroponics, as is used in the RTG. To calculate the potential production of RTGs in Rubí, it was believed that the tomato crop production (unheated greenhouses) in the study area had a yield of 16.2 kg/m^2 (the actual amount obtained in the iRTG of the ICTA-ICP building, Fertilecity project) (Nadal et al. 2017). For the self-sufficiency potential, a figure of 15.3 kg/person/year is used (annual average tomato intake) (Sanyé-Mengual et al., 2015).

3.3.2.. Analysis and quantification of the potential area for RTG

A total area of 1,243,540 m^2 of rooftops was identified in the industrial area of Rubí. After applying the improved methodology, a potential area of 36,312 m^2 rooftops (Figure 3) shows the basic differences between the previous guide and the present improved guide, and in Figure 5, a graphical summary of the rooftops that meet the criteria for the implementation of greenhouses was recorded. The summary represents 3% of the total roof area and could produce almost 588.25 tons of tomatoes per year, satisfying the average intake for 38,448 individuals, which represents 50% of Rubí total population. These values are similar to those found by Sanyé-Mengual et al. (2015) in Zona Franca Park (Barcelona, Spain) using the previous guide: 13.06 ha were identified for the implementation of RTG systems in the short-term, representing 8% of the total roof area, and could produce almost 2,000 tons of tomatoes per year, which can satisfy the average intake of 130,000 people in the study area.

For this case study, the material of the roof system is the most restrictive barrier for the implementation of RTG because most of the companies in the industrial park have roofs with metal deck and light or metal covering, which are usually systems with low load bearings. Additionally, approximately 60% of the roofs do not have a minimum area of 500 m2, so they are not compatible with the use of RTGs for economic reasons. The use of this methodology has proven to be helpful for the identification of rooftops with potential for the implementation of RTGs.

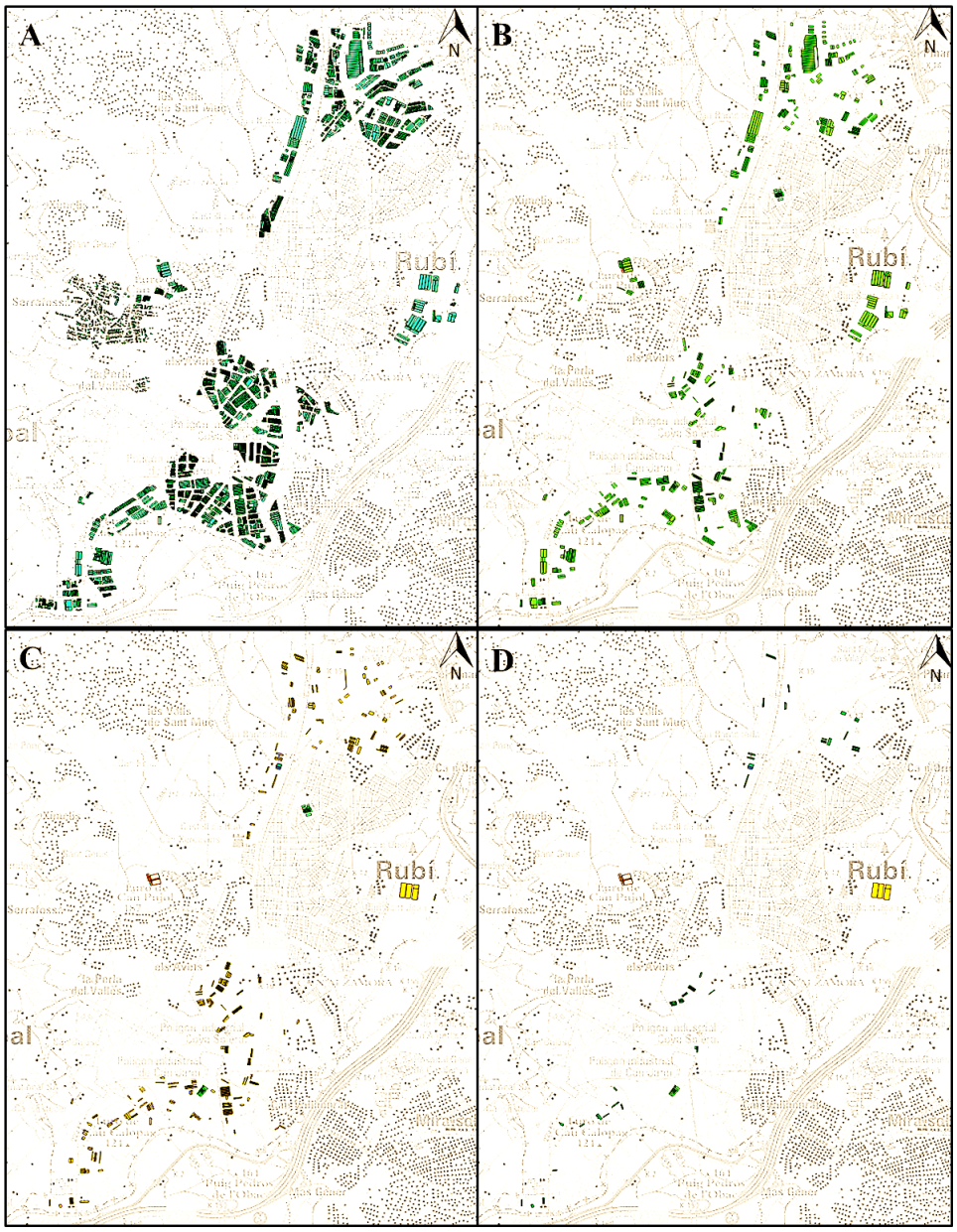


Figure 5. Application of the methodology (guide) in the industrial area of Rubí, Barcelona. A) total roofs studied (1,243,540 m2); B) total free roofs with a minimum area of 500 m2 (503,431.5 m2); C) total free roofs with a minimum area of 500 m2 meeting the solar radiation criterion (188,965.1 m2); and D) roofs that meet all the criteria for the implementation of RTG (36,312 m2).

3.3.3. Validation of LWIR data for material identification

To verify the use of the TASI-600 and Leica ALS50-II sensors to identify the characteristics and roof materials, field visits to 7 companies in the industrial area of Rubí were arranged. The companies visited were Roche Hermanos SA, Watts Ind Iberica, S.A., Ipagsa Industrial S.L., Continental Automotive Spain S.A., Top Cable SA, BASF Spanish S.L.

and JOVI S.A because the materials that were most commonly used in the corresponding building's rooftops are representative of the area.

Table 4 shows the results obtained by the TASI-600 and Leica ALS50-II sensors and their verification in the visit to the site. The identification of parameters of the area, that the roof was free of elements that divided the surface, and the slope and aspect using the LIDAR data were accurate. The precision of the LIDAR points in elevation is high, approximately 10 cm. The point density, 6 points/m^2, is sufficient to generate a DSM of 0.5 m. During the visits to the seven companies, it was noted that the information provided by the Leica ALS50-II sensor was correct and coincident with the geometric characteristics of the roofs.

The TASI-600 sensor was able to identify the materials of the surface roof covering but neither of the whole constructive solution nor the characteristics of the roof deck. The information was able to be grouped into categories that presented similar but not identical characteristics. These results are similar to those reported by Ayuga et al. (2007), that encountered some difficulties to discriminate the different materials of rooftops and roads. When two surfaces present similar materials of composition, errors of identification may appear.

For the Rubí case, Figure 6 shows hyperspectral signature for some parts of JOVI, S.A. building rooftop. In this image it is possible to identify notable differences between the surfaces of two different materials (gravel and apparent concrete). So, hyperspectral signature allows discrimination between them. However some urban building covers with similar material may respond in a similar way producing confusion in the classification of urban rooftops. For these reasons, technical visits on site can still be necessary in some cases and more research will be required to know which process features or algorithms should be improved in order to more effectively discriminate similar material surfaces.

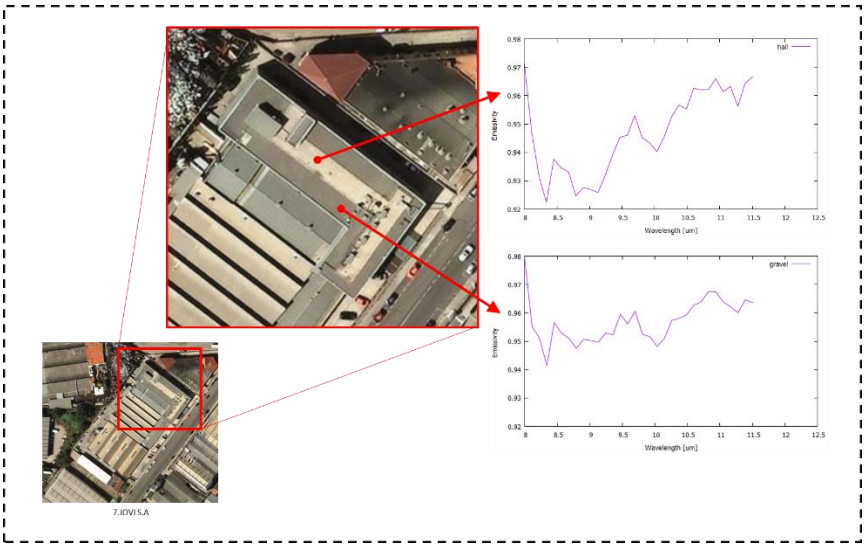


Figure 6. Hyperspectral signature for JOVI, S.A. building rooftop (gravel and apparent concrete).

Therefore, the use of the TASI-600 sensor was shown to be an acceptable alternative for the identification of surface materials. The LWIR data can be used to discard non-ideal roof materials for RTG implementation. However, it may be necessary to pay a verification visit to the site.

The Leica ALS50-II sensor has greater certainty for the acquisition and identification of roofs with suitable characteristics for the implementation of greenhouses. It is necessary to remember that the TASI-600 sensor is an airborne push broom hyperspectral TIR sensor. The data acquired by the TASI-600 is the incoming radiance of the sensor in the TIR spectrum, which is an observation with contributions of the object surface temperature, the object emissivity and the radiance reflected from other sources, particularly the Sun. Once the data had compensated for sensor calibration, the temperature and emissivity contributions may be derived. It must be said that LWIR data sets, which have been used in this work, was acquired previously with the goal of analyzing roof temperature anomalies that may indicate heat loss instead of material detection. For this reason, the data set was acquired at night when temperature was not influenced by sun activity. Note that nocturnal acquisitions are the most appropriate for temperature analysis. However, nocturnal data sets are not the most appropriate for analyzing the emissivity of materials because derived emissivity is noisy due to the low signal level. To obtain an appropriate data set for a material or cover analysis, it is recommended to perform a diurnal acquisition (flight) to obtain a better signal to noise ratio in the derived emissivity values.

Table 4. Verification of LIDAR and LWIR data through a technical visit to the site

Sensors	**LIDAR data**				**LWIR data**			
Company	*Area (m²)*	*Roof free of elements that divide the surface*	*Solar radiation kWh•m²•year*	*Slope*	*Surfaces materials (Preliminary identification)*			
					M	*AC*	*G*	*F*
Roche Hermanos S.A.	106	No	1293	Flat and inclined (5%)	X	X		X
Watts Ind Iberica, S.A.	1041	Yes	1461	Gabled (9%)	X			
Ipagsa Industrial S.L.	3180	No	1394	Flat, inclined, gabled, convex (8-29%)	X	X		X
Continental Automotive Spain S.A.	2929	No	1425	Convex (5%)	X			
Top Cable S.A.	23069	Yes	1439	Convex (6-10%)	X			
BASF Spanish S.L.	111	No	1357	Flat and convex (10-19%)	X	X		X

JOVI S.A.	5550	Yes	1392	Flat and inclined (5-30%)	X	X	X	
Technical visit	Area: Positive verification [a]	Roof free of elements that divide the surface: Positive verification [a]	Solar radiation kWh•m²•year: Positive verification	Slope: Positive verification	Surface material potential identification: Positive verification [b]			

[a] The information collected during the visit to the site is in line with the information supplied by the Leica sensor.

[b] Identification for material surfaces

M: Metal roofing (mainly metal roofing sheet structure or metal sandwich panel roofing)
G: Gravel
AC: Apparent concrete
F: Fiber cement (with or without asbestos fibers)

4. DISCUSSION

Methodology automatization outcomes

The airborne sensors for the automatization of this methodology present a good alternative to acquire and quantify key parameters for a preliminary selection of potential rooftops that are appropriate for greenhouse implementation. In particular, LIDAR and LWIR data are useful for eliminating roofs that do not possess the suitable characteristics for the implementation of an RTG.

The four main advantages of the use of these sensors in this guide are as follows:

- The scope or size of the study area: the use of airborne sensors allows for an extension of the area of study, through air travel, it is possible to cover large areas and entire cities without the amount of m^2 or km^2 representing a drawback.
- The time savings: being able to acquire information from all the rooftops of a city does not mean an increase in the time needed for this work. Automating the data acquisition of the TASI-600 and Leica sensors can extend the study area and reduce the capture time.
- The amount and reliability of the information collected: flying over the study area allows for the acquisition of reliable information of rooftops in real time without having to resort to secondary sources of information as a database or files.

The use of airborne sensors allow the acquisition of quantitative first-hand, updated and reliable data.
It is important to note that the airborne sensors must be operated by experts and that the number of flights over the study area depends on its dimensions. A small area may only need a few flights, while a larger area will need more flights. The latter involves an increase in cost and could restrict the use of the methodology only for institutions or companies that can afford it. In the future, the use of emerging and compact technologies could facilitate the use of

sensors, cameras, drones and satellites for the observation of roofs at lower prices. A LWIR and LIDAR survey for RTG applications will likely always be anti-economical, but there is a trend to make aerial and satellite images and LIDAR data that have been paid with taxes publicly available. The use of these data in many different applications allows the systematic surveys performed by governments to be socially rentable.

This new methodology mostly improves the data acquisition of some quantitative information. Despite the fact that the on-site verification of resistance and structural characteristics of roof systems and buildings and legal information collection continues being necessary, it allows some buildings to be immediately excluded because of the roof covering material identification. Rooftop surfaces on which materials are identified as potentially resistant (like gravel or apparent concrete). Usually, gravel surface have a sturdy concrete structure, but must be checked on site.
However, rooftops with coverings made of non-resistant materials (metal sheets, fiber cement with or without asbestos fibers), can be eliminated directly.

4.1. Adaptation of rooftops in Rubí

Industrial rooftops that have the dimensions, location and solar radiation appropriate for the implementation of an RTG but does not meet the structural requirements could be adapted in the mid or long term to meet the resistance requirements and be able to incorporate an RTG.

Currently, most of the companies in the industrial park of Rubí have roofs with metal deck and light or metal covering, all of them with low resistance, following a standard industrial warehouse design for the buildings. This characteristic (low resistance) is a limitation for implementing an RTG and is related to the year of the construction of the industrial area of Rubí and to the fact that at that time, the multi-functionality of spaces was not taken into account. In new industrial parks, if the rooftops are to be used for the implementation of RTGs, they must be designed to support higher loads, allow user access, comply with safety standards and provide the opportunity to develop parallel activities, such as rainwater and solar energy harvesting.

For economic reasons, most companies have warehouses with metallic structures and metal roof systems (metal roofing sheets structure or metal sandwich panel roofing), because these constructive systems meet the needs of large space at a relatively low cost, and also brings an advantage because of the facility and quickness of construction. However, a lot of these metal roof systems are usually calculated to withstand a light load and are not considered walkable or visitable. In these cases medium or long-term rooftops can be considered viable for RTG implementation because of reinforcement needs or modifications to develop a greenhouse. Nevertheless, these renovations involve many resources and energy costs, which in turn generate emissions and waste. Therefore, it is necessary to individually analyze the environmental impact that remodeling the rooftop can produce. The benefits that an RTG can generate (for the company and the city) should be greater than the environmental impact caused by their construction.

In this sense, the regulations on industrial parks in Spain and other locations should promote the use of existing roofs for agriculture production (or collecting rainwater and solar energy) and should require that the architectural and structural design of new industrial buildings consider the use of their roofs. An industrial rooftop may have diverse uses. The re-use of rooftops directly supports the development of cleaner industries and eco-parks that are responsible for their environmental impact.

5. CONCLUSIONS AND FUTURE WORK

This methodology has proven to be a promising updated, adaptable, global, fast and digital tool for identifying all rooftops with the potential for the implementation of RTGs in a study area through compliance with legal, economic, agricultural and quantitative technical criteria and the use of airborne sensors as tools for data acquisition.

This study can support the decision-making process in the field of urban planning at a large scale. It can also help the design activity in interventions that promote sustainability in non-residential urban areas. This guide provides the basic guidelines for the identification of rooftops with suitable characteristics for the implementation of RTGs: legal, economic, agricultural and technical criteria. The acquisition of the main quantitative characteristics of rooftops is performed by airborne sensors with high precision in short time. Possible constraints that may arise in the selection, such as the legal requirements in each geographical area, are also considered. Visits to buildings to verify their status and structure capacity may be necessary as well.

Although these early results are encouraging, more studies confirming that airborne sensors are reliable for the identification of constructive solutions with different materials are needed. It is also necessary to perform future tests in laboratory to identify the percentage of effectiveness of the TASI-600 sensor for the identification of structures and the materials of roofs. These results must be compared to results obtained by means of flights over the study area.

This methodology should be applied in different geographical areas to analyze the variability of the basic criteria. In this way, adaptability and effectiveness are tested, and important improvements can be made for better results. Additionally, the use of other airborne sensors and variations in the characteristics of flights should be explored in future research. The use of airborne sensors may open a new study area in green urbanism and in the construction industry.

In terms of the verification of this methodology, the industrial area of Rubi showed great potential. Despite this, only 3% of roofs of all industrial buildings had adequate features for the implementation of RTGs. With the development of RTGs in the area, it was possible to achieve tomato production of 600 tons per year, satisfying the need for food for about 50% of Rubí total population (38,448 people). However, the main barrier for the implementation of RTGs on most industrial parks roofs is the use of materials with a low-bearing capacity.

It is necessary to perform more research on topics on sustainability in industrial areas because industrial parks are an essential part of planning a city with significant potential for diverse uses. An opportunity appears through the concept of multipurpose rooftops from the early design stage of parks and industrial zones.

Acknowledgments

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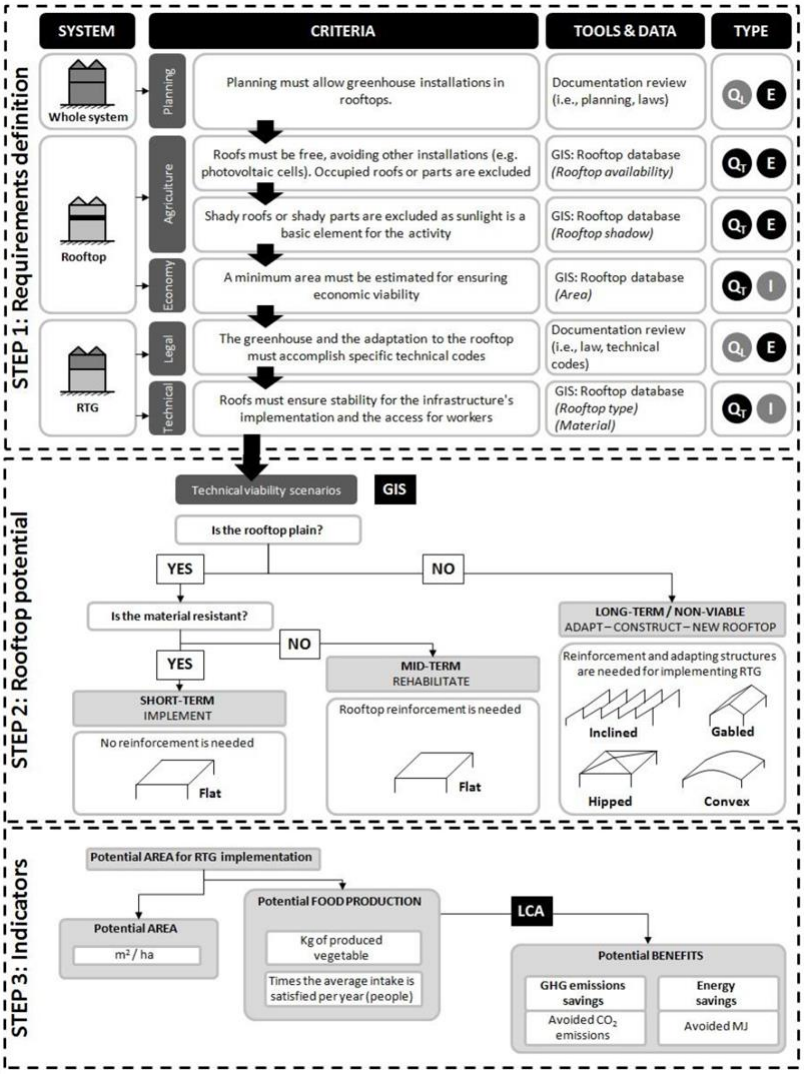
Appendix

Appendix A.1.

Guide specifications defined in Sanyé-Mengual et al., (2015).

The criteria can be Quantitative (QT) or Qualitative (QL) regarding the type of data needed for validation; and External (E) or Internal (I) if the criteria depend on external conditions (e.g., laws, third parties) or can be decided internally (e.g., economic outputs and RTG dimension).



Source: Sanyé-Mengual, E., Cerón-Palma, I., Oliver-Solà, J., Montero, J.I., Rieradevall, J., 2015. IntegratingHorticulture into Cities: A Guide for Assessing the Implementation Potential of Rooftop Greenhouses (RTGs) in Industrial and Logistics Parks. J. Urban Technol. 1–25. doi:10.1080/10630732.2014.942095

Appendix A.2.

<Table Appendix A.2.>

Table A.2. LIDAR parameter configuration

Characteristic	Information
FOV (max scan angle)	40º
Pulse Frequency	134400 Hz
Scan Frequency	35 Hz
Height (above mean ground)	1490 m
Distance between flight lines	360 m
Overlap	66.8 %
Point density	6 points/m^2
Precision vertical/horizontal	9/18 cm
Ground speed	100 - 120 knots

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Appendixes

Appendix A.1.

<Figure Appendix A.1.>

Appendix A.2.

<Table Appendix A.2.>