Influence of social housing models in the development of urban agriculture in Mexico

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Abstract

This study examines urbanization patterns linked to social housing units and the way in which such patterns influence the practice of urban agriculture (UA) in Mexico. Due to the transformations that take place over time in Mexican social-housing units, impervious surfaces tend to increase at the expense of greenspace and UA possibilities. The research aims to identify the negative impact of social housing transformations on UA and suggest a policy framework for sustainable housing development in Mexico. The empirical analysis distinguishes four social housing typologies within two emblematic neighborhoods in the city of Merida, Mexico: Las Magnolias and Ampliación Tixcacal-Opichén. A survey of 157 housing units combines quantitative metrics and qualitative descriptors to unveil the detrimental impact of development on UA.

The results show that UA takes place within the building lots and around the housing units, rather than in public urban areas. 60% of the sampled units practiced UA, with traditional backyard gardens being the most common modality. The research findings point to a systematic expansion of impervious surfaces, limitation of both cultivation choices and crop variety, and major restrictions on UA practices. Social housing represents the bulk of residential developments in Mexico (42.7% out of 35.5 million housing units). Left unregulated, the types of social housing transformations that have been empirically verified in this study endanger the availability of green space as the primary resource for UA. This research sheds light on critical policy changes and formulations that are required to enhance UA practices and to establish greener cities and more sustainable housing development.

Keywords

Latin America; Urban Farming; Self-sufficiency; Sustainable Cities; Urban Gardening; Urban green spaces

Abbreviations:

United Nations Convention to Combat Desertification (UNCCD)

Urban Agriculture (UA)

Average (AVG)

Minimum Monthly Wage (SMW)

Highlights

- Urban agriculture (UA) is widely practiced in Mexico's social housing lots.
- Survey results detect UA in 60% of backyard gardens in social housing.
- Impervious surfaces spread from the exterior to the interior of the housing lots.
- Impervious surfaces the main limiting factor for UA, plant diversity, and cropping.
- Modifications to housing units and UA appear to be mutually exclusive.

1. Introduction

Demographic growth within urban areas is relentless within both megacities and intermediate cities, due to interurban migration and the natural increase (United Nations, 2012). In the Latin American and Caribbean (LAC) region, these trends advance at an accelerated pace in the peripheries of intermediate cities, jeopardizing access to quality public services and generating socio-economic and residential segregation, which have negative effects on social vulnerability and sustainable economic development (CEPAL, 2017).

In Mexico, urban sprawl is related to the national social housing development policy that the Federal Government has implemented since the early 2000s, through the massive granting of financing, lack of territorial or urban impact considerations and disconnected from local urban planning capacities and instruments. The housing sector usually represents 6% of the national GDP and it is estimated that at least 42.7% of the total national housing stock (35.3 million) corresponds to social housing; and in 2019 around 45mil new homes were built (INEGI, 2021, 2020; INFONAVIT, 2021). Mass construction of new housing developments is oriented to individual workers or families earning 1 - 3.9 times the Minimum Monthly Wage (MMW). Building layout, materials, and living spaces are basically the same nationwide (kitchen-dining room, 1 to 2 bedrooms, bathroom, parking space) and climatological characteristics are not usually taken into account. And offered in three basic typologies depending on income and built area of anywhere between 42 to 76 m^2 (‘economic’ with a cost of up to 118 times the MMW, ‘popular’ from 118.1 - 200 times the MMW, and ‘traditional’ from 201 - 350 times the MMW) (Cerón-Palma *et al*., 2013; SHF, 2015).

This standard model disregards social, family, and cultural aspects that might define the housing unit and ultimately influence the construction of impervious surfaces and the reduction of green areas. Urban planners, architects, and decision makers therefore face competing goals such as protecting urban land, supporting green areas, and reaping economic benefits through the extension of impervious surfaces on large tracts of land allotted for social housing. As a result, precarious urbanization at a mass scale is generating widespread changes of land use in peripheral areas from rural to urban residential that expand impervious surfaces and built-up urban sprawl (World Bank, 2009; Glaeser and Henderson, 2017; Hertwich and Peters, 2000).

The negative effects of high urbanization rates include high levels of inequality, residential segregation, gentrification, mobility gaps, insecurity, heat islands, and environmental impacts (Barcenas, 2017; CEPAL, 2017; ONU-Habitat and CAF Banco de Desarrollo de América Latina, 2014; UN, 2016). A significant alteration of the urban landscape and the related social environment are behind some of the main social and environmental concerns both in Mexico and in other parts of LAC.

Hence, the adoption of urban planning models that support sustainability is a priority. Among the strategies to support such models is the promotion of Urban Agriculture (UA). Understood as the cultivation of food crops and the raising of small livestock within cities, UA contributes to the food supply, and reduces CO_2 emissions from food transportation; the practice of UA helps to combat poverty and food insecurity (FAO, 2011). Despite the long history of UA in LAC linked to indigenous traditions, research on this subject matter has mostly focused on traditional community gardens in peri-urban areas (Alban *et al*., 2017; Ávila Sánchez, 2019; Lattuca, 2011; Orsini *et al*., 2013; Rodríguez, 2020). This modality of UA tends to be explored through studies on the classification of plant species in gardens within peri-urban and rural areas, and on the cultural significance of crops (Cahuich-Campos et al., 2014; Domínguez Santos et al., 2011; J. S. Flores and Ek, 1983; González, 2012; Jiménez-Osornio et al., 1999; Mariaca Méndez, 2003). While providing valuable inslights, the existing literature provides an incomplete picture of the socio-environmental implications for sustainability and their adaptive capacity.

In view of the rapid growth of LAC cities and the notable increase in impervious surfaces, and responding to the need to contribute to strengthening the sustainability of Latin American cities, improving the health and quality of life of the inhabitants, this research provides first-hand and pioneering information so that future social housing projects can enhance urban agriculture, strengthen communities and food, as well as contribute to the transformation of our existing neighborhoods and cities into greener, more resilient places and reduce the negative effects of urbanization.

Additionally, among the few studies on the relationship between UA and city development in LAC, none addresses the rapid urban transformations after the construction of social housing; so, the analysis of this topic remains as a research gap to understand the large-scale social changes in the region mentioned above. Unveiling how this process, which often goes unnoticed or remains hidden, occurs at the neighborhood scale is fundamental to understanding the relationship between the urbanization patterns of social housing and the ways of living and practicing UA in households. In view of this, some questions arise that motivate us to develop the present investigation: Is UA currently being developed in contexts with a high number of impervious surfaces, such as social housing neighborhoods? How does it develop? In this sense, what can we expect in terms of the evolution of UA in medium-sized cities? And what intervention mechanisms can be developed to reinforce AU in the face of increasing permeable surfaces?

To answer these questions, two research objectives are therefore proposed. The first one is to identify and to understand the different forms of practicing UA in social housing lots in Mexico with a view toward its definition and its promotion in the development of sustainable Latin American cities. The second one is to analyze how UA and impervious surfaces (or constructed areas) compete in the transformation of Mexican social housing units.

In order to address the socioeconomic and the environmental dynamics of intermediate cities in the LAC region, we take the city of Merida (Yucatan, Mexico), as an emblematic example. Two social housing neighborhoods in Merida were selected as representative cases of Mexican urban clusters, using criteria such as location, housing typology, urban planning, neighborhood design, and year of construction. Both neighborhoods are of interest, because they represent low and medium-high socioeconomic lifestyles, despite having the same architectural characteristics. Quantitative and qualitative research methods, such as surveys, descriptive statistics, and network analyses are used for data collection and analysis.

This pioneer study of the relationship between UA and impervious surfaces in the context of social housing within Mexico provides an overview of UA practices, forms, and limitations. Therefore, it contributes to strengthen urban sustainability literature, guiding both the design and the modification of future settlements. Specifically, the study underpins Goal 11 of the Sustainable Development Goals promoted by the United Nations “Make cities inclusive, safe, resilient and sustainable" (ONU, 2015), while expands the scientific literature on UA and social housing settlements in LAC.

1.1. Background. Social housing and urban agriculture

Over the past fifty years, urban sprawl within LAC has expanded city boundaries and demarcated mainly residential neighborhoods with irregular population densities (Rojas, 2016). Moreover, these urban areas with limited connectivity between each other are often interspersed with open spaces around the city limits (Janoschka, 2002). Only limited service infrastructure is provided within the urban periphery of these residential districts, which mainly consist of social housing for low-income working-class families (CEPAL, 2017).

The complex and extensive economic policies of the housing sector offer incentives promoted through housing markets, policies, and public housing programs with the purpose of expanding and densifying the cities of the region (Rojas, 2016). These subsidies have the purpose of promoting housing projects with the aim of cutting costs and maximizing rents through the purchase and the subdivision of land in the urban periphery, where the cost of land is lower and urbanization is easier (CEPAL, 2017). It is a trend that transforms peripheral areas into urban areas and increases the surplus value of vacant land between newly built neighborhoods. (Cobos, 2014; Duhau, 2003).

Mexico is a good example, although these processes are commonplace in almost all countries in LAC (Calderón, 2015; Rodríguez and Rodríguez, 2016; Ziccardi and Alicia, 2016). The metropolitan areas of Mexico present new spatial architectures. From an economic and functional viewpoint, the largest cities have developed polycentric structures organized into nodes or islands with decentralized activities and services scattered over an extensive territory (Janoschka, 2002). The widespread use of automobiles, industrial relocation processes, a lack of urban regulation, and the housing policies developed over the past few years are all factors that contribute to the feasibility of this model (Ziccardi and Alicia, 2016).

The features of housing complexes are very similar in almost all Mexican cities: these are large groups of housing blocks consisting of small single-family houses of one or two floors with low-quality building materials (stone foundation and walls made of concrete blocks), a lack of basic (*e.g.*, education, culture and health) infrastructure and more often than not leisure centres (Cobos, 2014; Duhau, 2003; Eibenschutz and Goya, 2009; Pírez, 2014; SHF, 2015). And the mega-complexes of social housing have been built at great distances from the city centers of all medium and large-size Mexican cities where the low-cost of land offers advantageous terms to developers.

In 2015, 78% of the 119.5 million inhabitants of Mexico were living in urban areas where 27.74 million private social housing units were registered, which represented 66% of the total private housing market in the country (35.6 million) (INEGI, 2015). A situation that is summed up by the fact that between 50 and 51.8 % of land use in Mexico is for residential use (PAOT, 2006). Hence, housing is considered a national problem, due to the need for an ever-larger housing stock as the population expands. This situation limits the development of green areas in Mexico in very similar ways to many other cities within the Latin American region. In the light of this situation, UA is an option for supporting urban sustainability and food security within urban settings, as well as healthier diets (Nadal *et al*., 2017). UA also plays a key role in the objectives of the cities of the future, because of its impact on society, environmental harmonization, and sustainable economic development (Azunre *et al*., 2019; Berger, 2013; Losada *et al*., 2000; Nadal *et al*., 2018, 2015).

UA increases biodiversity, contributes to efficient resource use, guarantees affordable food, reduces food-related expenditure, promotes job creation, and environmental and nutritional education, raises awareness of food-related issues, improves health and quality of life, and upgrades deteriorated and abandoned urban spaces, among many others (Armar-Klemesu, 2000; Arosemena, 2012; FAO, 2005; Zezza and Tasciotti, 2010). By its very nature, it involves multiple scales, forms, actors, objectives, and dimensions of sustainability (Nadal *et al*., 2018). Figure 1 shows the main forms of UA when adapted to housing, neighborhoods and built environments: rooftop greenhouses, green walls, vegetable gardens, green roofs, backyards, and basements, among others (Nadal, 2015).

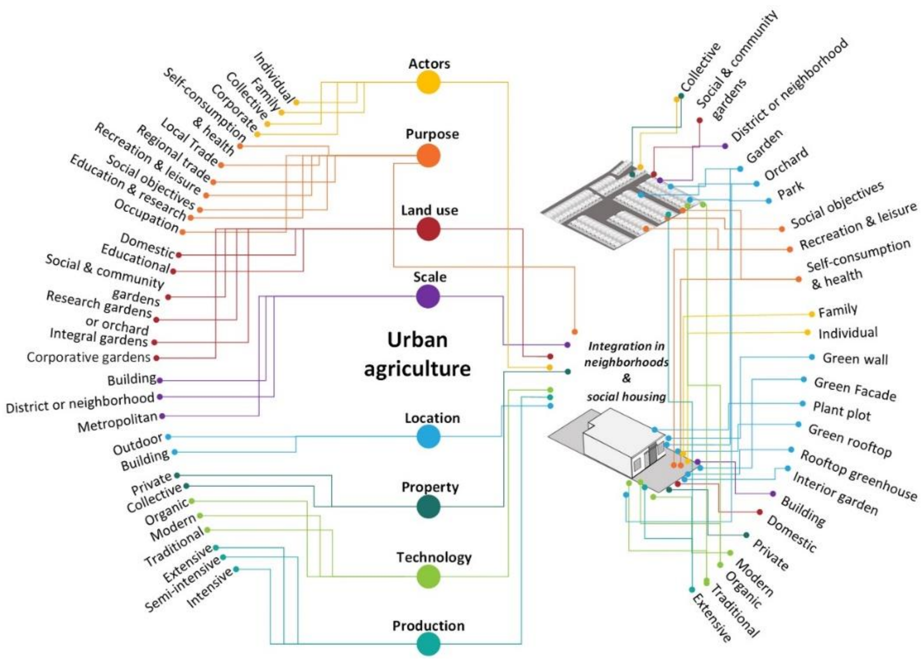


Figure 1. Classification and integration of Urban Agriculture (UA) in neighborhoods and social housing, based on Nadal *et al*. (2015) and Nadal *et al* (2018).

1.1.2. Gray houses and impervious surfaces

Cities comprise a mosaic of diverse land uses and land coverage that shapes the urban context through concreted surfaces and green areas (Gill *et al*., 2008). This mosaic arises from their spatial complexity and heterogeneity (Pickett *et al*., 2011). However, at present, urban agglomerations are characterized by extensive impervious surfaces (European Commission, 2011). Thus, the waterproofing of urban soils (*e.g*., asphalt, buildings and concrete) is one of the main global challenges of sustainable urban development (Artmann, 2016). Soil sealing is the result of the transformation of natural and semi-natural areas into human settlements and mobility zones (European Commission, 2012).

In this sense, soil is sealed by "impervious surfaces',' which are defined as artificial (non-natural) surfaces through which water cannot penetrate (including driveways, parking lots, sidewalks, roofs, and roads) (RIDD, 1995; Weng, 2012). Impervious surfaces give rise to spatial processes that act as important drivers of ecological impacts such as climate change (Buyantuyev and Wu, 2010), biodiversity loss (Ortega-Álvarez and MacGregor-Fors, 2009), heat islands (Haselbach *et al*., 2011; Pauleit and Duhme, 2000; Weng *et al*., 2004), and runoff generation (Angrill *et al*., 2017; Sjöman and Gill, 2014). An impervious surface goes beyond a purely surface aspect and has two dimensions: physical and social. Basically, the physical dimension refers to the material properties and the characteristics of the artificial surface. The social dimension is interrelated with the requirement to support compact cities as a sustainable urban form to decrease urban sprawl and natural resource consumption (European Commission, 2011). This dimension also includes the complexity of human relationships between people, government administrations, and businesses that influence land use and land cover (Liu *et al*., 2014).

Both dimensions are addressed in current international policy that aims to protect soil from degradation and to limit land sealing. For example, the United Nations Convention to Combat Desertification (UNCCD) recommends a Sustainable Development Goal for Rio+20 in which net land cover is reduced to zero (Zero Net Land Degradation) by 2030 (Ashton, 2012). Furthermore, 2015 was declared the International Year of Soils by the 68th UN General Assembly with the aim of promoting effective strategies for soil protection, sustainable soil management, awareness raising, and monitoring (FAO, 2015). However, housing policies in LAC continue to be developed beyond city limits, which considerably increases impervious surface (Janoschka, 2002).

Despite its importance, this issue is often addressed without considering its close relation with the processes involved in the modernization and individual modification of housing units, which significantly influence the increase of impervious surfaces within Latin American cities (Torres Pérez, 2014). For this reason and due to its complexity, urban land management should be considered a priority to solve the pressure of urban expansion on natural resources (Dalal-Clayton and Bass, 2002). To this end, it is necessary to analyze the impervious surfaces that are (gradually and progressively) generated over the lifetime of social housing and the ways in which urban agriculture adapts to cope with this loss of permeable surfaces.

In the present study, the need for a detailed study of the relationship between impervious surface patterns and green spaces is argued. Specifically, we address the case of urban agriculture as a sustainability strategy through its implementation in social housing in medium-sized Latin American cities. We seek to provide first-hand information that may facilitate cooperation between urban social actors and decision-makers when developing housing and urban planning strategies, so that dynamic and sustainable cities can be shaped through urban agriculture.

2. Study area and methods

2.1. Case study selection: Two emblematic social neighborhoods in Merida, Mexico

The study was conducted in Merida, the capital city of Yucatan state (southeast Mexico). Based on the 2010 census, the population of Merida amounted to 830,732 inhabitants (42.5% of the total population of Yucatan) and it had 12,000 housing units (45.3% of the housing stock of Yucatan) (Inegi, 2010). With an area of 883.40 km^2 (2.19% of the state) (SEDUMA, 2006), rapid growth over the past 50 years had led to the construction of almost 3 thousand homes in 2015. Merida was selected as a study area following the criteria defined by Nadal (2018): a) it is a good example of a medium-sized Latin-American city with residential segregation (García *et al*., 2012); it has b) consolidated areas of social housing with a high percentage of impervious surfaces; and c) adequate climatic conditions for the development of UA, *i.e.*, average annual temperature between 24.5 and 27 °C, annual rainfall of 805.4 to 1120.5 mm, and average global solar radiation of 5.0 $kWh/m^2/day$ (García, 2004; UADY, 2016). In addition, d) Merida has both a rich pre-Hispanic history and heritage of growing fruits and vegetables in home gardens (Mayan solar in Spanish or “Ich-tankaab” in the Mayan language) (J. Flores and Ek, 1983; Gómez-Pompa, 1987); and e) it presents the most common degenerative diseases related to diet problems in Mexico and LAC (Prevalence of diabetes of 9.2%, overweight 35.5% and obesity 44.8% in the population) (IDF, 2013).

The sample included two neighborhoods: Ampliación Tixcacal and Las Magnolias (Figure 2 and Table 1). Both are representative of the 209 existing social housing neighborhoods built up until 2010 in Merida and have the most important characteristics of this housing typology (Nadal 2018), *i.e*., common housing design, location, house size, and socioeconomic status, as well as similar spatial distributions, room numbers, and construction areas.

Figure 2. Location of Merida, city limits and location of the two social housing neighborhoods.

Table 1. Urban and architectural characteristics of the sample social neighborhoods.

Name	Ampliación Tixcacal-Opichén	Las Magnolias
Year of construction	2007	2005
Location	West of Merida	North of Merida
Context typology	Low socioeconomic level	Medium-high socioeconomic level
Total area (ha)	30	20
Houses per block	38	34
Average housing area (m^2) [a]	56 (big house model) 46 (small house model)	56 (big house model)
Total # of houses	332	568
Housing typology	Social housing	Social housing
Average household size	3.6 people	3.6 people

[a] Constructed area of the basic typology

These two neighborhoods, each with an average of 38 houses, built of 150 x 40 m breeze blocks, have basic infrastructure and services (*e.g.*, electricity, drinking water, sanitary drainage, paving, sidewalks, *etc*.). The sample has two basic housing typologies (Figure 3): small house (I) and big house (II). The big house is similar in both neighborhoods. The area of each lot is 160 m^2 with a constructed area of 56 m^2 on one floor and a usable floor area of 50 m^2. The area available for green spaces within the lot is 70% of its available space (72.8 m^2), since the remaining surface area comprises the house, the entrance, paths, driveways *etc*. (Cerón-Palma *et al*., 2013). And at the regulatory level, 20% of the land surface is usually considered as a minimum permeable and green area (Ayuntamiento de Mérida 2017-2018, 2017). The single family house, usually inhabited, has a bathroom, two bedrooms, and a living room with a kitchen and is usually home to young families (Cerón-Palma *et al*., 2013; Gil *et al*., 2012). The small house design has the same lot area with a constructed area of 40 m^2 on one floor and a usable floor area of 37 m^2. This design has one bedroom and the same distribution of space as in the big house; a typology that is only found in the Ampliación Tixcacal-Opichén neighborhood.

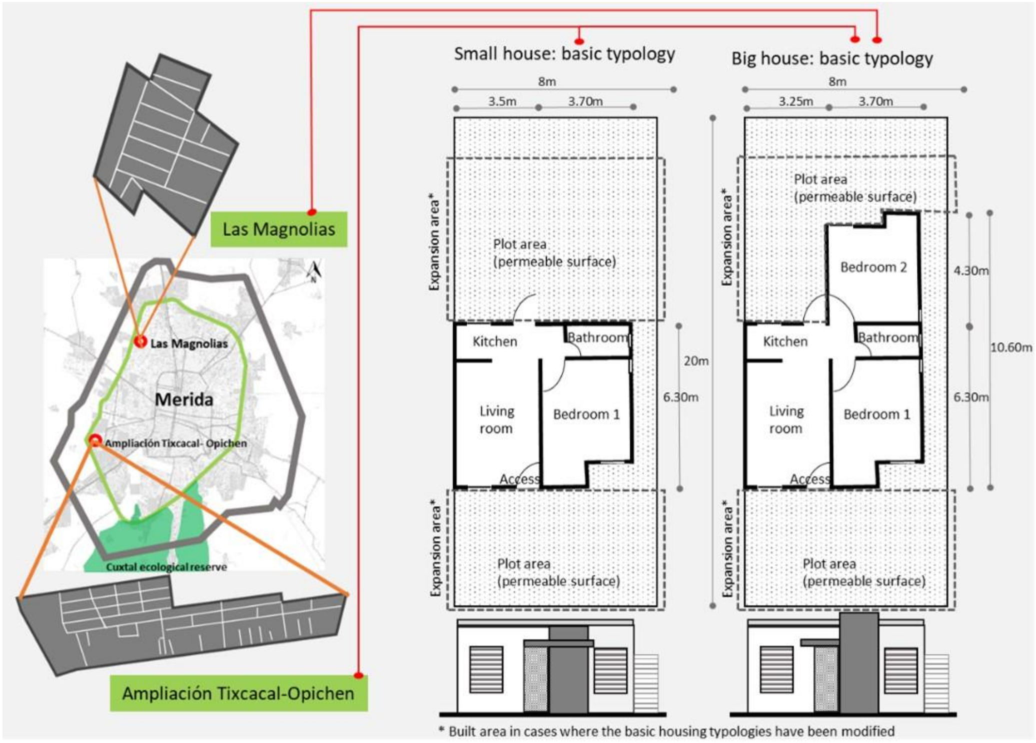


Figure 3. Urban plan of the two sample neighborhoods and dimensions and distribution of the two basic typologies of social housing.

Usually many of the residents tend to extend or to remodel their homes to meet family needs, so the basic social housing typologies often undergo an architectural transformation that can change both the use and the surface of the lot (Figure 4). Two additional housing units may be mentioned: modified small house (III) and modified big house (IV). In most cases these modifications take place in the second stage (densification) of the housing consolidation (García-Huidobro *et al*., 2011). Nadal (2018) focused on the construction perspective and noted that these changes occur progressively in four steps when new spaces are gradually added (garage, bedrooms and bathrooms), including new impervious surfaces that generate a loss of green areas (basically intended for recreation and gardening).

Figure 4. Merida social housing, impervious surfaces and lemon cultivation.

2.2. Data collection

2.2.1. Sample design

We used quantitative and qualitative research methods through a stratified random sampling design, which provides a broad overview of the research problem (Hernández Sampieri *et al*., 2006). With a sample universe of 900 houses and a maximum admissible error of 10% and a confidence interval of 95%, we estimated that a total of 157 houses should comprise the sample of the present study: 82 houses in Las Magnolias and 75 houses in Ampliación Tixcacal-Opichén neighborhood (Table 2). Item B in Table 2 defines each cluster of the sample that corresponds to a social housing unit typology, as well as the quantity and distribution of houses that integrate them.

Table 2. Delimitation of the sample and breakdown of survey results by conglomerates.

	Neighborhood	
	Las Magnolias	Ampliación

				Tixcacal-Opichén	
A) Delimitation of the sample	Population size	568		332	
	Maximum error admitted	10%		10%	
	Confidence interval	95%		95%	
	Total	82		75	
B) Breakdown of survey results by conglomerates (number of questionnaires)		Cases	Sample	Cases	Sample
	Basic small house model	242	35	-----	-----
	Modified small house model	15	2	-----	-----
	Basic big house model	116	17	44	10
	Modified big house model	195	28	288	65
	Total	568	82	332	75

2.2.2. Survey design

We designed a survey drawing on the information from the results of social perceptions of UA in social housing by Nadal (2018). A total of 20 pilot surveys were administered to test the questionnaire. The authors administered these face-to-face surveys in January 2017 that revolved around two topics: social housing and UA.

We conducted surveys in the neighborhoods with both standardized and open-ended questions in order to collect the information. The standardized questions elicited quantitative information of statistical significance and the open-ended ones, qualitative information that supplemented the narrative. A total of 46 questions were considered in the survey, of which 10 were open-ended questions. Each survey took approximately 15-to-25 minutes to administer. We interviewed people of all ages without a minimum of years living in the neighborhoods. Those under the age of 18 were asked for consent from their parents or guardians.

Appendix 1 describes the survey structure, which has three main parts and an additional module for urban farmers and/or UA practitioners. The first part was meant to collect general information from the interviewee, *i.e.*, age, education level, work, income, and weekly expenditure on food, among other points. The second part focused on specific topics of the housing typology, *i.e.*, years of residence, inhabitants, number of spaces, use of spaces, construction order, housing extensions, and others. The third part covered the questions related to interest in and knowledge of urban agriculture and its viability in social housing. Questions included whether residents cultivated inside their homes, what spaces are used to do so or what the characteristics of the ideal cultivation plot would be, among others. The additional module for urban farmers addressed specific questions on the variety of crops, the destination of production, irrigation systems, and problems with the productive system, amongst others.

2.3. Data gathering

Our data-collection method was through survey protocols based on exploratory, probability sampling, considered both statistically and demographically as representative of the residents of the social neighborhoods of Merida. This exploratory approach is suitable because it offers preliminary insights into a previously unexplored issue. Each of the houses was assigned a color and number code based on the type of home (modified or otherwise) and the neighborhood. The surveys were administered to the residents of the houses that had been randomly selected with Excel software from the numerical codes assigned to each house.

The housings units at the corners of the blocks were overlooked, because their dimensions were larger than the standard sizes. The sampling unit was the house; hence, we conducted the surveys with the residents of each house. We first invited a resident of the randomly selected houses to participate in the survey. In the case of a negative response, we administered the survey to a resident of the adjacent house on the right-hand side.

2.4. Data organization and analysis

The information gathered during the surveys was stored in an Excel database. The data were organized into three broad categories: urban agriculture, housing, and social aspects. The category of urban agriculture includes topics related to the development of UA, location, crop varieties, diseases, and crop strengths. The category of housing included the individual modifications to social housing units, the spaces annexed to the houses, their order of construction, and the main problems for the practice of UA within those housing units. The social aspects referred to various issues related to the relation between UA and housing: origin, sex, age, family income, and expenditure on food.

The specific information was coded in quantitative terms for the analysis as were the responses to the open questions. The answers to ordinal and nominal questions were analyzed with descriptive statistics, using Microsoft Excel and IBM SPSS Statistics (Statistical Package for the Social Sciences) (IBM, 2013) for Windows (version 22.0). Descriptive statistics methods were used to analyze the frequencies and the concurrence of the different types of codes (Hernández Sampieri *et al*., 2006). Descriptive numerical information was generated for the characterization of urban agriculture developed in the dwellings.

A network analysis was also performed to study the evolution in the changes of social housing typology using Gephi 0.9.2. software (Gephi.org, 2018) for Windows. Network analysis allows to examine the cohesion of a network of connections, and both the role and the influence of each connected node (Otte and Rousseau, 2016; Zedan and Miller, 2017).

We used this approach to understand the chain of changes between the different housing spaces (nodes) that are added or modified throughout the useful life of the social housing unit. Thus, we could visualize how the practice of UA changes as permeable areas are lost.

3. Results

3.1. Characterization of urban agriculture

We detect that UA is present in 60% (94 units) of the 157 surveyed housing units and is limited to the interior of the lot around the housing unit. It usually develops in one of five ways: plant-pots (23%); front garden (16%); backyard garden (40%); front garden or backyard plus plant-pots (9%); and front garden plus backyard garden (12%). Interest in practicing UA collectively is low at only 5%. Regional tropical fruits and aromatic plants used in traditional food preparation dominate the cultivation that is practically all self-consumed (99%). Figure 5 summarizes main indicators about UA in social housing detected through the survey.

20 different plant species we identified in Merida's UA include papaya (*Carica papaya*), soursop (*Annona muricata*), nance (*Byrsonima crassifolia*), guava (Psidium guajava), sugar-apple (*Annona squamosa*), chi'aval plum (*Spondias purpurea*), lemon (Citrus × lemon), maax'ik pepper (*Capsicum annuum*), mint (*Mentha spicata*), epazote (*Dysphania ambrosioides*), and coriander (*Coriandrum sativum*). Most gardens usually include multiple crops with at least one variety of fruit, vegetable, and aromatic plant. We did not detect small livestock or farmyard animals (e.g., chickens or pigs).

Production requires few external inputs, as residents occupy the remaining land on their property for cultivation and used their own seeds. Household members would exchange or share plants with family members and use household organic waste as organic fertilizer. Only 3% of the crops were fed with chemical fertilizers and 10% were treated with chemicals for pest control. Traditional irrigation with domestic water supply is used in all the crops.

70% of interviewees considered that the main limitation for the development of UA in Merida is the lack of space at home and in the lot; but only 25% of all housing units that practiced UA reported constraints for UA related to lack of space for adequate plant growth. Other crop problems include problems with neighbors (due to plants invading adjacent lots) (25%), pests (25%) and to a lesser extent excessive exposure to sunlight (3%). The strengthening and improvement of agricultural activity in social housing involved plant donations (40%), government support (25%), agricultural training (15%), access to financial support (10%), urban spaces for cultivation (5%), spaces for the exchange and sale of products (83%), and for the development of seed fairs (2%).

The characteristics of the households that practiced UA reflect a predominantly urban origin (80%), with a high level of property ownership (97%), a family farming tradition (63%), and a residence period equal to or greater than 10 years (56%). There were at least three members of each household. The predominant age range of the interviewees was between 35-40 years (32%) and 53% were women. 48% of households include car owners. While a 30% non-response to questions on family income prevented us from estimating this indicator, we could obtain data on weekly food expenditure, which ranged between MXN 500-1000 for 84% of the interviewees.

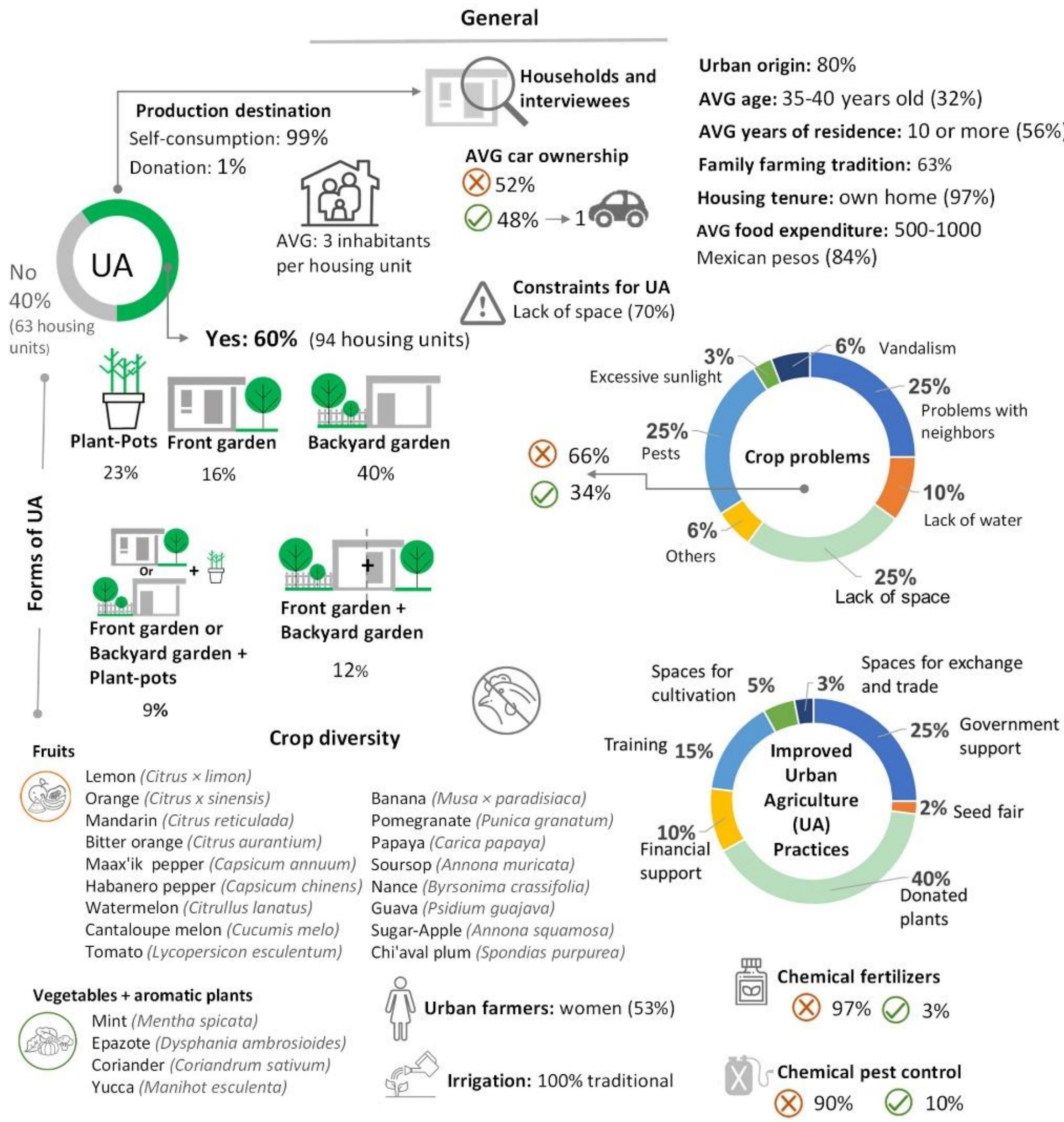


Figure 5. Urban Agriculture (UA) in social housing based on the main survey results.

The practice of UA can be disaggregated according to the neighborhoods under analysis (Figure 6). In the Ampliación Tixcacal-Opichén, at least 79% of housing units practiced UA. At least 70% of each house typology had some form of UA: UA was practiced in all small houses that had been individually modified, 86%, of the basic small houses, 76% of the basic big houses and 71% of the big modified houses. Backyard garden was the most popular modality (45%), and front garden plus backyard garden was the least prevalent (9%).

In Las Magnolias, the development of UA was considerably lower. 39% of the surveyed units practiced UA. The percentage was uneven across housing types: most of the basic big houses (90%) and slightly under one third (31%) of the big modified houses practiced UA. Only three forms of UA were developed: plant-pots as the most popular modality (52% of UA practitioners), followed by backyard garden (31% of UA practiotioners), and front garden plus backyard garden.

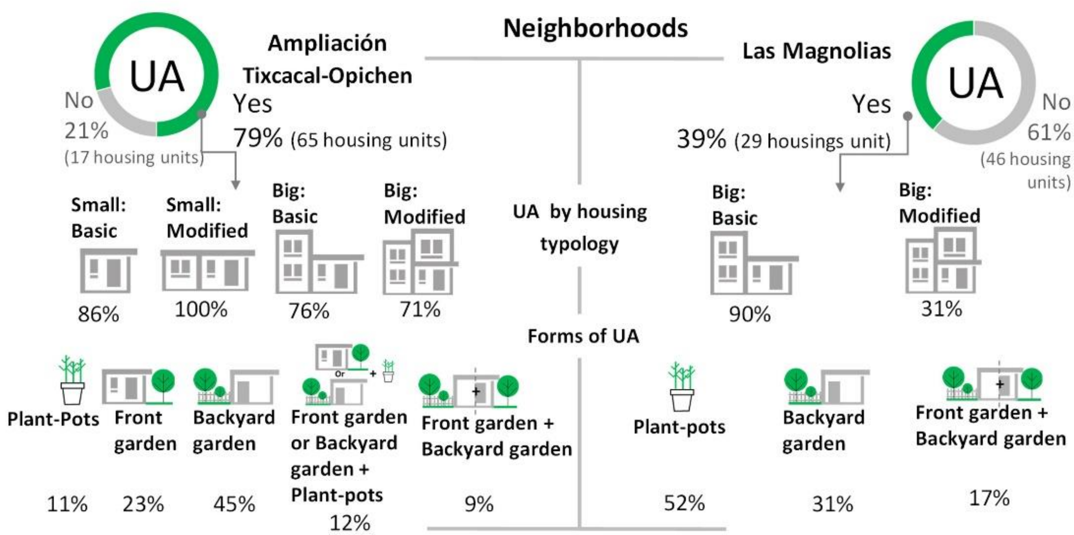
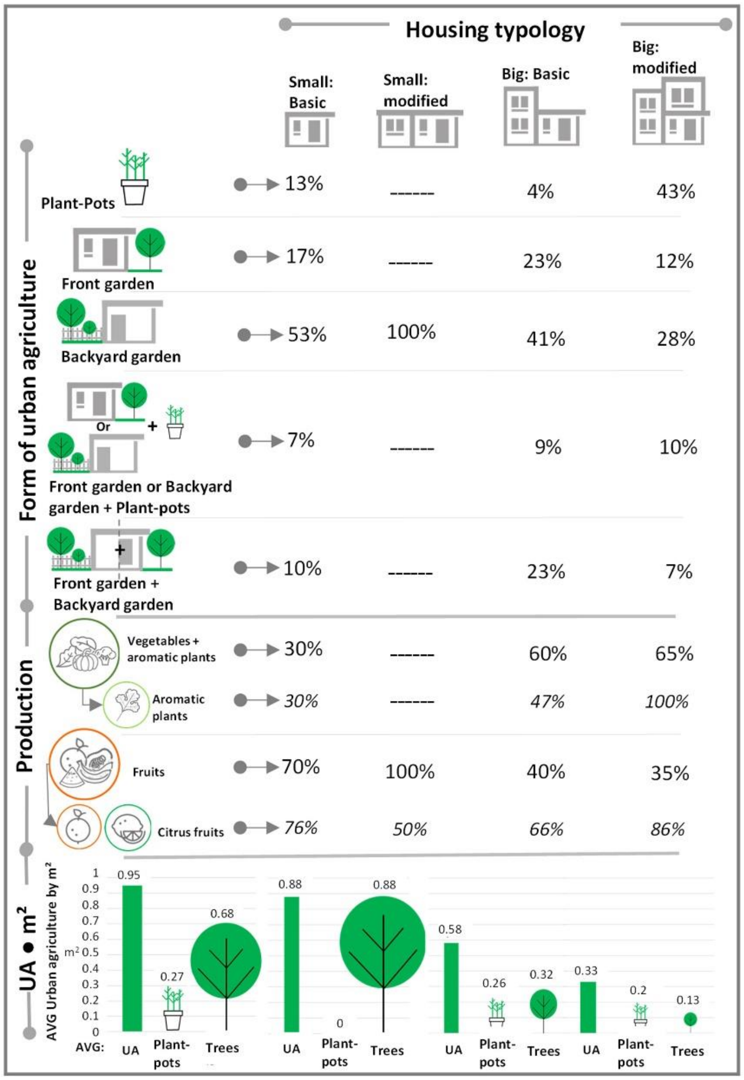


Figure 6. Characterization of Urban Agriculture (UA) in social housing at a neighborhood level.

Looking at results according to four housing typologies across neighborhoods (Figure 6), the most widely practiced form of UA (53% of the houses) was the backyard garden in the basic small housing units, and the least developed (7%) is the front garden or backyard garden plus plant-pots combination. All the modified small housing units practice UA in the backyard garden, which is also the most common modality in the basic big housing typology (41%). In modified big houses, the most prevalent UA practice is the plant pot (43%).

Two trends in terms of production are worth noticing. First, small (basic and modified) housing units focus on cultivating fruits (70%), out of which three-quarters are different varieties of citrus. Second, the cultivation of aromatic and vegetable plants represented over 60% of the crop diversity in the big (basic and modified) housing units.

How much space does UA use per type of social housing? Based on survey data, direct observation, we calculated the average UA/m^2 (plant-pot + tree), plant-pot/m^2 and tree/m^2 indices commonly found in the social housing lots, assuming that an average aromatic plant pot occupied 0.13 m^2 (Figueroa-Pérez *et al*., 2018; Figueroa Pérez *et al*., 2014; Rojas-Valencia *et al*., 2011) and that the average surface area of a citrus tree is 0.25 m^2 (R. Almenares Garlobo *et al*., 2015). The results (Fig. 7) suggest a maximum of 0.95m^2 of UA/m^2 in the typology of basic small housing and a minimum of 0.33m^2 of UA in the modified big housing. The small (basic and modified) housing units had the highest tree/m^2 index. The modified small housing units and the modified big housing units had tree/m^2 indices of 0.88 and 0.13 tree/m^2, respectively. The plant-pot/m^2 index was lower compared to the tree/m^2 index in the (basic small, modified small, and basic big) housing typologies. The highest plant-pot/m^2 index was found in the basic small housing units (0.27m^2). The highest presence of plant-pot/m^2 represented 30% of the highest tree/m^2 index; which is to say that trees constituted the largest area of UA/m^2. These are the first estimates of UA areas in social housing units in the LAC context.



(UA: Plant-pots + Trees)

Figure 7. Development of Urban Agriculture (UA) in the four typologies of social housing.

3.2. Increased impervious surfaces in social housing

Figure 8 illustrates the evolution in the modification of social housing units. The nodes indicate the housing spaces identified through the surveys. The node size specifies the frequency of appearance, the width of the arrow indicates the frequency of the connection, and the nodal proximity indicates more frequent relations. Seven spaces are usually modified or incorporated into the functional and aesthetic structure of the basic (small and big) house: garage, bedroom, perimeter wall, bathroom, corridor, kitchen and facade. The most frequent tendency consisted of home improvements or individual modifications of the basic typology through the construction of garages, corridors, and facades. The second tendency was to construct an additional bedroom, garage or corridor, and facade. Less frequently, the modification process began with the perimeter wall, continuing with the garage and/or the corridor and finally the facade. The bathroom was usually built after the bedroom or garage. The kitchen and facade were usually the last spaces incorporated into the housing.

According to Nadal (2018), the process of modifying social housing (which includes the loss of free or permeable surface area) takes place in four steps: i) the basic typology; ii) construction of a garage, an additional bedroom and a perimeter wall; iii) building the corridor and bathroom; and iv) the construction or modification of the kitchen and the facade. In turn, these steps are included in the phases of evolution of social housing: its establishment, subsequent modifications, and complete impermeabilization.

Specifically, the loss of permeable surface area is linked to housing unit modifications. During the establishment phase, the impervious surface is limited in both types of social housing (40 and 56 m^2) and corresponds to the surface occupied by the house. In the subsequent modifications, the impervious surface area of the housing and floor space can double or even triple in size, reaching approximately 117 m^2 for the small house and 123 m^2 for the big house. In the third phase (complete impermeabilization), the expansion of the impermeable surface is slightly less than following the modifications in the second phase. It is nevertheless of greater significance, because all the available plot for UA can be sealed, leading to a complete loss of permeable or free surface area of the (160m^2) lot.

The phase of subsequent modifications was the most significant for large housing as it implied the largest increase in impervious surfaces (about 50%), a process in which one third of the UA that had been developed was lost. The third phase was the most alarming for all types of housing, as it can involve a total loss of UA and the cultivatable surface of the lot. Likewise, the individual home improvements have been seen to impact the loss of crop variety and the choice of the best form of UA to practice. It is estimated that at least two-thirds of large housings have some type of modification.

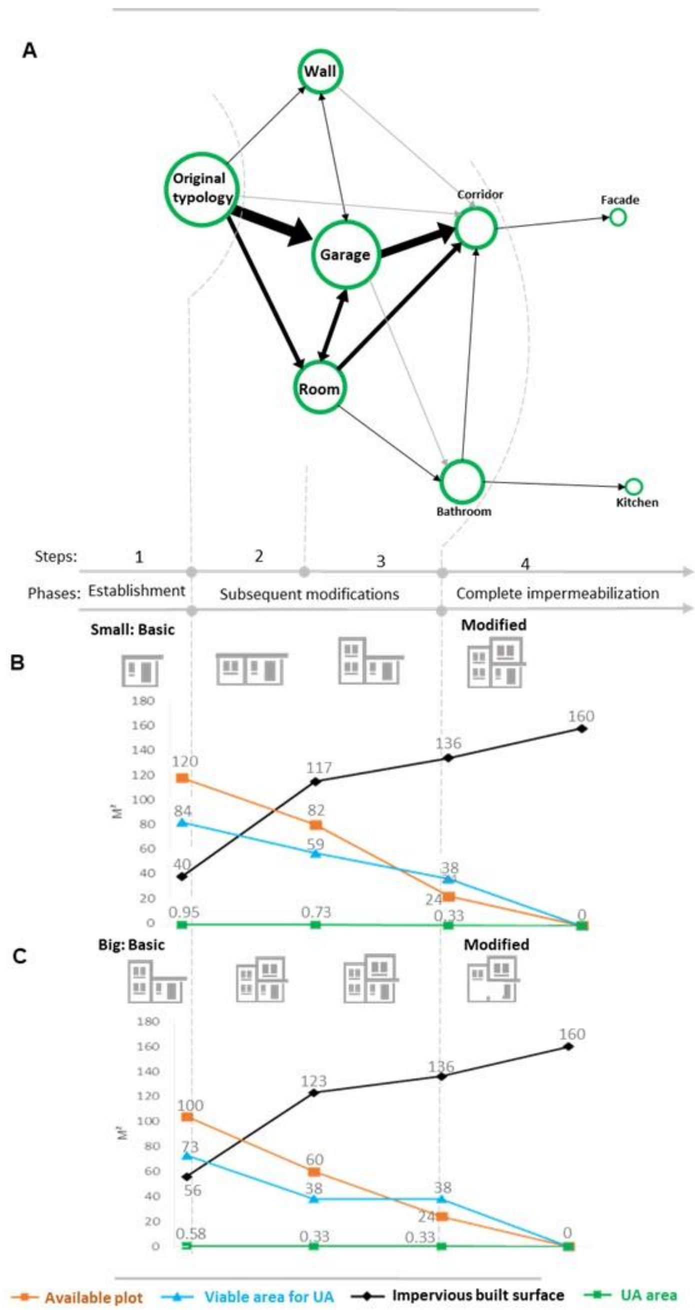


Figure 8. Loss of permeable surfaces in social housing units and its relationship with Urban Agriculture (UA).

4. Discussion

In Mexico, as in the rest of LAC, UA has not been promoted as an important component for urban sustainability (Cortes Rojas, 2009). Meanwhile, the modernization paradigm has considerably increased impervious surfaces (Barrandas, 2013; Correa *et al*., 2003). In medium-sized cities such as Merida, the same trend is curtailing UA, already limited to interior lots in social housing. This situation differs from European practices, where UA is often developed in communal urban spaces such as allotments, parks, and vacant lots with a social function that favors cohesion (Arosemena, 2012; Aubry *et al*., 2012; Mougeot, 2006, 2000; Quon, 1999). In this respect, cultivating within the housing lot diminishes interaction between neighbors and can limit social cohesion in medium-sized cities within LAC. Less coexistence and convivial exchanges of experience and knowledge between neighbors and different generations reverts to lessened opportunities for further UA.

Currently, the increase of impervious surfaces through the modification of housing and UA are presented as mutually exclusive phenomena in social housing. Unfortunately, UA is not considered part of the basic design of social housing means the resident are forced to decide between practicing UA (regardless of the housing unit) or losing the opportunity to improve their houses. Despite these limitations imposed by the "modernization" of the Latin American city and globalization (de Mattos, 2002), UA is present in 60% of the surveyed housing units in Merida across housing models and the stage of modification.

In spite of the limited size that UA currently occupies compared to the impervious surface areas, there is still diversity in the crops found in the two neighborhoods of this study. As

Nadal (2018) noted, this diversity responds to the adaptive capacity of the UA to the urban built environment. Among the crops grown in the social housing of this region, tropical fruits that represent 70% of overall production abound: papaya, watermelon, melon, pineapple, guava, and citrus fruits (lemon, tangerine, and orange). The agricultural tradition of the region explains this choice, as Mexico is among the leading global producers and exporter of lemons and the Yucatan is one of its most productive states (SAGARPA, 2016). Unfortunately, the process of modifying social housing directly impacts on the loss of crop variety. As the impervious surfaces increase, aromatic plants (for seasoning traditional food) replace the cultivation of citrus fruits.

In both neighborhoods (Las Magnolias and Ampliación Tixcacal-Opichén), the loss of pervious surfaces and UA followed the same expansive trend but varied in area and impact depending on the size of the housing. The loss of permeable surfaces within the basic small housing units was perceived to be slower with less impact. Usually, the residents had practiced UA since the acquisition of the dwelling. Time invested and constant work on the crops generated an attachment to UA and since the modification process was slower and of a smaller size (with respect to the large houses in the second phase of the process), then the link with UA could be strengthened and when the impervious surfaces were considerably increased (third phase of the process), the resident opted to switch to plant-pots rather than practice no UA whatsoever.

So, this phenomenon suggests that UA is perceived as an activity linked to a reduced economic income and a small typology house, which is eliminated or lost when the family increases its economic income and expands its housing. McClintock (2010) and Tornaghi (2014) point out that UA is often considered a source of food in fast-growing cities and as a strategy to improve household economy in developing countries. However, the results of the present research indicate that the variety of fruit crops, harvested biomass is low and only represents minor savings on food expenditure. In this case, the main motivators for the AU were the interest in preserving a cultural link with the Mayan milpa and Yucatecan gastronomy, concurring with Calderón Cisneros (2016), UA systems in medium-sized Mexican cities are largely based on personal and cultural motivations, and not on their productivity.

This personal and cultural motivation in many cases is associated with a family tradition that is passed from generation to generation, which as Nadal (2018) points out may be motivated by the migration of the population from rural to urban areas; and in turn strengthens the sense of belonging and the intergenerational bond of the family (Companioni et al., 2018). At this point, the development of urban agriculture in social housing in Merida is visualized as a practice linked to keeping a tradition alive and is far from both UA in developed countries, linked to a lifestyle or health mainly (McClintock, 2010), and urban agriculture developed in Central America or other South American countries, where UA is usually aimed at improving food security (FAO, 2010).

The modification of housing and the increase in impervious surfaces highlights complex and long-standing challenges for Mexico: on the one hand, social housing is not adapted to the current needs of its inhabitants; on the other hand, the planning of social housing cannot be separated from larger-scale urban sustainability policies. Since the housing modification trends are unlikely to change, the promotion of UA in contexts such as the one under analysis call for the consideration of policies promoting UA and social housing as a key, binding, and unavoidable binomial to achieve greener and more sustainable cities; and not only focus on it as an alternative for the food security of cities (Hermi Zaar, 2011). In turn, it should promote urban agricultural production based on successful experiences that highlight the contributions of these initiatives to cities and the environmental, economic, health and urban benefits they can generate, as indicated by Tiraieyari et al. (2019) for the case of Central America.

Due to the rapid growth and the magnitude of impervious surfaces in social housing neighborhoods, UA will be lost unless vigorous measures are taken in the short term that go beyond one-off, temporary UA programs such as those that have been implemented in recent years. Although the formation of a public UA policy is complex, a good start could be to focus on maintaining existing home gardens, gradually exploring forms of UA that take over sealed surfaces (such as roofs and walls) (Despommier, 2011; Germer et al., 2011) and that encourage green verticality in previously constructed spaces and optimize the production of plant species (Nadal et al., 2019). Subsequently, broaden stakeholder participation and expand into public space to strengthen the social fabric, increase biodiversity and other positive impacts of greenery in cities (Oyarzún and Qiu Sun, 2013; RUAF Foundation, 2015).

In this sense, it is necessary to explore successful experiences of UA systems in LAC to provide reference elements for the design of a public UA policy for Merida or México; an example that illustrates this transition process to make UA a permanent activity and to incorporate it into the Municipality's Land Use Plan is the example of Rosario, Argentina, which began in 1987 through family and collective gardens in the most vulnerable regions and was consolidated and institutionalized in 2002 (Lattuca, 2011). At the housing design level, new typologies inspired by progressive development can be developed that allow for expansion without reducing or eliminating the permeable areas of the lot, and that involve participatory design between inhabitants and developers (Aravena, 2011); this could encourage the development of UA and green areas, in harmony with the geographic and climatological characteristics of the location. Another possible idea is that low-income housing should be delivered with a front garden and backyard with vegetation and crops at an early stage, in order to encourage their care and expansion.

Following this line, a fair question after our results is what surface area requirements in social housing units would be conducive to UA in the backyard garden modality? Our study did not aim to estimate this variable that is basically linked to the development of the traditional UA modality. It is necessary to point out that each city has specific regulations for the minimum permeable, green, landscaped or wooded areas in social housing, so giving a specific figure is complicated; it is also necessary to consider the time and basic knowledge for the maintenance of the garden.

Pending the development of future research, we can only advance some recommendations:

1) Based on current parameters, a minimum reserve of 4 m^2 per inhabitant or 15m^2 of traditional garden per housing unit in general could provide space for a variety of crops, sufficient production and adequate maintenance of the garden, considering that in Mexico the average household size is 3.6 people (CONAPO, 2020). For Merida, this amount of area for traditional UA practice would represent approximately 65% of the minimum regulatory green area (20% of the lot area) of the housing unit (Ayuntamiento de Mérida 2017-2018, 2017). In the case of highly modified houses, at least 5m^2 of traditional vegetable garden could be a base to start the practice of UA, but it would be necessary to complement it with crops on walls or roofs so that the production would support self-consumption.

2) Given the modification dynamics of the houses detected here, the sensitive surface areas to be regulated are the space originally designed for the front garden, since it is the most visible and has the implicit objective of having vegetation either for decorative purposes or for food production. It is important to deepen at the regulatory level that there should be a clear difference between a landscaped area for decorative purposes and a UA area, since the landscaped area may present differences in terms of ecological, biological, and social benefits.

3) It is advisable to opt for regionally and culturally appropriate crops to facilitate their growth, adaptation to climate and irrigation and for a better use of the products. Ultimately, the general description provided in this document constitutes an excellent baseline for such a study.

Finally, building codes and regulations that directly affect vegetation cover in cities must be tightened, in order to maintain the regulatory permeable surfaces and curtail such huge impervious surfaces that cause serious environmental damage. Subsequently, new and varied strategies must be implemented, which have been addressed in other medium-sized Latin American cities and that support the sustainable practice of UA (López-Eccher *et al*., 2021; Nadal *et al*., 2019; Salvador *et al*., 2019).

5. Conclusions

This study pioneers the enquiry on the relation between urban agriculture, social housing, and the spread of impervious surfaces in Mexico and in LAC. An updated *in situ* overview of the different UA typologies in medium-sized Latin American cities is essential in the midst of a generalized tendency to expand the peripheries through the construction of social-housing neighborhoods. For this purpose, an empirical and mixed (qualitative, quantitative) analysis of 157 social housing units in two neighborhoods in Merida, Mexico: Las Magnolias and Ampliación Tixcacal-Opichén included 4 typologies of housing units as representative examples of Mexican social housing.

Responding to the concerns and objectives raised, our study yielded three key findings: The first one is regarding the development and modalities of UA. Despite the high number of impervious surfaces, UA is currently developed in social housing neighborhoods, albeit encapsulated within the limits of the lot or the dwelling. In the analyzed neighborhoods, 60% of the housing units practiced UA, with the traditional backyard vegetable garden and pot cultivation as the most popular modalities. We did not detect modern or high-tech systems of UA. The surveyed UA systems had low productivity, being personal and cultural motivations the driving forces for the development of UA.

The second finding is that the modifications of the housing units start from the exterior in three phases: establishment, subsequent modifications, and complete impermeabilization. Each phase has an impact on UA and limits the practice, magnitude, modality, and the personal and social motivations. UA practice tends to relate to limited economic income and little modified housing units. If the increase in impervious surfaces continues, the UA in traditional modalities may vanish; therefore, exploring modalities that adapt to impervious surfaces (roofs or walls) is time sensitive.

Finally, promoting and guaranteeing the conservation of urban green areas and within lot boundaries during the expansion or modification of social housing is urgent; it is during this process when there is a considerable increase in impervious surfaces limits the development of UA. Likewise, the development of a public policy that integrates UA and social housing is a priority at local and national level to avoid the loss of green, permeable, and agricultural production areas within neighborhoods and cities; this public policy should indicate a clear differentiation between a landscaped area for decorative purposes and a production area through UA. Some guidelines to be considered include the strengthening of existing home gardens, the exploration of green verticality, the promotion and inclusion of new actors, and the expansion of urban public spaces. Specifically, a minimum reserve of 4 m^2 per inhabitant of traditional vegetable garden per housing unit could provide space for a variety of regionally and culturally appropriate crops, adapted to the climate, irrigation possibilities, and local uses.

The results obtained have also broadened both our knowledge and understanding of the practice of UA within the city from the perspective of urban planning and architectural. Furthermore, they have highlighted the need to address social housing in Mexico and LAC as key points to achieve more sustainable and greener cities. Promoting UA as a tool to compensate for the green areas lost in the process of social housing expansion is a priority: Besides being critical to strengthen the region in the face of environmental challenges, UA would provide social benefits and an avenue to food security.

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