Universitat Autònoma de Barcelona

Urban agriculture in the framewok of sustainable uranisme

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Urban agriculture in the framework of sustainable urbanism

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Doctoral thesis

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"El que se va no vuelve, aunque regrese"

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Abbreviations

AGROCALIDAD: Agriculture Ministry agency

BIA: Building Integrated Agriculture

CRTG: Commercial Rooftop Greenhouse

CSCSM: Comuna Santa Clara de San Millán

CUO: Community Urban Orchard

DIF: System for Integral Family Development of Mexico

DMQ: Metropolitan District of Quito

DSM: Digital Surface Model

DTM: Digital Terrain Model

ECLAC: The Economic Commission for Latin America and the Caribbean

EVG: Educational Vertical Garden

FAO: Food and Agricultural Organization

FAO: Food and Agriculture Organization

GE: Google Earth

GIS: Geographic Information Systems

GNSS: Global Navigation Satellite System

ICP: Catalan Institute of Paleontology

ICTA: Institute of Environmental Science and Technology

ICTA-ICP: Institute of Environmental Science and Technology & Catalan Institute of Paleontology

IG: Inside Garden

INEN: Ecuadorian Institute of Normalization

iRTG: Integrated Rooftop Greenhouse

LAC: Latin America and the Caribbean

LED: Light-Emitting Diode

LIDAR: Light Detection and Ranging

LWIR: Long Wave Infrared

MAUT: Multi Attribute Utility Theory

MCDM: Multi-Criteria Decision Making

MDGs: Millennium Development Goals

MIVES: Integrated Value Model for Sustainability Assessment

NCDs: Diet-related Noncommunicable Diseases

NGOs: Non-Governmental Organization

OECAS: Organizaciones Económicas Campesinas, Indígena Originarias [*First people and peasant economic organisations*]:

OECOM: Organizaciones Económicas Comunitarias [*Community economic organisations*]

PR: Potential Production

PRG: Private rooftop garden

RC: Reinforced concrete

RG: Rooftop Garden

RTG: Rooftop greenhouse

RTGs: Rooftop greenhouses

SAGARPA: Secretary of Agriculture, Livestock, Rural Development, Fisheries and Food of Mexico

SDGs: Sustainable Development Goals

SEDESOL: Social Development Secretary of Mexico

SEMARNAT: Secretary of Environment and Natural Resources of Mexico

SS: Self-Sufficiency

UA: Urban agriculture

UN: The United Nations

UNESCO: United Nations Educational, Scientific and Cultural Organization

UO: Urban Orchard

UOPL: Urban Orchard in Private Land

UPA: Urban and Peri-urban Agriculture

VF: Vertical Farming

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SUMMARY

To achieve urban sustainability, understanding the complexity of the urban environment and addressing its problems is essential. As a result of demographic growth, the expansion of the limits of the cities is part of its natural evolution. However, it has generated a series of problems that affect the balance of ecosystems and influence the quality of urban life around the world. The excessive exploitation of natural resources and the space densification have generated significant changes in the features of the territory and the social environment. Currently, these problems have become one of the main social and environmental concerns around the world, as they represent a challenge to achieve a balance between the environment and the systems that make up the city.

Adopting an urban model that interweaves human activities with natural processes is key for urban sustainability. Sustainable urbanism promotes decision-making processes that seek to minimize the impacts on the environment through the development of strategies for the sustainability of the territory. One of these strategies is urban agriculture (UA), which contributes to the supply of food, avoids CO_2 emissions resulting from transporting food from rural areas to the city, and helps combat poverty and food insecurity, among others. Thus, there are currently a number of strategies and forms of UA that can positively influence the urban ecosystem, both in compact and diffuse cities.

Rooftop greenhouses are an alternative that in recent years has had a considerable rise in European compact cities, as they enable the cultivation of food in the city without compromising permeable soil surface. However, research that addresses their energy behavior and provides tools for the quantification and analysis of their viability is limited. In the case of the diffuse cities of Latin America and the Caribbean, urban agriculture presents unique conditions derived from the origin of its urbanism, which are intertwined with highly demanding social conditions such as hunger and poverty. Nevertheless, the study of UA is still in an initial stage, so it is necessary to deepen and promote its analysis. Recognizing that the city is a constantly evolving medium, the changes in its morphology, and the socio-environmental issues involved in UA, cities demand new alternatives that contribute to sustainable development. In this sense, the present doctoral thesis aims to cover these areas of study and answers the following four questions:

For developed countries

1. To what extent do urban-architectural, social and sustainable tools contribute to assessing the potential for implementation of agriculture on roofs of existing buildings in Southern European cities?

2. Can the integration of a greenhouse into the rooftop of a building, taking advantage of its exchange of residual thermal flows, contribute technologically and architecturally to the development of urban agriculture?

For developing countries

3. What is the current state of urban agriculture in developing countries in Latin America and the Caribbean?

4. What are the implications of urban planning and social housing in the promotion of urban agriculture for the sustainability of the medium-sized Latin American cities?

UA is a complex phenomenon and by its nature involves multiple scales, forms, actors, objectives, and dimensions of sustainability. Therefore, for its study it is necessary to use and combine various disciplines, tools and methodologies. This thesis includes an interdisciplinary framework that combines quantitative and qualitative aspects of the disciplines of Architecture, Environmental sciences, Urbanism, Agronomy and Social sciences. In each line of research studied, complementary

materials and methods have been used to obtain specific data. To name a few: TASI-600 and Leica ALS50-II airborne sensors, air humidity and temperature sensors, various software, document review, interviews, focus groups, and a decision support methodology. This methodological framework is adaptable and enables the evaluation of UA at the neighborhood and building scales considering the urban forms of the compact city in Europe and the diffuse city in LAC.

In order to address the first question posed in the block concerning UA in Europe, a practical study was carried out in an integrated rooftop greenhouse (iRTG), specifically in the ICTA-iRTG. The interior climate conditions of the iRTG were monitored in 2015 to know its thermal performance and its energetic strengths. The results showed that an iRTG can provide temperatures within the range of 14-26 °C, which are ideal for closed horticultural systems in the Mediterranean area. These temperatures are achieved by means of thermal "coupling" with the building, based on the reuse of the residual heat of the building itself; all this without consuming additional energy. Specifically, the results of the energy simulation showed that, under the same climatic conditions and control regimes, the cases of "suboptimal" temperatures (outside the range of 14-26 °C) would have been 33.5% higher in a conventional greenhouse. It was also shown that, due to the integrated nature of the iRTG, 341.93 kWh / m2 / year of heating energy can be "recycled" from the rest of the building; these results were used to calculate the financial and carbon savings of an iRTG relative to a conventional greenhouse with equivalent heating using associated carbon intensities derived from regional sources. The results showed that an oil boiler that satisfies the heating demands would produce 113.8 kg of CO_2 (eq) / m^2 / year, at a cost of 19.63 € / m^2 / year.

The second question has been studied firstly through the development of tools and methodologies, which enable decision-making and the identification of the roofs that have the potential for the implementation of a rooftop greenhouse (RTG). The first method is based on technical, legal, economic and agricultural criteria and uses airborne sensors (TASI 600 and Leica ALS50-II) to obtain first-hand information on the dimensions, area, inclination, sunlight and material of the roofs. The case study consisted of 11 industrial parks located in the city of Rubí (Barcelona); and the results indicated that the use of these sensors for the identification of the basic characteristics of the roofs is viable and reliable. In the study case, a viability of 3% of the total of the roofs of the industrial parks was obtained. This is because most of the roofs are built with materials of low load capacity. But despite the fact that the percentage is low, it is possible to achieve a production of 600 tons of tomato per year (which can satisfy the need for tomatoes of 50% of the total population of Rubí).

The second methodology focuses on decision-making for the selection of the roof with the highest sustainability index for the implementation of an RTG, using the MIVES methodology (Integrated Value Model for Sustainability Evaluations). Subsequently, both methodologies were applied to practical case studies in Barcelona and its surroundings. The case study comprised 11 elementary schools in Barcelona. The results indicated that the proposed multi-criteria tool is a viable and objective in which the use of a global sustainability index (ranging from 0 to 1) derived from the MIVES requirements tree, minimizes the subjectivity of the process and helps to select the most sustainable alternative for the potential installation of an RTG. Specifically in the case study, the social factors (for the support of the school staff, parent-teacher associations, and the UA school projects) were the determining factors for the selection of the best alternative. The case with the highest and lowest global sustainability index reached a score of 0.60 and 0.33, respectively.

In order to know the current status of UA in LAC and to answer the third question of this dissertation, a review of the scientific literature was made. The results showed that UA develops in at least 14 countries, but 86% of the research is developed in Brazil, Cuba, Mexico, Colombia and Argentina. We identified five functions that UA develops in the region: ecological-environmental, social, productive, urban-political and economic. With 46% of publications, the ecological-environmental function is the most developed; conversely, the economic function is the least explored with 3%. In

LAC, the UA is an emergency measure in the face of social problems and natural hazards and not a planned activity included in the strategies for urban sustainable development. This is partly due to the fact that UA promotion programs have an ephemeral nature and do not persist to be part of the urban environmental aspects.

Finally, responding to the fourth research question, UA in LAC is linked to social housing and urban planning, as the growth of the city is usually due to the construction of social housing neighborhoods. Social housing usually presents large areas of impervious surfaces, as a result of a modification process to adapt to the needs of the users (considering the social housing districts Villa Magna II, Tixcacal Opichen, Ampliacion Tixcacal Opichen and Las Magnolias in Mérida, México as an example). This results in small areas for the development of UA in its traditional forms. However, social housing neighborhoods have characteristics that make them suitable spaces for the development of vertical agriculture, such as rooftops greenhouses. In this sense, the potential for the implementation of RTGs in a social neighborhood (Comuna de Santa Clara de San Millán) in Quito, Ecuador was analyzed. The results obtained are encouraging and highlight the high potential of social housing for vertical agriculture: roofs with high load capacity and unfinished roofs that facilitate the implementation of RTGs. 33.2% (1160 ceilings, 7.7 hectares) of the 3494 ceilings analyzed can house an RTG and can produce 28 360 kg / year of lettuce and 789 750 kg / year of tomatoes.

At the urban planning level, urban public space is extremely limited for the development of the UA, which is why UA usually develops within the boundaries of private properties. As the results showed in the neighborhoods of Ampliación Tixcacal Opichen and Las Magnolias, UA is developed on a small scale and privately in more than half of the homes studied (out of a total of 157). It is cultivated in pots and in the little remaining free space of the modifications of the house. Fruit cultivation is imposed (70%) against vegetables and aromatic plants (30%). Within fruits, citrus are the prevalent crop, perhaps due to its easy maintenance and that Yucatán is a historical region of citrus production at a national level. In addition, crops with a greater variety of species are located in households with a lower degree of modification as a direct consequence of the free space available.

In this sense, this thesis contributes to the study of UA in the compact cities of developed countries and in the diffuse cities of developing countries through the development of new tools and data for the analysis of the topic. The results obtained extend the knowledge and understanding of the UA phenomenon and its close relationship with the city from a point of view of urban planning and architecture. It provides support to the decision-making processes in the areas of sustainable planning, the use of roofs in compact cities and LAC's social housing and opens up new lines of research. Future research in Europe should focus on the analysis of the bidirectional energy interconnection between the iRTG and the building; deepening the identification of roof materials using airborne sensors through laboratory tests; analyzing the feasibility of multipurpose covers in industrial parks, and adapting the decision-making methodology to the identification of roofs for the implementation of RTG in other geographical areas. In the case of LAC, future research should focus on exploring the less developed functions of UA (economic and political-urban); working with LAC community organizations to quantify the potential of agriculture on the roof; developing a database on the current development of UA in social housing, and analyzing the use of public spaces and their limitations in terms of urban policy.

RESUMEN

Para lograr la sustentabilidad urbana, es primordial comprender la complejidad del entorno urbano y abordar su problemática. La expansión de los límites de las ciudades, por el crecimiento demográfico, es parte de su evolución natural; sin embargo, ha generado una serie de problemas que afectan el equilibrio de los ecosistemas e influye en la calidad de vida urbana en todo el mundo. La explotación excesiva de los recursos naturales y la densificación del espacio han generado alteraciones significativas en el aspecto del territorio y del entorno social. Actualmente, estos problemas se han convertido en una de las principales preocupaciones en el ámbito social y ambiental alrededor del mundo; ya que representan un desafío para lograr un equilibrio entre el medio ambiente y los sistemas que integran la ciudad.

El adoptar un modelo urbanístico que entrelace las actividades humanas con los medios naturales es clave para la sustentabilidad urbana. El urbanismo sostenible promueve la toma de decisiones que busquen minimizar los impactos ocasionados al medio ambiente, por medio del desarrollo de estrategias en pro de una sostenibilidad del territorio. Una de estas estrategias es la agricultura urbana (AU), en la cual la producción de alimentos dentro de las ciudades contribuye al suministro de alimentos, evita emisiones de CO_2 derivadas del transporte de alimentos, ayuda en el combate a la pobreza y a la inseguridad alimentaria, entre otros. Es así que actualmente existen diversas estrategias y formas de la AU que pueden influir de manera positiva en cada uno de los elementos del ecosistema urbano, tanto en ciudades compactas como en ciudades difusas.

Los invernaderos en la azotea son una alternativa que en los últimos años ha tenido un auge considerable en las ciudades compactas de Europa, ya que permiten el cultivo de alimentos en la ciudad sin comprometer superficie de suelo permeable. Sin embargo, las investigaciones que aborden su comportamiento energético y que brinden herramientas para la cuantificación y análisis de su viabilidad son limitadas. En el caso de las ciudades difusas de América Latina y el Caribe (LAC), la agricultura urbana presenta condiciones únicas derivadas del origen de su urbanismo; y que se entrelazan con condicionales sociales altamente demandantes como el hambre y la pobreza. Pese a ello el estudio de la AU aún se encuentra en una etapa inicial, por lo que es necesario profundizar y promover su estudio. Reconociendo que la ciudad es un medio en constante evolución, los cambios en su morfología, las cuestiones socioambientales que involucra y que la ligan con la AU, la ciudad exige nuevas alternativas que contribuyan al desarrollo sustentable. En este sentido, la presente tesis doctoral pretende cubrir estos ámbitos de estudio a través de intentar dar respuesta a las siguientes cuatro preguntas:

Para los países desarrollados

1. ¿En qué medida las herramientas urbanas, arquitectónicas, sociales y sostenibles contribuyen a evaluar el potencial de implementación de la agricultura en azoteas de edificios existentes en ciudades del sur de Europa?

2. ¿Puede la integración de un invernadero en la azotea de un edificio, aprovechando su intercambio de flujos térmicos residuales, contribuir tecnológicamente y arquitectónicamente al desarrollo de la agricultura urbana?

Para los países en vías de desarrollo

3. ¿Cuál es el panorama actual de la agricultura urbana en los países en desarrollo de América Latina y el Caribe?

4. ¿Cuáles son las implicaciones de la planificación urbana y la vivienda social en la promoción de la agricultura urbana para la sostenibilidad de la ciudad latinoamericana de tamaño mediano?

La AU es un fenómeno complejo y por su propia naturaleza involucra múltiples escalas, formas, actores, objetivos y dimensiones de la sostenibilidad. Por lo tanto, para su estudio es necesario emplear y combinar diversas disciplinas, herramientas y metodologías. La presente tesis incluye un marco interdisciplinar que combina aspectos cuantitativos y cualitativos de las disciplinas de Arquitectura, Ciencias ambientales, Urbanismo, Agronomía y Ciencias sociales. Y en cada línea de investigación estudiada se han utilizado materiales y métodos complementarios para la obtención de datos específicos; por nombrar algunos: sensores aerotransportados TASI-600 Y Leica ALS50-II, sensores de temperatura y humedad del aire, diversos softwares, revisión documental, entrevistas, grupos de interés, metodología de soporte a la toma de decisiones. Este marco metodológico resulta adaptable y permite evaluar la AU en las escalas de barrio y de edificio dentro de las formas urbanas de la ciudad compacta en Europa y la ciudad difusa en LAC.

Con el objetivo de abordar la primera pregunta planteada del bloque referente a la AU en Europa, se ha realizado un estudio práctico en un invernadero integrado en la azotea (iRTG), específicamente en el ICTA-iRTG, en el cual se monitorizaba durante el 2015 las condiciones climáticas interiores del iRTG para conocer su comportamiento térmico y sus fortalezas energéticas. Los resultados demuestraron que un iRTG puede proporcionar temperaturas dentro del rango 14-26 °C, las cuales son idóneas para los sistemas cerrados de horticultura en zona mediterránea. Estas temperaturas se consiguen por medio del "acoplamiento" térmico con el edificio, basado en el reutilización del calor residual del propio edificio; todo esto sin consumir energía adicional. Puntualmente, los resultados de la simulación energética realizada mostraron que bajo las mismas condiciones climáticas y regímenes de control, los casos de temperaturas "subóptimas" (fuera del rango de 14-26 ° C) hubieran sido un 33.5% mayores en un invernadero convencional. También se demostró que debido a la naturaleza integrada del iRTG, se puede “reciclar” 341.93 kWh / m^2 / año de energía de calefacción del resto del edificio; estos resultados se usaron para calcular el ahorro financiero y de carbono de un iRTG relativo a un invernadero convencional con calefacción equivalente utilizando intensidades de carbono asociadas derivadas de fuentes regionales. Los resultados mostraron que una caldera de aceite que satisfaga las demandas de calefacción produciría 113.8 kg de CO_2 (eq) / m^2 / año, a un costo de 19.63 € / m^2 / año.

La segunda pregunta ha sido estudiada primeramente, mediante el desarrollo de herramientas y metodologías que permiten la identificación y la toma de decisiones de aquellas azoteas que poseen potencial para la implementación de invernaderos en la azotea (RTG). Posteriormente, ambas metodologías se aplicaron a casos de estudio prácticos en Barcelona y sus alrededores. La primera se apoya en criterios técnicos, legales, económicos y agrícolas y hace uso de sensores aerotransportados (TASI 600 y Leica ALS50-II) para la obtención de información de primera mano sobre las dimensiones, área, inclinación, asoleamiento y material de las azoteas. El caso de estudio estuvo integrado por 11 parques industriales localizados en la ciudad de Rubí (Barcelona); y los resultados señalaron que el uso de estos sensores para la identificación de las características básicas de las azoteas es viable y confiable. Se obtuvo una viabilidad de 3% del total de las azoteas de los parques industriales. Esto debido a que la mayor parte de las azoteas están construidas con materiales de baja capacidad de carga. Pero a pesar de que el porcentaje es bajo, es posible lograr una producción de 600 toneladas de tomate por año (que puede satisfacer la necesidad de tomates del 50% de la población total de Rubí).

La segunda metodología se enfoca en la toma de decisiones para la elección de la azotea con el mayor índice de sustentabilidad para la implementación de un RTG, mediante la metodología MIVES (Modelo Integrado de Valor para Evaluaciones de Sostenibilidad). El caso de estudio estuvo conformado por 11 escuelas de educación básica en Barcelona. Los resultados indicaron que la herramienta multicriterio propuesta ha demostró ser una alternativa viable y objetiva; en la cual el uso de un índice de sostenibilidad global (que va de 0 a 1) derivado del árbol de requisitos de MIVES, minimiza la subjetividad del proceso y permite seleccionar la alternativa más sostenible para la instalación potencial de un RTG. Específicamente en el caso de estudio, los factores sociales (a poyo del personal escolar y los padres y las asociaciones docentes y los proyectos escolares de AU) fueron los determinantes para la selección de la mejor alternativa. El caso con el índice de sostenibilidad global más elevado alcanzo un puntaje de 0.60 y 0.33 el de menor viabilidad.

Para conocer el estado actual del estudio de la AU en LAC y dar respuesta a la tercera pregunta que se plantea en la presente disertación, se realizó una revisión de literatura científica. Los resultados demostraron que la AU se desarrolla en al menos 14 países, pero el 86% de la investigación es desarrollada por Brasil, Cuba, México, Colombia y Argentina. Se identificaron cinco funciones que la AU desarrolla en la región: ecológico-ambiental, social, productivo, urbano-político y económico. Con el 46% de las publicaciones, la función ecológica- ambiental es la más desarrollada; contrariamente la función económica es la menos explorada con 3%. En LAC la AU es una medida de emergencia frente a problemas sociales y desastres naturales; y no una actividad planeada que forme parte de las estrategias para el desarrollo sustentable urbano. Esto se debe en parte a que los programas de fomento de la AU poseen un carácter efímero y no logran perdurar para formar parte de los aspectos urbanos ambientales.

Finalmente, respondiendo a la cuarta pregunta de investigación, la AU en LAC está vinculada a la vivienda social, ya al planeamiento urbano; ya que el crecimiento de la ciudad suele deberse a la construcción de barrios de vivienda social. Las viviendas sociales suelen presentar grandes áreas de superficies impermeables, como resultado de un proceso de modificación para adaptarse a las necesidades de los usuarios (considerando los barrios de vivienda social Villa Magna II, Tixcacal Opichen, Ampliacion Tixcacal Opichen y Las Magnolias en Mérida, México como ejemplo). Lo que deriva en áreas pequeñas para el desarrollo de la AU en sus formas tradicionales. Sin embargo, los barrios de vivienda social tienen características que los hacen espacios apropiados para el desarrollo de la agricultura vertical, como los invernaderos en la azotea. En este sentido se analizó el potencial para la implementación de RTGs en un barrio social (Comuna de Santa Clara de San Millán) en Quito, Ecuador. Los resultados obtenidos son alentadores y resaltan el alto potencial de las viviendas sociales para la agricultura vertical: azoteas con alta capacidad de carga y azoteas sin terminar que facilitan la labor de implementación de los RTG. El 33.2% (1160 techos, 7.7 hectáreas) de los 3494 techos analizados pueden albergar un RTG y puede producir 28 360 kg / año de lechuga y 789 750 kg / año de tomates.

A nivel de planificación urbana, el espacio público urbano para el desarrollo de la UA es extremadamente limitado; razón por la cual la AU suele desarrollarse dentro de los límites del predio. Tal como señala los resultados, obtenidos en los barrios de Ampliación Tixcacal Opichen y Las Magnolias, la AU se desarrolla a escala pequeña y de forma privada en más de la mitad de las viviendas estudiadas (de un total de 157). Se cultiva en macetas y en el poco espacio libre restante de las modificaciones de la vivienda. El cultivo de frutas se impone (70%) frente a las verduras y plantas aromáticas (30%). Dentro de las frutas, los cítricos son el cultivo prevalente, debido quizás a su fácil mantenimiento y a que Yucatán es una región histórica de producción de cítricos a nivel nacional Además, los cultivos con mayor variedad de especies se encuentran en las viviendas con menor grado de modificación; como una consecuencia directa del espacio libre disponible.

En este sentido, la presente tesis contribuye al estudio de la AU en las ciudades compactas de los países desarrollados y en las ciudades difusas de los países en vías de desarrollo mediante el desarrollo de nuevas herramientas y datos para el análisis del tema. Los resultados obtenidos amplían el conocimiento y la comprensión del fenómeno de la AU y su estrecha relación con la ciudad desde un punto de vista del planeamiento urbano y de la Arquitectura. Brinda apoyo en los procesos de toma de decisiones en los ámbitos del planeamiento sostenible, el uso de las azoteas en las ciudades compactas y la vivienda social de LAC y abre nuevas líneas de investigación. Futuras investigaciones en Europa deberían centrarse en el análisis de la interconexión bidireccional energética entre el iRTG y el edificio; en profundizar por medio de pruebas en laboratorio la identificación de materiales en cubiertas usando sensores aerotransportado; en analizar la viabilidad de cubiertas multipropósito en parques industriales; en adaptar la metodología de toma decisiones para la identificación de azoteas para la implementación de RTG en otras zonas geográficas. En el caso de LAC, las investigaciones futuras deben de focalizar en explorar las funciones menos desarrolladas de la UA (económica y político-urbana); en trabajar con organizaciones comunitarias de LAC para la cuantificación el potencial de la agricultura en cubierta; en desarrollar una base de datos sobre el desarrollo actual de la UA en la vivienda social y en analizar el uso de los espacios públicos y sus limitaciones en materia de política urbana.

RESUM

Per aconseguir la sostenibilitat urbana, és primordial comprendre la complexitat de l'entorn urbà i abordar la seva problemàtica. L'expansió dels límits de les ciutats degut al creixement demogràfic, és part de la seva evolució natural; no obstant això, ha generat una sèrie de problemes que afecten l'equilibri dels ecosistemes i influeix en la qualitat de vida urbana a tot el món. L'explotació excessiva dels recursos naturals i la densificació de l'espai han generat canvis significatius en l'aspecte del territori i en l'entorn social. Actualment, aquests problemes s'han convertit en una de les principals preocupacions en l'àmbit social i ambiental arreu del món ja que representen un desafiament per aconseguir un equilibri entre el medi ambient i els sistemes que integren la ciutat.

Adoptar un model urbanístic que entrellaci les activitats humanes amb els mitjans naturals és clau per a la sostenibilitat urbana. L'urbanisme sostenible promou una presa de decisions que busqui minimitzar els impactes ocasionats al medi ambient, mitjançant el desenvolupament d'estratègies a favor d'una sostenibilitat del territori. Una d'aquestes estratègies és l'agricultura urbana (AU), la qual amb la producció d'aliments dins de les ciutats contribueix al subministrament de menjar, evita emissions de CO2 derivades del transport d'aliments, ajuda en el combat contra la pobresa i la inseguretat alimentària, entre d'altres. És així que actualment existeixen diverses estratègies i formes d'AU que poden influir de manera positiva en cadascun dels elements de l'ecosistema urbà, tant en ciutats compactes com en ciutats difuses.

Els hivernacles en el terrat són una alternativa que en els últims anys ha tingut un auge considerable a les ciutats compactes d'Europa, ja que permeten cultivar aliments a la ciutat sense comprometre superfície de sòl permeable. No obstant això, les recerques que aborden el seu comportament energètic i que brindin eines per a la quantificació i anàlisi de la seva viabilitat són limitades. En el cas de les ciutats difuses d'Amèrica Llatina i el Carib (LAC), l'agricultura urbana presenta condicions úniques derivades de l'origen del seu urbanisme; i que s'entrellacen amb condicionals socials altament demandants com la fam i la pobresa. Malgrat això l'estudi de la AU encara es troba en una etapa inicial, per la qual cosa és necessari aprofundir i promoure més recerca. Tenint en compte que la ciutat és un mitjà en constant evolució, els canvis en la seva morfologia, les qüestions socioambientales que involucra i que la lliguen amb la AU, exigeix noves alternatives que contribueixin al desenvolupament sustentable. En aquest sentit, la present tesi doctoral pretén cobrir aquests àmbits d'estudi a través d'intentar donar resposta a les següents quatre preguntes:

Per als països desenvolupats

1. En quin mesura les eines urbanes, arquitectòniques, socials i sostenibles contribueixen a avaluar el potencial d'implementació de l'agricultura en cobertes d'edificis existents en ciutats del sud d'Europa?

2. Pot la integració d'un hivernacle en el terrat d'un edifici, aprofitant el seu intercanvi de fluxos tèrmics residuals, contribuir tecnològicament i arquitectònicament al desenvolupament de l'agricultura urbana?

Per als països en vies de desenvolupament

3. Quin és el panorama actual de l'agricultura urbana als països en desenvolupament d'Amèrica Llatina i el Carib?

4. Quines són les implicacions de la planificació urbana i l'habitatge social en la promoció de l'agricultura urbana per a la sostenibilitat de la ciutat llatinoamericana de mida mitjana?

L'agricultura urbana és un fenomen complex i per la seva pròpia naturalesa involucra múltiples escales, formes, actors, objectius i dimensions de la sostenibilitat. Per tant, per al seu estudi és

necessari emprar i combinar diverses disciplines, eines i metodologies. La present tesi inclou un marc interdisciplinari que combina aspectes quantitatius i qualitatius de les disciplines d'arquitectura, ciències ambientals, urbanisme, agronomia i ciències socials. I en cada línia de recerca estudiada s'han utilitzat materials i mètodes complementaris per a l'obtenció de dades específiques; anomenant-ne alguns: sensors aerotransportats TASI-600 I Leica ALS50-II, sensors de temperatura i humitat de l'aire, diversos programaris, revisió documental, entrevistes, grups d'interès, metodologia de suport a la presa de decisions. Aquest marc metodològic resulta adaptable i permet avaluar l'agricultura urbana en les escales de barri i d'edifici dins de les formes urbanes de la ciutat compacta a Europa i la ciutat difusa en LAC.

Amb l'objectiu d'abordar la primera pregunta plantejada del bloc referent a la AU a Europa, s'ha realitzat un estudi pràctic en un hivernacle integrat en la coberta (iRTG), concretament en el ICTA-iRTG, en el qual es monitoritzava durant el 2015 les condicions climàtiques interiors de l'hivernacle per conèixer el seu comportament tèrmic i les seves fortaleses energètiques. Els resultats demostren que un iRTG pot proporcionar temperatures dins del rang 14-26 °C, les quals són idònies per als sistemes protegits d'horticultura en zona mediterrània. Aquestes temperatures s'aconsegueixen per mitjà del "acoblament" tèrmic amb la resta de l'edifici, basat en el reutilització de la calor residual del propi edifici; tot això sense consumir energia addicional. Puntualment, els resultats de la simulació energètica realitzada van mostrar que en les mateixes condicions climàtiques i règims de control, els casos de temperatures "subòptimes" (fora del rang de 14-26 ° C) haguessin estat un 33.5% majors en un hivernacle convencional. També es va demostrar que a causa de la naturalesa integrada del iRTG, es pot "reciclar" 341.93 kWh / m^2 / any d'energia de calefacció de la resta de l'edifici; aquests resultats es van usar per calcular l'estalvi econòmic i de carboni d'un iRTG respecte a un hivernacle convencional equivalent amb calefacció utilitzant intensitats de carboni associades derivades de fonts regionals. Els resultats mostren que una caldera d'oli que satisfaci les demandes de calefacció produiria 113.8 kg de CO_2 (eq) / m^2 / any, a un cost de 19.63 € / m^2 / any.

La segona pregunta ha estat estudiada primerament, mitjançant el desenvolupament d'eines i metodologies que permeten la identificació i la presa de decisions d'aquells terrats que tenen potencial per a la implementació d'hivernacles en el terrat (RTG). Posteriorment, ambdues metodologies es van aplicar a casos d'estudi pràctics a Barcelona i els seus voltants. La primera metodologia es recolza en criteris tècnics, legals, econòmics i agrícoles i fa ús de sensors aerotransportats (TASI 600 i Leica ALS50-II) per a l'obtenció d'informació de primera mà sobre les dimensions, àrea, inclinació, insolació i material dels terrats. El cas d'estudi va estar integrat per 11 parcs industrials localitzats a la ciutat de Rubí (Barcelona).Els resultats assenyalen que l'ús d'aquests sensors per a la identificació de les característiques bàsiques dels terrats és viable i confiable. Es va obtenir una viabilitat del 3% del total dels terrats dels parcs industrials. Això és degut a que la major part dels terrats estan construïdes amb materials de baixa capacitat de càrrega. Tan mateix, malgrat que el percentatge és baix, és possible aconseguir una producció de 600 tones de tomàquet per any (que pot satisfer la necessitat de tomàquets del 50% de la població total de Rubí).

La segona metodologia s'enfoca en la presa de decisions per a l'elecció del terrat amb el major índex de sostenibilitat per a la implementació d'un RTG, mitjançant la metodologia MIVES (Model Integrat de Valor per a Avaluacions de Sostenibilitat). El cas d'estudi va estar conformat per 11 escoles d'educació bàsica a Barcelona. Els resultats indiquen que l'eina multicriteri proposada ha demostrat ser una alternativa viable i objectiva; en la qual l'ús d'un índex de sostenibilitat global (0 - 1) derivat de l'arbre de requisits de MIVES, minimitza la subjectivitat del procés i permet seleccionar l'alternativa més sostenible per a la instal·lació potencial d'un RTG. Específicament en el cas d'estudi, els factors socials (recolzament del personal escolar i els pares i les associacions docents i els projectes escolars de AU) van ser els determinants per a la selecció de la millor alternativa. El cas amb l'índex de sostenibilitat global més elevat aconsegueix una puntuació de 0.60 i 0.33 el de menor viabilitat.

Per conèixer l'estat actual de l'estudi de la AU en LAC i donar resposta a la tercera pregunta que es planteja en la present dissertació, es va realitzar una revisió de literatura científica. Els resultats van demostrar que la AU es desenvolupa almenys en 14 països, però el 86% de la recerca és desenvolupada per Brasil, Cuba, Mèxic, Colòmbia i Argentina. Es van identificar cinc funcions que la AU desenvolupa a la regió: ecològic-ambiental, social, productiu, urbà-polític i econòmic. Amb el 46% de les publicacions, la funció ecològica-ambiental és la més desenvolupada; contràriament la funció econòmica és la menys explorada amb un 3%. En LAC la AU és una mesura d'emergència enfront de problemes socials i desastres naturals; i no una activitat planejada que formi part de les estratègies per al desenvolupament sostenible urbà. Això es deu en part al fet que els programes de foment de la AU posseeixen un caràcter efímer i no aconsegueixen perdurar per formar part dels aspectes urbans ambientals.

Finalment, responent a la quarta pregunta de recerca, la AU en LAC està vinculada a l'habitatge social, i al planejament urbà; ja que el creixement de la ciutat sol ser degut a la construcció de barris d'habitatge social. Els habitatges socials acostumen a presentar grans àrees de superfícies impermeables, com a resultat d'un procés de modificació per adaptar-se a les necessitats dels usuaris (considerant els barris d'habitatge social Vila Magna II, TixcacalOpichen, Ampliacion Tixcacal Opichen i Les Magnolias a Mèrida, Mèxic com a exemple). Això comporta àrees petites per al desenvolupament de la AU en les seves formes tradicionals. No obstant això, els barris d'habitatge social tenen característiques que els fan espais apropiats per al desenvolupament de l'agricultura vertical, com els hivernacles en el terrat. En aquest sentit es va analitzar el potencial per a la implementació de RTGs en un barri social (Comuna de Santa Clara de Sant Millán) a Quito, Equador. Els resultats obtinguts són encoratjadors i ressalten l'alt potencial dels habitatges socials per a l'agricultura vertical: terrats amb alta capacitat de càrrega i terrats sense acabar que faciliten la labor d'implementació dels RTG. El 33.2% (1160 sostres, 7.7 hectàrees) dels 3494 sostres analitzats poden albergar un RTG i pot produir 28 360 kg/any d'enciam i 789 750 kg/any de tomàquets.

A nivell de planificació urbana, l'espai públic urbà per al desenvolupament de la UA és extremadament limitat; raó per la qual la AU sol desenvolupar-se dins dels límits del lot. Tal com assenyala els resultats, obtinguts als barris d'Ampliació Tixcacal Opichen i Les Magnolias, la AU es desenvolupa a escala petita i de forma privada en més de la meitat dels habitatges estudiats (d'un total de 157). Es conrea en tests i en el poc espai lliure restant de les modificacions de l'habitatge. El cultiu de fruites s'imposa (70%) enfront de les verdures i plantes aromàtiques (30%). Dins de les fruites, els cítrics són el cultiu majoritari, provablement degut al seu fàcil manteniment i al fet que Yucatán és una regió històrica de producció de cítrics a nivell nacional A més, els horts amb major varietat d'espècies es troben en els habitatges amb menor grau de modificació; com una conseqüència directa de l'espai lliure disponible.

En aquest sentit, la present tesi contribueix a l'estudi de la AU a les ciutats compactes dels països desenvolupats i a les ciutats difuses dels països en vies de desenvolupament mitjançant el desenvolupament de noves eines i dades per a l'anàlisi. Els resultats obtinguts amplien el coneixement i la comprensió del fenomen de la AU i la seva estreta relació amb la ciutat des d'un punt de vista del planejament urbà i de l'arquitectura. Brinda recolzament en els processos de presa de decisions en els àmbits del planejament sostenible, l'ús dels terrats a les ciutats compactes i l'habitatge social de LAC i obre noves línies de recerca. Les futures recerques a Europa haurien de centrar-se en l'anàlisi de la interconnexió bidireccional energètica entre el iRTG i l'edifici; també en aprofundir per mitjà de proves en laboratori la identificació de materials en cobertes usant sensors aerotransportat; analitzar la viabilitat de cobertes multipropòsit en parcs industrials i en adaptar la metodologia de presa decisions per a la identificació de terrats per a la implementació de RTG en altres zones geogràfiques. En el cas de LAC, les recerques futures s'haurien de focalitzar en explorar les funcions menys desenvolupades de la UA (econòmica i polític-urbana); a treballar amb organitzacions comunitàries de LAC per a la quantificació el potencial de l'agricultura en coberta; a desenvolupar una base de dades sobre el desenvolupament actual de la UA en l'habitatge social i a analitzar l'ús dels espais públics i les seves limitacions en matèria de política urbana.

PREFACE

The present doctoral thesis was elaborated, from October 2014 to July 2018, within the research group of Sustainability and Environmental Prevention (Sostenipra) at the Institute of Environmental Science and Technology (ICTA) of the Universitat Autònoma de Barcelona (UAB), which was awarded with María de Maeztu program for Units of Excellence in R&D (MDM-2015-0552). As well as, during the three-month research stay (December 2015-March 2016) at the Facultad de Ciencias Antropológicas de la Universidad Autónoma de Yucatán (UADY), in Mérida, Yucatán, Mexico. Moreover, the thesis was developed within the framework of the Fertileicty I project (MINECO: CTM2013-47067-C2-1-R) "*Agrourban sustainability through rooftop greenhouses. Ecoinnovation on residual flows of energy, water and CO2 for food production*" and the Fertilecity II project (MINECO/FEDER, UE: CTM2016- 75772-C3-1 R; CTM2016-75772-C3-2-R; CTM2016-75772-C3-3-R) "*Integrated rooftop greenhouses: energy, waste and CO2 symbiosis with the building. Towards foods security in a circular economy*". These projects were coordinated by the Institute of Environmental Science and Technology (ICTA), with the participation of the Universitat Politècnica de Catalunya (UPC) and the EnvironmentalHorticulture Unit at the Institute of Agriculture and Food Research and Technology (IRTA).

The dissertation consists of a multidisciplinary approach which intends to combine architecture, urbanism, environmental science, social science and agronomic sciences to is to analyze strategies for the development of urban agriculture at neighborhood and building scale for the improvement of sustainability and food security in developing countries and in developed countries. The novelty of the dissertation is based not only on the subject, but also on the integration of multidisciplinary tools to evaluate the social, energetic and environmental aspects of urban agriculture in two types of urban forms, in two geographical regions and in two urban scales. This dissertation provides greater knowledge about agriculture, greenhouses on the roof and the perception of agriculture in general to support the decision-making processes within the framework of sustainable urban planning. Specific tools and methodological proposals are also presented.

The dissertation is mainly based on the following papers and chapters either published or under review in peer-reviewed indexed journals:

- **Nadal, A.**, Cerón, I., Cuerva, E., Gabarrell, X., Josa, A., Pons, O., … Rieradevall, J. (2015). Urban Agriculture in the Framework of Sustainable Urbanism. Temes de Disseny, 0(31), 92–103. Retrieved from https://www.raco.cat/index.php/Temes/article/viewFile/299595/390474

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- **Nadal, A.**, Petit-Boix, A., Rodríguez-Labajos, B., Cuerva, E., Josa, A. & Rieradevall, J. (2018). Urban agriculture in Latin America and the Caribbean: planned activity or emergency measure? Submitted to Global Environmental Change.

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Also, the following oral communication and posters were presented in conferences as part of the doctoral thesis:

- **Nadal, A.**, Alamús, R., Pipia, L., Ruiz, A., Corbera, J., Cuerva, E., Rieradevall, J., Josa A. Airborne sensors for urban agriculture: Methodology for evaluation of the potential of rooftop greenhouses. International Symposium on Greener Cities for More Efficient Ecosystem Services in a Climate Changing World. Bologna, Italy, September 2017.

- **Nadal, A.**, Llorach-Massana, P., Cuerva, E., López-Capel, E., Montero, J.I., Josa, A., Rieradevall, J., Royapoor, M. Promoting local food production in Mediterranean cities. Energy efficiency of buildings metabolism through integrated rooftop greenhouses (i-RTGs). International Symposium on Greener Cities for More Efficient Ecosystem Services in a Climate Changing World. Bologna, Italy, September 2017.

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Book chapters

- **Nadal, A.**, Pipia, L., Alamús R., Ruiz, A., Cerón, I., Cuerva, E., Rieradevall, J., Josa, A. (2017). Agricultura en edificios urbanos: Metodología para la implementación de invernaderos en azoteas de áreas no residenciales urbanas. In: Ciudades verdes: Teoría y práctica hacia la sostenibilidad urbana. Universidad Anáhuac Mayab, CONAVI-CONACYT (2013-206715), 429-438. ISBN: 978- 607-8083-21-3

- **Nadal, A.**, Cuerva, E., Cerón, I., Josa, A., Rieradevall, J., (2017). Comportamiento térmico de un invernadero integrado en azotea en una ciudad mediterránea. Resultados preliminares. In: Ciudades verdes: Teoría y práctica hacia la sostenibilidad urbana. Universidad Anáhuac Mayab, CONAVI-CONACYT (2013-206715), 439-454. ISBN: 978-607-8083-21-3

Seminar

- **Nadal, A.**, Pons, O., Josa, A. MIVES, sostenibilidad para implantar agricultura urbana en escuelas verdes. Seminario: Agricultura urbana y sostenibilidad. Grupo de investigación Sostenipra, ICTA, UAB. Barcelona, España. May 2016.

In addition, during the development of the dissertation the opportunity was given to work in other studies, which are related with the goals of the dissertation:

Scientific papers

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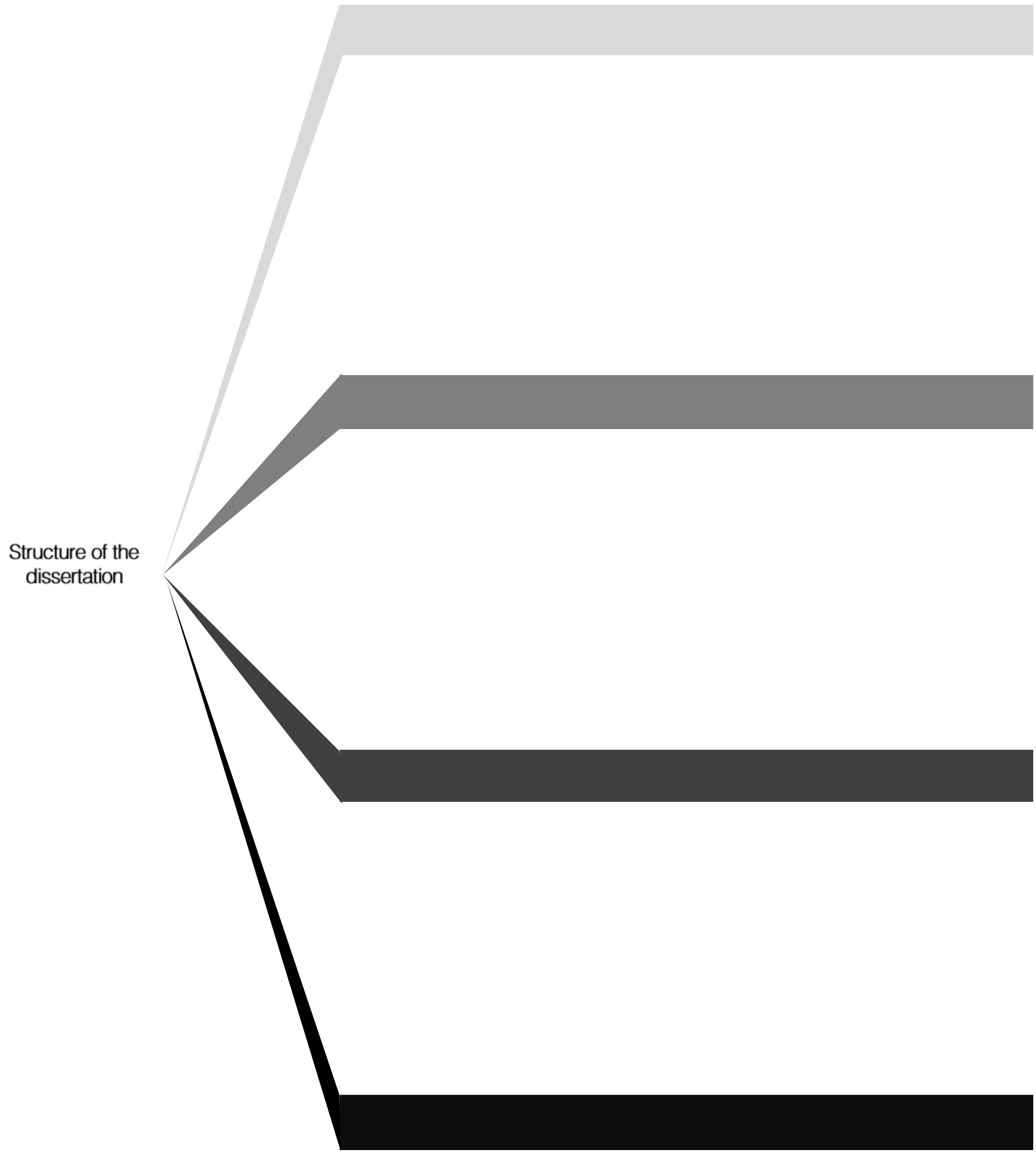
Structure of the dissertation

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