# Urban agriculture in the framework of sustainable urbanism

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## Doctoral thesis

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# Final remarks and future research

PART 4

# Chapter 12

## Discussion of the main contributions

## CHAPTER 12 - Discussion of the main contributions

This chapter discusses the main contributions of the present dissertation and the implications that these contributions may have for cities from a scientific perspective.

### 12.1. An integrated assessment of urban agriculture in compact and diffuse cities

The studies developed in the context of this dissertation are framed in urban environments and focus on urban agriculture as one of the tools to achieve sustainability in cities. The approach adopted includes the evaluation of various tools and methodologies for the evaluation and integration of urban agriculture on rooftops (in a compact European city context) and its relationship with social housing (in a diffuse Latin American city context).

As indicated in the introduction of the dissertation (Chapter 1), the city has been linked to urban agriculture since its formation, has gone through processes of exclusion of the urban perimeter (industrial revolution) and today is looking for re-integration to the urban fabric. Before the challenges that the city currently faces (overpopulation, food insecurity, climate change ...), it is necessary to strengthen the urban planning and food security areas to meet part of the needs that population demands.

This research covers different areas of interest and offers innovative approaches that can help the process of shaping the sustainable city through urban agriculture. Figure 13.1 illustrates the main contributions.

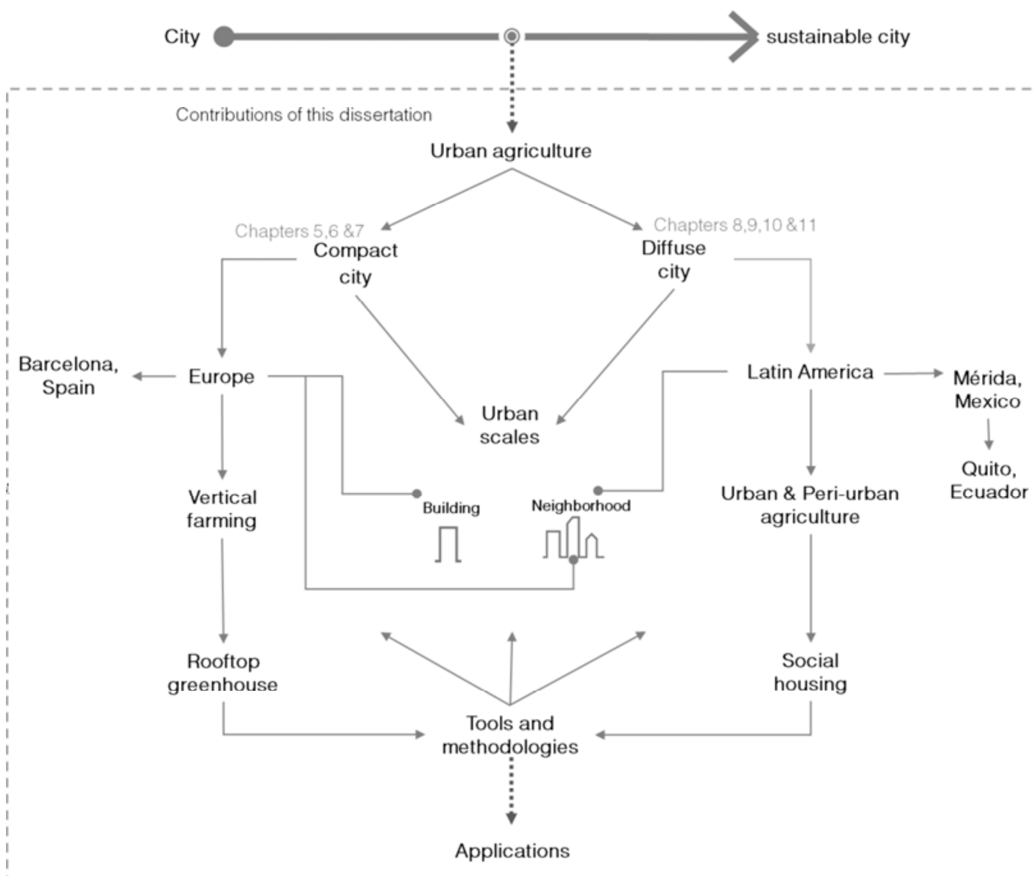


*Figure 12.1 Contributions of this dissertation in the field of urban agriculture.*

## 12.2. Analysis of urban agriculture in different urban scales and city typologies

Although UA takes place in and around city limits, in the present dissertation two different urban scales were considered (neighborhood and building, which are essential parts and elements of cities), within two city typologies (compact and diffuse).

### 12.2.1 European compact cities

In the context of a compact city, the neighborhood and building scales were analyzed. The building scale was addressed in chapters 5 and 7. The ICTA-ICP building and specifically the ICTA-iRTG was the object of the analysis of Chapter 5. This allowed knowing in situ the thermal behavior of the first iRTG in southern Europe, and the energy strengths that this form of UA can generate, as well as the challenges still to be addressed. The interconnection between the iRTG and the building can be positive for both the building and the greenhouse and is a potential tool to optimize the energy performance of the system, reducing energy consumption and improving indoor environmental conditions. This allows to reinforce the viability of non-traditional forms of UA and revalues the use of the roofs as highly functional spaces for food production. On the same scale, 11 elementary schools in Barcelona were analyzed to know their global sustainability index regarding the feasibility of the implementation of a RTG. Working on this scale allowed us to consider various functional and shape characteristics of each of the schools. This helped the specialization of the research and marked the difference in the choice of the case with the highest global sustainability index. The building scale provides the opportunity to work from the individuality of each case and meet the needs and requirements of each building in front of the UA.

In Chapter 6 the neighborhood scale was analyzed in 11 industrial parks of Rubí, close to Barcelona, to quantify the viability of RTGs implementation. This scale was chosen because through the use of airborne sensors (TASI 600 and Leica ALS50-II) in two flights it was possible to acquire information quickly and firsthand of the roofs' characteristics in the 35km$^2$ study area. The present dissertation leaves a precedent for the use of these sensors for UA functions; and it opens a new study area that allows working with large areas and complete cities, in rapid diagnoses to evaluate and quantify the capacity of implementation of crops on rooftops or other surfaces.

### 12.2.2 Latin American and the Caribbean diffuse cities

In the context of a diffuse city, the neighborhood scale was addressed for the study of the UA. The 5 neighborhoods of social housing studied are located in Latin America, specifically in Ecuador and Mexico. The Santa Clara Commune of San Millán in Quito, Ecuador was analyzed in Chapter 9 to know the potential for the development of UA on rooftops by means of RTGs. The neighborhoods of Villa Magna, Tixcacal Opichén, Ampliación Tixcacal Opichén and Las Magnolias in Mérida, Yucatán, Mexico, were the scenarios studied in Chapters 10 and 11. These chapters expose the more social aspect of the present dissertation, in which social perception of the inhabitants with respect to UA and relation between the social housing's typology were analyzed. The analysis of the UA at a neighborhood scale allows access to global information in order to provide an overview of a specific area. But above all, it offers the possibility of analyzing and comparing the implications and specific profiles of each area of study in relation to the UA.

## 12.3. The current outlook of urban agriculture in Europe

The process of urbanization and population growth produce an increase in the demand for food in cities (FAO, 2017a), generating a great concern for the environmental impact and the exploitation of natural resources that are caused with the current food system. This has led to a marked increase in the interest of people to know the origin and quality of food consumed in cities, mainly in the global north. This has influenced the trend of urban food production -mainly in European cities- through urban agriculture in balconies, terraces, parks, and others (Gasperi et al., 2016; Mougeot, 2005; Orsini et al., 2014). In this sense, urban agriculture is an element that interrelates with the social, environmental, and economic aspects of cities (Hernández, 2006). However, it is still far from its maximum use despite the many advantages it can generate in urban environments.

Generally, urban agricultural activities tend to develop on small surfaces and in public spaces that can be located near the place of residence (on-plot) or far from it (off-plot) (Drechsel and Dongus, 2010). However, the supply of free spaces for cultivation is usually very limited and the surplus value of the raised soil; which causes the soil (and access to water and sunlight) to be a limiting framework for the activity. In view of this, the practice of urban agriculture has been extended vertically (walls and roofs) (Despommier, 2011), which allows us to widen the limiting framework to which it was traditionally linked.

Specifically, urban agriculture in the rooftop greenhouse modality focuses on the idea of being able to cultivate in controlled environmental conditions using hydroponic systems in order to have a high efficiency of water consumption (in comparison with traditional agriculture)(J. I. Montero et al., 2017; J.I. Montero et al., 2017; Orsini et al., 2017; Sanjuan-Delmás et al., 2018). And if in addition, the greenhouse is connected to the building through the exchange of water, energy and $CO_2$ (as is the case of the iRTG), it is expected to present more advantages that the RTG. It is at this point that the research presented in Chapter 5 provides useful information on the energy performance of an iRTG and its technological application to reduce energy consumption compared to conventional greenhouses. This topic is of general interest, especially in the compact Mediterranean cities in which vertical urban agriculture begins its development (having the limitation of space).

The results (based on the ICTA iRTG in Bellaterra, Barcelona) show that, thermally, an i-RTG is ideal for crop growing in Mediterranean areas, since (in 2015) 76.3% of the annual hours (in the indoor climate of the iRTG) were within the optimum temperature range of 14-26 °C for the context of the closed system of Mediterranean horticulture. And due to its integrated nature, it was possible to "recycle" 341.93 kWh / $m^2$ / year of heating energy of the building, within 139-444 kWh / $m^2$ / year of the power requirements for conventional Mediterranean greenhouses with heating. What in avoided emissions and economic savings translates into 113.8 kg of $CO_2$ (eq) / $m^2$ / year, at a cost of 19.63 € / $m^2$ / year in oil boiler or 82.4 kg of $CO_2$ (eq) / $m^2$ / year, at a cost of € 15.88 / $m^2$ / year in gas boiler and 5.5 kg $CO_2$ (eq) / $m^2$ / yr at a cost of 17.33 € / $m^2$ / yr in biomass boiler. Therefore, the iRTG is an opportunity to improve energy efficiency in food production systems on the roofs of Mediterranean cities, since it allows a high yield in the production of vegetables and can reduce transportation costs and $CO_2$ emissions. And this in addition to providing a unique opportunity to reduce the use of fossil fuels for heating in greenhouses and reducing the price of food.

In this sense, for a proper operation of the iRTG it is necessary to have a detailed planning in the design stage and a constant supervision in the use stage since overheating in summer represents a great challenge. In general, these results can have a notable impact on the agricultural, food and other industries related to vegetable production. But also, in the sector of architecture, construction and urban planning, since they should consider their application or integration in new or existing buildings and they would also need to make changes in safety regulations and building codes. Urban agriculture has a positive influence in favor of urban resources and the microclimate of cities (FAO, 2011b). At neighborhood scale, it also fulfills functions of ecological regulation and has effects on the conformation of the space and the landscape, as the revaluation of the areas of the city and endows them with a natural character that favors the improvement of the quality of life of the inhabitants (Ilbery, 2010). In this line, industrial parks are areas of interest for the development of rooftop greenhouses since they are usually not considered as priority areas for their implementation and also have large rooftop areas.

In Chapter 6, a methodology is used to identify roofs with potential for the implementation of RTG for commercial purposes in industrial parks by means of technical, legal, economic and agricultural criteria, using airborne sensors (TASI-600 and Leica ALS50- II) for the acquisition of information on the physical characteristics of the roofs in large areas (complete cities). Although the methodology with the use of the sensors turned out to be an ideal tool with high effectiveness, fast and adaptable, the study area (11 industrial parks in Rubí, Barcelona) only presented a viability of 3% of the roofs. The main barriers for the implementation of the RTG were the low bearing capacity of the rooftops (for instance with light metal cover) and surfaces less than $500m^2$ (area stipulated as minimum for economic viability (Sanyé-Mengual et al., 2015a).

This topic is interesting in the field of urban planning since it can be a support for decision-making for large-scale urban agriculture and to promote urban sustainability in different areas and neighborhoods. However, it is necessary to consider the possible restrictions regarding the legal and urbanistic requirements of the use of the roofs in each geographical area. This would be a challenge for urban planners since currently there are few cities that have regulations on the use of roofs in the field of urban agriculture. It also opens new ways to continue researching the rapid and reliable identification of roofing construction materials, by means of airborne sensors.

Environmental education in schools (mainly in elementary education) plays a key role in the promotion of social, community and environmental functions of urban agriculture. In this sense, Chapter 7 addresses this issue, through the generation of an evaluation tool for the selection of the most suitable school building for the location of a RTG, based on an objective and numerical index of global sustainability. The results indicate that the strengths of this tool lie in its objective, adaptable and multidisciplinary sense; its social approach and its educational nature; and its application in stages, which is reinforced through the use of the Multi-Criteria Decision Making tool MIVES (Integrated Value Model for a Sustainable Evaluations) (Viñolas et al., 2009a). Of the 11 elementary education centers studied in Barcelona, the best alternative for the implementation of a RTG obtained a sustainability index (ranging from 0 to 1) of 0.60, compared to 0.33 for the least favorable location. The difference between both indexes lies mainly in the social aspect, specifically in the support of the school staff and the parent-teacher association.

So, the implementation of RTG in schools provide a unique opportunity to strengthen the environmental and nutritional education of children, in those cases where there is no space for the creation of a garden or that you want to opt for a system of more technological agriculture. This generates new opportunities to study the social and educational implications of urban agriculture in the context of urban sustainability and strengthens the healthy and local diet through the consumption of products grown in the same educational center. At the same time, it provides the opportunity for the generation of new jobs related to the construction, operation, and maintenance of the RTG and crops.

Considering that the positive effects of urban agriculture depend on the typology developed (RTG, green roof, orchard, private garden, and others), it is important to promote sustainable agriculture. It should also be noted that rooftop urban agriculture is a viable alternative for the production of food in cities, and that it is a considerable support for the supply of food from the countryside; but it is not usually possible to reach a total supply only with these products. In this sense, urban agriculture must be formulated as a principle, a means and an end for sustainability in European compact cities. It is necessary to include it in the questions of territorial and urban planning and seek to improve the quality of life of users. And promote patterns of food supply more efficient both energy and environmentally; without neglecting the political-urban and social-educational aspects that support their development.

## 12.4. The current outlook of urban agriculture in Latin America and the Caribbean

*In this section, we use the term UA to refer to the general form of agriculture in cities, both the one developed within and in the periphery of the city. The term UPA is not used since it can generate some confusion in the sense that Latin American cities may have diffuse limits.*

The origin of urban and peri-urban agriculture in Latin America and the Caribbean dates back to pre-Hispanic times (Flores, 2016; J. Flores and Ek, 1983). And throughout history, UA has been evolving along with population growth (FAO, 1999e) and has gradually been diluted in the face of new city typologies . Today, the most representative model of UA in LAC is that of Cuba, which was increased by the economic crisis of 1998 and was considered an integral part of urban development in Havana (FAO, 2014c).

Despite the numerous studies carried out and the various initiatives developed, it is very difficult to know what the current dimension of the UA in LAC is. The scientific production dedicated to the study of the UA can be considered an indicator of its expansion since scientific production is a reflection of the areas of interest of various disciplines, such as urbanism, architecture, environmental sciences, agronomy, and others. In this point, Chapter 8 of the present dissertation provides information that allows visualizing the current panorama of the UA in LAC in relation to the scientific publications developed, as well as also the main functions that UA performs. The results indicate that there is a dispersion of research throughout the area and UA research is carried out in 14 countries, but there are five that lead it: Brazil, Cuba, Mexico, Colombia and Argentina. They represent 86% of the total production of 220 scientific articles found. The functions performed by UA are environmental-ecological with 46%, social with 23%, productive with 16%, urban-political with 12% and economic with 3%.

Publications analyzed in the revision date from 1983 and generally focus on UA as an emergency measure in the face of social problems and natural hazards. These results are of great importance to be able to direct the research in the less developed and more needed directions in the region, such as urban planning and the economic sector. They can also be a precedent to be taken into account when generating new programs that promote UA. In large part, the interest in UA in LAC is related to the international or national cooperation programs that are being developed; but there are also municipal initiatives that are perhaps much more successful since they directly involve the various actors that make up the city.

A city that stands out for its municipal initiatives in favor of UA (referring to agriculture developed within the city limits) is Quito, Ecuador. In 2000, it was the host city for the Quito Declaration in which the local governments of nine LAC countries committed themselves to developing AU. Jointly, diverse local initiatives were implemented between 1980 and 2000 due to the arrival of Andean indigenous migrants to the city and AU responded as an activity that helped the generation of food to strengthen food security (FAO, 2014c). In this sense, Chapter 9, having as background the various initiatives developed in Quito in favor of UA, identified the potential for implementation of RTGs in the social neighborhoods of Quito through the adaptation of social neighborhoods of the methodology developed by (Sanyé-Mengual et al., 2015b).

The results indicated that this new methodology is a promising and adaptable tool that allows identifying all roofs that have potential for the implementation of RTG from a social perspective. In this investigation the study area (Comuna Santa Clara de San Millán) consisted of a total of 3494 roofs, of which 1160 (33.2%) were considered feasible for the implementation of RTGs, representing 12% (7.70 hectares) of the surface of roofs of the study area. These 7.7 hectares of roofs have the possibility of providing 9% and 4.5% of the demand for tomatoes and lettuce from Quito, with a production of 789,750 kg / year of tomatoes and 28,360 kg / year of lettuce, which would support the food security within the neighborhood. These guidelines can be useful to reformulate urban planning policies and social support programs in the region and would create opportunities to project a future in which cities can actively collaborate to guarantee food security.

Urban growth in LAC generally occurs in small and medium-sized cities (with less than one million inhabitants) (P. da Cunha and Rodríguez, 2009b), in which the possibilities of practicing agriculture are higher because customs and traditional agricultural knowledge are more entrenched than in large cities and megacities. That is, urban and rural lifestyles overlap much stronger, so these cities have a very high spatial and sociocultural potential for the development of UA (FAO and EFE, 2017). In addition, these cities are those that represent the majority of the LAC region and are extremely complex in terms of food systems. By having a multidimensional nature, food systems involve environmental, political, socio-cultural and economic conditions, with a wide variety of actors and numerous agri-food value chains interconnected in dynamic conditions (FAO, 2017b). Currently, these value chains of agricultural production and marketing become global, which implies a globalization of diets; and it brings with it important changes in the consumption of food and increases the rates of chronic degenerative diseases (obesity and diabetes) (Perez Izquierdo et al., 2012). In addition, the region presents the impacts of climate change, violence, insecurity, increased pressure on natural resources and biodiversity, substitution of traditional food habits and urbanization (FAO, 2017c).

The rapid urbanization is one of the biggest problems that affect the alimentary systems in the region of LAC. The limits of the city are continuously extended by the construction of social housing neighborhoods, which are often far from the main urban facilities of the city. The use of the automobile is something daily as a means to access the basic services of food acquisition, since these can be found at distances of up to 1.6 km generating the food deserts, which implies the exclusion of consumers in areas with restricted access to nutritious and fresh foods (FAO, 2017c). The diffuse city model, together with the limited supply of public policies in favor of UA and the problems mentioned above, create inadequate conditions for food security and sovereignty. In light of this, Chapter 10 examined the social perception of UA in four Mexican neighborhoods of social housing in Mérida, Yucatán (as an example of the diffuse median city of LAC and the typology of housing built in Mexico), to identify and understand the relationship between the role of UA in the neighborhoods of social housing in Mexico and the perceptions of the interested ones on the current and future UA developments.

The results indicated that the main actors (residents, urban government officials and technical experts) consider that agriculture is not developed in Mérida, due to the lack of space in the house and within the neighborhood, adding to the almost null promotion and support by government institutions. This lack of development of the UA is reflected in the limited consumption of vegetables, in the ignorance of the concept of UA and in the mentality of "buying is easier than cultivating." Regarding the basic typology of social housing, it is modified regularly by its residents (since it does not meet the needs of the user), generating high percentages of impervious surfaces that do not allow the development of the UA in a traditional way. However, the neighborhoods of social housing in Mérida have characteristics that make them suitable spaces for the development of vertical agriculture and those interested know the social, environmental and economic benefits that UA can generate.

The above provides a general and up-to-date overview of the UA for decision-making in technical, urban, legal, political and architectural areas. Specifically, it provides initial guidelines for the re-design and construction of social housing and its neighborhoods, because currently do not meet the needs of users and do not support urban sustainability either. To move forward in this sense, it is necessary to quantify the current development of UA. In the case of Mérida, the quantification of the different types of agriculture that could be developed within the housing areas and plots, would be a necessary step to investigate the direct influence that the modification of the housing has on the development of UA; and to be able to see it as an opportunity and not an obstacle to its development. For this, Chapter 11 focused on urban systems and the socioeconomic and environmental dynamics of the medium-sized cities of LAC (Mérida, Mexico, as an example), on a neighborhood scale with the aim of exposing the relationship between the patterns of the inhabitants and the characteristics of the social housing with respect to the developed urban agriculture models. First, the competition between naturalization (agriculture) and artificialization (architecture) was analyzed and then the association of socio-environmental factors in the households that trigger the artificialization.

The results of the two neighborhoods studied indicated that UA is present in 60% of the total sample studied (157 housings) and includes species (coriander, chili pepper, papaya, soursop, yucca, tomato, nanche, native plum, among other) related to pre-Hispanic cuisine and the milpa diet. UA is within the limits of the house in the traditional model and in pots (indoor and outdoor). Unlike Europe, UA in LAC is closely related to housing. It practically emerges from the house and expands to the exterior public spaces. The spaces and minimum dimensions of houses, the need to have a garage for the car and the lack of free time, are the main socio-environmental factors associated with the artificialization that limit the development of UA. In spite of the above, urban farmers perceive UA as an activity that offers them nutritionally and leisure benefits, but they are aware that their development only occurs inside homes, since developing it in public spaces is illegal since it does not have authorities support.

In general, one of the main obstacles that UA encounters is that it is usually not recognized in land uses or municipal ordinances (FAO, 1999c), so that the continuity of projects, programs and initiatives cannot be guaranteed. This means that UA should be fully supported and promoted at local, state and national levels in order to support basic food supplies. In addition, it is necessary to develop management structures in which all UA actors participate in order to ensure the maintenance of its different functions. Under this approach, planning entities should pay more attention to the potential of urban agriculture to improve the food security and health of the city's inhabitants since at this moment the contribution of UA is essential for food and nutrition for many families of LAC.

But we must also bear in mind that UA is a form of resistance and peaceful protest for the need to opt for more sustainable urban development in the LAC region: an urbanism that offers the possibilities of food security and food sovereignty and lays the foundation for inclusive and resilient cities. It is clear that today UA in LAC is a strategy that helps reduce the environmental impact of current food system and meet the demand for food in emergency situations. But it is not enough to resolve social contradictions and the quality of life that the poorest and most vulnerable inhabitants of cities go through. Faced with this challenge, it is necessary to advance and formulate UA as an integral and permanent part of the city, and not only as a support in emergency situations. In this way, production can be increased and progress towards a sustainability approach to food systems that satisfies food security and materializes the food sovereignty of the present and future generations of LAC.

## 12.5. Perspectives for urban agriculture in urban planning: Europe and Latin America and the Caribbean

UA has been part of the process of shaping cities and has been closely linked to periods of wars, famines, economic and social crises, fulfilling the function of food production for subsistence (Armar-Klemesu, 2000; FAO, 2014d; Mougeot, 2000). However, UA is a phenomenon that has an adaptive evolution and diverse functions that are constantly renewed according to the needs of the site in which it develops. That is why the present dissertation addresses two different and distant regions in which UA is present and fulfills specific functions: Europe and Latin America and the Caribbean.

The first part of the present dissertation corresponding to Europe covers Chapters 5, 6 and 7, which studied the UA as a support tool to achieve urban sustainability. The modality analyzed is vertical, specifically the RTGs. Chapter 5 analyzes its energy viability, Chapter 6 its implementation in industrial areas and Chapter 7 its social importance in the educational field. The results obtained are positive for the implementation of this modality of UA, strengthens the implementation of vertical agriculture and seeks to expand the traditional image of the UA associated only with urban gardens. The technologies applied range from temperature sensors, airborne sensors, energy simulation software, image processing and decision making. In this context, UA fulfills functions related to community strengthening, environmental education, job creation and economic activities. But above all, it seeks to promote changes in the current urban metabolism to achieve a circular one that allows sustainable development. It is important to note that in this context, UA is an activity that seeks to strengthen its promotion as an urban and architectural tool which is supported by the growing need to consume local foods and improve the environmental conditions of cities.

In the case of LAC, Chapters 8, 9, 10 and 11 analyzed the current state of UA, its main functions addressed in the scientific literature (environmental-ecological, social, productive, urban-political and economic), the feasibility for vertical agriculture in social housing, the social perception of UA and the main characteristics that define the relationship between it and social housing. And, though UA in LAC shows consistency between its developed function with the profile of each country in which it develops, in general, UA is still considered as an emergency activity in the face of natural hazards and social problems. That is to say, the activity is still in its first stage as a tool to cover the demand for food for subsistence. Contrary to this concept of UA developed in Europe, where despite recognizing its importance as an essential element for food security in critical processes, it is also seen as part of urban strategies for environmental improvement and even as an alternative leisure.

In this sense, the fact that the dissertation addressed the phenomenon of UA in two regions, made it possible to make this differentiation between the main functions and the contexts in which UA is currently developing. This information is important at the level of the development of strategies and programs in both regions, since it allows visualizing the needs and opportunities to boost the development of UA. It has also allowed us to understand that there is no concrete global significance of the AU that unifies all its dimensions and functions as current practice. Otherwise, the same initiative can mean the search for contact with nature, the search for political and cultural recognition, the participation of citizens and support for social cohesion, a local diet and in harmony with the environment, a strategy of community development, an opportunity for leisure and physical exercise, a profitable commercial activity, an educational apprenticeship, and a need to be able to survive poverty and be able to satisfy hunger.

The current situation once again poses to the cities, both in the north and the global south, as the key to the challenge of the ecological, energy and economic crises that are being fought. But it also exposes the vulnerability of LAC, where UA continues in many cases as an informal activity and that is not part of the urban measures. It is important to increase the value that UA has for present and future generations. An alternative is to support their visualization within the current global situation and to consider their potential in urban political decisions. UA should be strengthened as part of a comprehensive and dynamic system in ecological, economic and social urban projects, in which its benefits are addressed at various scales and have a foundation and local perspective over the global manifestations.

In the specific case of LAC, this dissertation helps to visualize the growing need to integrate UA within the processes of urban and territorial rehabilitation, as one more element of urban complexity, and not only as occasional or special cases. It should formulate or adapt the initiatives of UA to the needs, strengths and local and particular conditions and integrate them into the environmental, social and economic systems, in order to achieve Sustainable development Goal 11 promoted by the United Nations: Make cities inclusive, safe, resilient and sustainable.

# Chapter 13

## Conclusions

# CHAPTER 13 - Conclusions

After discussing the potential contributions of this dissertation to the UA in Europe and LAC, this chapter summarizes the general conclusions of the dissertation, based on the research questions presented in Chapter 3.

## 13.1. Answering the research questions

This section addresses the four questions set out in this dissertation

### 13.1.1. Developed countries

**QUESTION 1. Can the integration of a greenhouse on the rooftop of a building, taking advantage of its exchange of residual thermal flows, contribute technologically and architecturally to the development of urban agriculture?**

An iRTG is a great opportunity for the development of UA in cities and specifically in buildings. At architectural and technological levels, an iRTG provides considerable thermal advantages compared to a conventional greenhouse and a traditional building since the internal temperatures of the iRTG are stabilized to a large extent by a thermal "coupling" with the rest of the building (based on the reuse of the waste heat of the building itself). This generates that air temperatures inside the iRTG are closer to the thermal mass of the building, than to the external climatic conditions. That is, without consuming extra energy, an iRTG can present the ideal thermal conditions for growing food through proper programming in its program for opening and closing windows, cover and thermal curtains. The above is also an advantage at the architectural level since it makes it possible to grow food in the same building, reassessing and giving a new meaning to the roofs, and compensating the impervious surface of the building.

Supported on the results obtained in 2015 in ICTA-iRTG (Chapter 5), an iRTG can provide the ideal thermal conditions for cultivation in the context of a closed system of Mediterranean horticulture (within the range of 14-26 °C). This is reflected in the productivity of 16.2 kg / $m^2$ of Cor de bou tomato and two successive crops of lettuce that were produced in that year. Based on the energy simulation performed, the results showed that under the same climatic conditions and control regimes, instances of "suboptimal" temperatures (outside the range of 14-26 °C) would have been 33.5% higher in a conventional greenhouse (in winter) and excessive summer temperatures. It was also shown that the integrated nature of the iRTG resulted in 341.93 kWh / $m^2$ / year of heating energy being 'recycled' from the rest of ICTA building; this is within 139-444 kWh / $m^2$ / year of the reported energy requirements for Mediterranean greenhouses with heating. Under this same comparison and with a power conversion efficiency of 100%, the financial and carbon savings of an iRTG using associated carbon intensities derived from regional sources were calculated. The results show that an oil boiler meeting the heating demand would produce 113.8 kg $CO_2$ (eq) / $m^2$ / yr, at a cost of 19.63 € / $m^2$ / yr; a biomass boiler would result in 5.5 kg $CO_2$ (eq) / $m^2$ / yr, at a cost of 17.33 € / $m^2$ / yr; and a gas boiler would produce 82.4 kg $CO_2$ (eq) / $m^2$ / yr, at a cost of 15.88 € / $m^2$ / yr. Despite the many advantages of the iRTGs, some overheating in summer is a challenge to overcome.

Therefore, these results can have a direct impact on the agronomic industry, food industry and other industries related to food production. But also, they can have a considerable impact on urbanism, architecture and construction industry, since a new concept of buildings that support food cultivation in cities should be taken into account. In addition, its application or integration into new or existing buildings should be considered and the iRTG concept should be included in the building codes and safety standards so that they have legal backing.

QUESTION 2. 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 cities in southern Europe?

The urban-architectural, social and sustainable tools developed in the present dissertation are of great importance and represent a first step for the evaluation of the implementation potential of UA in roofs. RTGs turned out to be promising, reliable, innovative, adaptable and of high viability at city and building scale following environmental and social objectives. These tools can support the decision-making process in the field of urban planning on a large scale or on a precise scale, and in interventions that promote sustainability in urban areas, facilitating the work of professionals in urban planning, architecture, commerce or socio-environmental education, among others.

Specifically, the tools developed in Chapters 6 and 7 (the methodology that uses airborne sensors, Chapter 6; and the one used by MIVES, Chapter 7) compared to other tools, provide advantages in the aspects of: obtaining in situ data, short time of obtaining roofs characteristics, information reliability , support of specialized software, semi-automated processes, objectivity of the results and multidisciplinary character.

In addition, they allow visualizing the main conditions and advantages for such work by integrating aspects relating to various disciplines (Agronomy, Architecture, Engineering, Urban Planning, Geography, Politics and Education) and numerous key actors, which emphasizes its multidisciplinary nature. The use of different urban scales (city and building) and urban areas (industrial parks and educational buildings) strengthens their capacity to adapt to different contexts and needs. The results obtained in both chapters are the basis of the strengths and viability of these tools for the selection of roofs for the implementation of RTGs:

A) For assessing rooftop greenhouse potential of non-residential areas using airborne sensors

- For the selection of appropriate roofs for implementation of RTGs, criteria of several disciplines are considered: technical, legal, economic, agricultural. The acquisition of the main quantitative characteristics of roofs is done by airborne sensors with high precision in a short time (Tasi - 600 and Leica ALS50-II).
- Possible restrictions that may arise in the selection are also considered, such as the legal requirements in each geographical area and low bearing capacity of roofs. Also, visits to buildings to verify their status and load capacity are part of the procedure.
- The use of airborne sensors for UA is innovative and proved to be reliable instruments that facilitate the work of identifying the basic characteristics of roofs (dimensions, area, slope, solar radiation, construction materials). This may open a new area of study in sustainable urbanism and the construction industry.
- In its current state, and in accordance with the case study analyzed, the roofs of industrial parks show a reduced potential for the implementation of RTG. In the Rubí case (Barcelona), 3% of the total studied parks was viable. However, 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, 38,448 people). The potential can be significantly increased if structural remodeling of the roof and buildings is carried out since in spite of having large flat roof surfaces, the main limitation for the implementation of RTGs was the use of materials and structures with low bearing capacity.

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- Elementary schools are key points within the city for their educational work and their wide range of dissemination of social and environmental issues, so represents an opportunity for the promotion of urban agriculture in the form of RTGs. The proposed multicriteria tool has proved to be a viable, objective and adaptable alternative that facilitates the decision-making work regarding the suitability of schools for the implementation of RTGs and the support of urban sustainability.

- The use of a global sustainability index through the value functions and the weights assigned to the different requirements, criteria, and indicators of the requirements tree minimizes subjectivity in the process that evaluates, compares and selects the best alternative for the potential installation of RTGs in schools.

- The methodology has a social and multidisciplinary approach (considering the functions that schools promote within society in terms of education and strengthening of social values) in some of the steps of its application. Step 1 considered a minimum viable area of between 50 and 100 $m^2$ in the pre-selection principles (this area facilitates the work of environmental learning and crop maintenance). While Step 3, on the social and governance requirements (R3 and R4) of the decision tree responds to the need to promote healthy eating habits, the consumption of local products and the strengthening of the involvement of families in food and agriculture issues.

- In the cases studied (11 schools in Barcelona), the support of the school staff, parents and teachers' associations and urban agriculture school projects were the key factors to achieve a high sustainability index regarding the feasibility for the implementation of a RTG. The case with the highest index (ranging from a minimum of 0 to a maximum of 1) reached a score of 0.60 compared to 0.33 of the case with lower viability.

### 13.1.2. Developing countries

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

Based on the review of the scientific literature made in Chapter 8 of this dissertation, results indicate that, currently, UA is developed in at least 14 countries in the region since 1983; and it is distributed throughout the region. Supported in 220 scientific publications analyzed, the main functions of UA in LAC are: Economic; Environmental-ecological; Productive; Social, and Urban-political. These five functions are present throughout the region, but they have not been investigated with the same magnitude and importance. The scientific interest in the subject depends on the priorities and specialties of each country: biodiversity conservation, physiological analysis, biological control of pests, improvement of crop yield processes, local business or right to the city, among others. The environmental-ecological function leads scientific publications (46%); followed by social (23%), productive (16%), urban-political (12%), and economic (3%). In addition, there are five countries that lead the scientific literature on the subject and represent 86% of the total production of LAC: Brazil (62 papers), Cuba (49 papers), Mexico (29 papers), Colombia (26 papers) and Argentina (24 papers).

Currently, UA is developed in LAC as a strategy to combat poverty and hunger, in emergency situations caused by social problems (migrations between countryside and city, violence, insecurity, among others) and natural hazards (hurricanes, earthquakes, etc.). In this sense, UA research carried out in LAC follows the same line of action as FAO objectives, as a means of support for food security. UA in LAC is an emergency measure and not a planned activity. This causes that UA road, which is a fundamental part for the sustainable development of cities, is still long. In part, this is because there is a tendency to use generic strategies, which tend not to be adapted to the needs of each specific site. And they only play their role of support in an emergency situation and do not manage to get involved in the urban fabric as part of it.

To strengthen the development of the UA as one of the strategies for sustainable development, and not only as an emergency measure against hunger and poverty, the AU's promotion programs must be generated taking into account the particular needs of each site and not replicating strategies but adapting them to each specific site. In this way, there would be more opportunities to involve population and generate a true and lasting development of the AU in the region.

### QUESTION 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 city?

Based on Chapters 9, 10 and 11 results, it is considered that the development of UA in LAC is closely linked to urban planning and social housing. And in part, its limited development as a promotion strategy for sustainable development, is due to the lack of adequate space in homes and neighborhoods and the lack of promotion by government institutions. Given that the growth of the cities of LAC is usually due to the construction of neighborhoods of social housing, which generates huge artificial surfaces, it can be pointed out that urban planning and social housing are factors of great importance and basically determining for the development and shape of UA in the region. Practically, it can be pointed out that the development of UA in LAC takes place inside the lot of the house to the outside, contrary to what happens in Europe where UA tends to be more communal and in external public spaces.

The basic typology of social housing (based on social housing in Mexico) is modified regularly by its residents because it does not meet their needs and almost losing all permeable surface destined to green surfaces. This process is developed gradually in four stages: 1st, starting with the house without any modification (Free land area: $100m^2$ & built area: $55m^2$); 2nd, there is the construction of a front annex (garage) or backyard (Free land area: 60-$65m^2$ & built area: 100-$135m^2$); 3rd, construction of one or two bedrooms in the backyard (Free land area: 25 $m^2$ & built area: around or above 135 $m^2$) and $4^{th}$, construction of spaces in the second level of the house (Free land area: 25 $m^2$ or less & built area: superior to 135 $m^2$). Although UA can be developed in only 1 $m^2$, the interest groups analyzed (residents, urban government officials and technical experts) pointed out that they consider insufficient the space provided by social housing for the development of UA after the modifications that could occur. This may be due to the traditional implications and other uses (recreation, drying clothes outdoors, …) that are often given to free spaces in the housing area.

Therefore, having a high percentage of built areas is not suitable for the development of urban agriculture in traditional form. However, the neighborhoods of social housing have characteristics that make them suitable spaces for the development of vertical agriculture since at the same time that the construction of new spaces in the houses occurs, the roof areas also expand. Chapter 9 analyzed the potential for vertical agriculture in Santa Clara Commune of San Millán, in Quito, Ecuador, obtaining encouraging results that support the feasibility for the implementation of RTGs. The results indicated that social housing in Quito has a high potential for the implementation of RTGs, because they have the proper architectural characteristics: high bearing capacity and unfinished covers facilitate the labor of the implementation of RTGs. Specifically, 33.2% (1160 roofs, 7.7 hectares) of the 3494 roofs analyzed have the capacity for the construction of an RTG. These 7.7 hectares of roofs have the possibility of providing 9% and 4.5% of the demand for tomatoes and lettuce from Quito, with a production of 28,360 kg / year of lettuce and 789,750 kg / year of tomatoes. So, RTGs in social housing in Santa Clara Commune of San Millán and in Quito is a great opportunity for the food security in the region, because it is possible produces a considerable among of food in rooftops for a nutritional and adequate alimentation.

At level of urban planning, UA is considerably limited, since it is not usually included in the agendas and development plans of the governments (national, state and municipal). So, the supply of public urban spaces for the development of the UA is extremely limited. In this sense and in accordance with what was analyzed in Chapter 11, UA development is given as individually from within the boundaries of the housing lot, in pots (inside or outside the home) or traditional way in the little remaining free space. The factor that is most correlated with the development of UA in social housing are the neighborhood conditions. The housing typology defines the area or magnitude in which it is developed. Likewise, no strong relationship was found between social factors (sex, origin and inhabitants) and the development of UA.