Chapter 11

Evolution and Dynamics of Fractal Growth of the Urban Green Spaces in Seville (Spain)

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Additional information is available at the end of the chapter

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Abstract

Like urban growth, the increase in the area of urban green spaces can be described using fractal design, a measure, of the dynamic evolution of public space of leisure and recreation of the citizens, associated with the growth form of the city. Throughout the history, the city of Seville has been a good example of sustainability and eco-design in spite of the enormous physical transformations carried out both in the city center and in the periphery. In essence, the evolutionary process of the city is both technical and social giving rise to a landscape that is transformed and remains. In this work, from the evolution of green area per inhabitant from 1842 to 2016, a prediction model capable of characterizing the changes of fractal dimension associated with the growth of Seville is proposed. This prediction model can be used to estimate the growth rate of the fractal dimension, and therefore to reveal the spatiotemporal process and pattern of Seville growth. Especially, the model lays a foundation for researching the correlation between urban form and urbanization and for developing the theory of spatial replacement dynamics.

Keywords: Seville, green areas, fractal growth, eco-design, sustainability

1. Introduction

Environmental sustainability, defined as the set of policies and processes aimed at maintaining an adequate level of development that does not jeopardize existing natural resources, is a complex concept, since it depends on the criterion chosen to determine when a certain level of development does not jeopardize the survival of existing resources in a geographical space [1]. In this regard, and considering the scope of the city, it may be interesting to highlight the dual relationship between the functioning of the city and the sustainability of the city ecosystem, due to the great diversity of areas (industrial, residential, commercial, recreational, etc.) that coexist.

From the point of view of eco-design, and according to [2], this dual relationship reveals the use of certain amounts of environmental resources, which must be transferred through a series of eco-efficient strategies implemented in the initial phase of the urban development project.

According to [3], the relative growth of urban population in the city of Seville has been 11.75% between 2002 and 2012, which has led to a continuous transformation of the traditional agricultural landscape in order to create new urbanized zones. This constant growth has led to the exhaustion of the agricultural resources supplied to the rural areas that have been absorbed by the urban fabric, resulting in an incessant migration from rural to urban as a result of the rapid and consequent economic growth that existed from 1970 to 2007 [2]. This, which can be seen as an advantage from the point of view of growth and development of the Andalusian capital, can become one of the main obstacles to maintaining the current sustainable and eco-efficient urban development (SEUD) in Seville. The existing migratory balance in the city of Seville should not be forgotten, which although low, 2.69% between 1981 and 2011 [2], is important in the total count as a result of the fact that from 2012 the migratory balance is negative up to and including, 2016 [4]. In this regard, [5] specifies that policies aimed at improving the problems of mobility, sustainable development, quality of life, urban competitiveness and strategic marketing constitute a new frame of reference.

Several studies have analyzed the urban expansion of the city of Seville. According to [2], from the formal point of view, the growth of Seville has an irregular and radio-centric form, which counteracts the eastward development trend of the city and turns the basin of the former Guadalquivir river into the backbone of its plane, from where the best urban landscape perspectives are offered, both in its historical areas, as well as in those most related to the port or to the northern part of the metropolis. On the other hand, [6] specifies that the growth of the city is influenced by the development of the social differentiation of Seville in both the Southwest-Northeast direction as in East-West direction, occurring outside these two directions the emergence of a series of islands scattered throughout the territory, with its own social character independent of contiguous urban sectors and that has its origin in the local and particular dynamics that give rise to its development and colonization.

Then again, and based on the study carried out by [7], the city of Seville is transforming part of the typical pattern of Mediterranean city, based on compactness and drastic countryside-city separation, for a more decentralized one. Initially, the confirmation of the metropolitan model at Seville city resulted in the materialization of suburban cities, around the central city, with a high index of building density, which housed a significant part of the industry. At the same time, most of the tertiary functions remained in the central area. This imbalanced model demanded a significant mobility of the population, due to the necessity of the center-periphery displacements for reasons of work and of satisfaction of great part of the personal services.

Currently, the new model of activity dispersion across the Sevillian territory has generated increasingly complex urban structures that require the articulation of more and more disconnected and fragmented spaces. The decentralization of equipment and companies (universities, technological, and business parks, etc.), although tending to compensate for the deficits in

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the periphery, predominant in the previous model, increases the demand for mobility, which has meant the need to build an extensive network of roads and urban highways throughout the territory, to which must be added the construction and expansion of the Seville metro.

On the other hand, and as is well known, the process of occupying urban spaces, associated both the spatial and temporal dynamics of city morphology, has given rise to a progressive adaptation of design rules by local governments in order to adjust to the needs of use and enjoyment of citizens [8].

Then again, and according to [9], the process of urban growth, as well as that of its associated green surface, is related to the shape of the city, ecology and urban system, variables that have to be taken into account when choosing the model to be used to predict the fractal dimension of green areas over time. In this sense, one of the models most used to date is the logistic model [8].

Although the analysis of land use changes (LUC) as well as the assessment of urban sustainability in the city of Seville has been treated to a greater or lesser extent, less attention has been paid to the study of the growth of urban green spaces (GUGS). In fact, hitherto, there is no work that focuses on the city of Seville. For this reason, in the present chapter, the main objective will be to use, jointly, statistical and urban data to obtain the aforementioned relation (LUC vs. GUGS) and, explain the reason that causes the city of Seville has an evolution and dynamics of its green spaces that resemble a logistic model.

2. Study area

The city of Seville, throughout its history, has undergone a continuous transformation, which has allowed it to adapt in a systematic way to the evolution of the times but always maintaining the base of the pre-existing city (**Figure 1**).

After the conquest of Seville by the troops of King Fernando III in the mid-thirteenth century, the scheme of Muslim city is maintained with narrow streets and domestic architecture overturned inland. The density of the buildings decreased as we moved away from the oldest area, with huge gaps mostly occupied by orchards. This structure will be maintained for several centuries as a result of the fact that the new settlers were inferior in number to those expelled [9].

In the sixteenth century, another great transformation of the city took place with new ideas about the monumentality of the buildings, their perspectives, widening and straightening of the streets, as well as the incorporation of squares destined to the development of economic, political and social life. According to [2], the strong population growth, in this century, had the consequence of silting the urban perimeter up.

As a result of various calamities (earthquakes, epidemics, and floods), there was a notable population decline in the middle of the seventieth century, which led to the transformation of many places destined to housings and plots in vacant spaces and orchards, especially in popular neighborhoods to the North of the city. There was no change in the external appearance

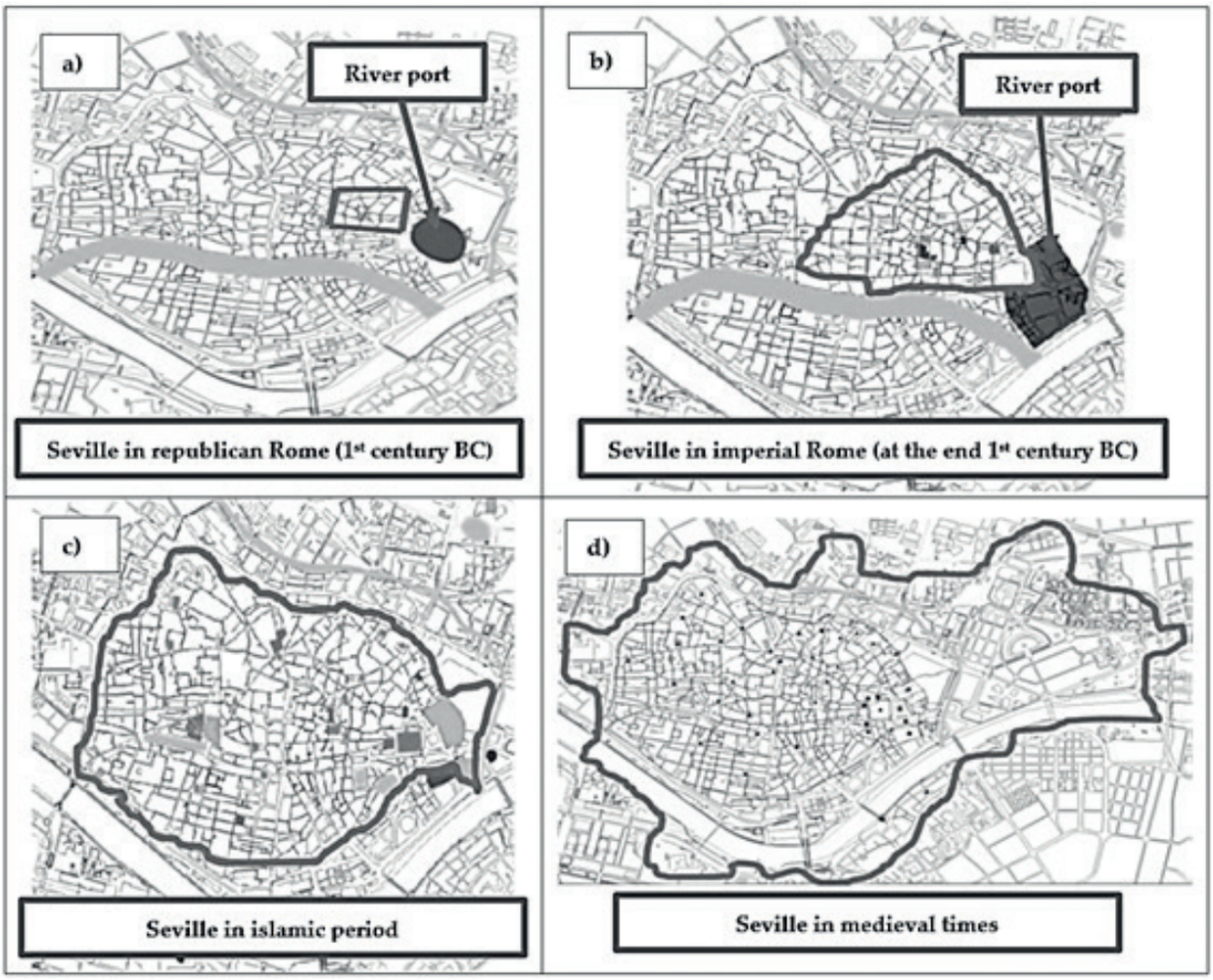

Figure 1. Evolution of Seville throughout history.

of the city. In fact, in the eighteenth century the existence of the urban plot of the seventieth century gave rise to a congestion of that one, making the transit through the metropolis very difficult.

The first third of the nineteenth century was very important for Seville to raise the quality of life of citizens were made urban reforms aimed at the beautification of the city, such as improvements of promenades and gardens, reforms of La Alameda de Hércules, the Cristina Gardens or the Las Delicias Gardens. This was followed by the economic growth of the city as a result of the promotion of the port and the establishment of the railroad, which led to an expansion of the city in a diffuse way with the demolition of walls, mainly due to the existence of a global urban project that allowed the connection between the different independent plots that were formed.

During the first third of the twentieth century, there are few reforms of the urban center that were taking place as a consequence of the Universal Exposition of 1929 was being developed, which meant an expansion of the city Southward. On the other hand, Eastward an expansion

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takes place through the roads that arrived at the city, which went across to empty zones (plots) for arriving at the neighborhood of Nervión, being this the first transformation of rustic land in urban of true importance in area (for this reason in 1940 there was a substantial increase in the urban green area per inhabitant (**Figure 2**)). Then again, in the North, several nuclei had begun to appear, lacking the minimum urban services (El Fontanal, La Corza, etc.), which gradually became part of the city.

From 1960, there was a decline of the historic center derived from the appearance of new neighborhoods, such as Los Remedios, which caused the displacement of the more well-off classes to these new areas; the real state pressure suffered by the historic center as a result of the disappearance of historic buildings; and the expulsion of the poorer classes to the periphery.

Later, with the preservation policy of the historic center, which has been maintained during the last years, as well as with the 1992 Universal Exposition [2, 10], a requalification of urban endowments were achieved that reached the eastern part of the city, as well as a considerable improvement in urban and interurban communications both by road and rail, offering a neo-city vision, totally adapted to the possible changes that may arise in the future, that offers the visitor an endless number of displacement possibilities, shopping centers, green areas, leisure places, monuments, etc. Currently, and due to the construction of new communication infrastructures (bike lane and metro), as well as the architecture sustainable management in the urban fabric of Seville, the city is combined in a complex framework of overlapping, giving rise to an urban landscape that adapts to the socio-economic moments prevailing in each era, and that remains throughout time.

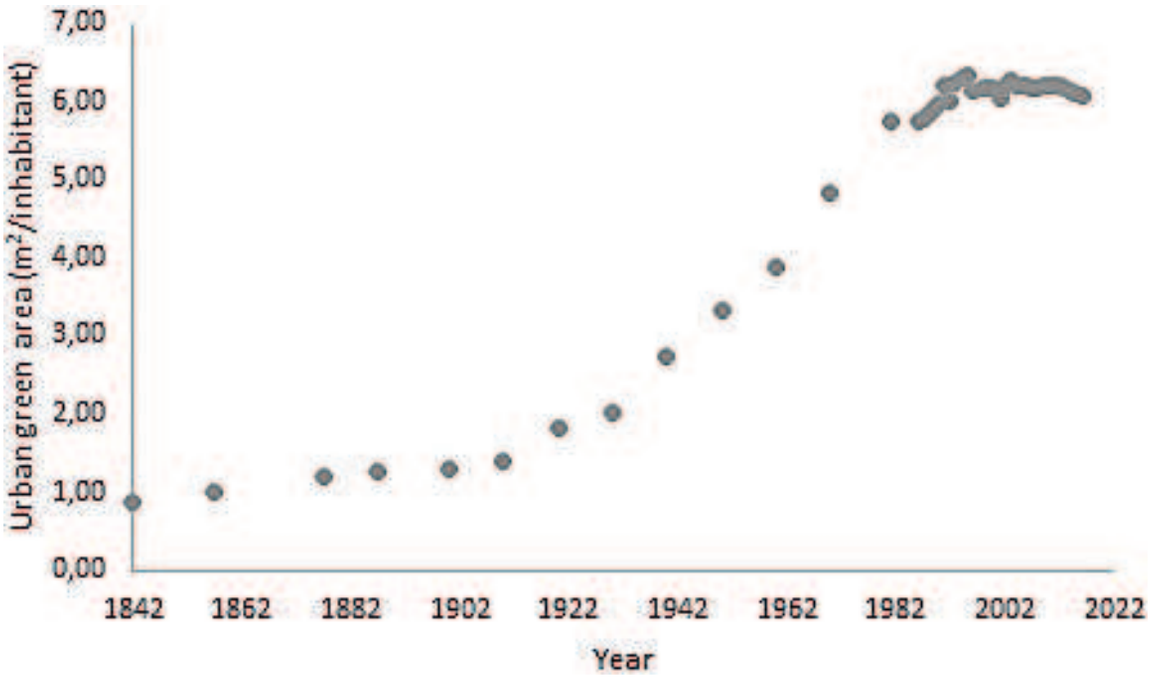

Figure 2. Evolution of urban green area of Seville from 1842 to 2016.

3. Fractals and logistic model

As is well known, fractal designs preserve many aspects of natural landscapes by ensuring that the spatial scaling of the landscape is built [11]. In this sense is interesting to specify that Euclidean geometry, trigonometry and calculus are the tools that are generally used to model natural phenomena. In a broad sense, models are described in terms of points, straight lines, circles, parabolas and other simple curves. Thus, points of zero dimension, one-dimensional lines and curves, two-dimensional plane figures such as the square and the circle, and three-dimensional bodies such as cubes and spheres make us see the world as we understand it up to now. However, some phenomena, such as the growth dynamics of urban green areas, are best described by a dimension whose value is not precisely a whole number (0, 1, 2, …), in other words, it does not correspond to a Euclidean dimension. This value (1.1, 1.12, …, 1.35, …, 2), then, corresponds to a fractal dimension.

According to [8], the function of a measurement or parameter rest with a comparison of values (including year-to-year comparison and one-to-one comparison). Therefore, by comparison of fractal dimension values of different urban green areas in different years, we can reveal the spatiotemporal information about green areas evolution from a city as a system. In this way, evolution and growth of green areas can be associated with spatial dynamics of city morphology.

On the other hand, it is known that the measure of a system has both an upper limit and a lower one, so that the growth of the measure (urban green area) will have an S-shape, called sigmoid function, as long as the speed of growth of the system is not uniform.

Currently, in whatever city around the world has a level of green spaces ranging from 0 to 1 (or 0–100%). As a consequence of the fact that growth of green areas is based on two-dimensional maps, the upper limit of fractal dimension will be 2 ($D_{max} = 2$) while the lower limit will have a value equal to 0 ($D_{min} = 0$).

As a result, and using the logistic model, the sigmoidal growth of urban green areas can be described, according to [12], by Eq. (1):

$$D(t) = \frac{D_{max}}{1 + A \cdot e^{-k \cdot t}} \tag{1}$$

In Eq. (1), the time "t" is the difference between the year in which we want to obtain the fractal dimension and the initial year of the time series, "D(t)" is the fractal dimension at the "t" moment, "A" is the quotient given by Eq. (2), "D_0" is the fractal dimension corresponding to the initial year of the series (1842 in this case), and "k" is nothing other than the original growth level of the fractal dimension of the series corresponding to the variable analyzed.

$$A = \frac{D_{max}}{D_0} - 1 \tag{2}$$

4. The case of Seville

In this work, an exhaustive bibliographic search was carried out in order to find a time series, broad and significant enough, to be able to infer the fractal dimension of the green areas corresponding

to the city of Seville (**Table 1**), based on the existing relationship between the surface of the large parks and gardens of the Sevillian city and, the total area corresponding to all the green areas of the city up to the end of 2016 [13]. In this sense, and due to this surface is related to the number of inhabitants of the municipality of Seville, the information provided by [2, 14, 15] was very useful.

The growth trend of fractal dimension values, from 1842 to 2016, was modeled by the logistic function (Eq. (1)), and the logistic pattern of this variable is presented in **Figure 3**.

The logistic patterns of fractal dimension growth of green areas of Seville, for the period 1842–2016, is presented in **Figure 3**, and the logistic model obtained is shown in Eq. (3).

$$D(t) = \frac{0.9654}{1 + 0.0482 \cdot e^{-0.0156 \cdot t}} \tag{3}$$

The goodness of fit is about $R^2 = 0.9378$.

Year	Dimension	Year	Dimension
1842	0.921	1995	0.9653
1857	0.9283	1996	0.9652
1877	0.9355	1998	0.9651
1887	0.9340	1999	0.9649
1900	0.9268	2000	0.9648
1910	0.9226	2001	0.9646
1920	0.9379	2002	0.9645
1930	0.9432	2003	0.9644
1940	0.9535	2004	0.9642
1950	0.9585	2005	0.9641
1960	0.9612	2006	0.9639
1970	0.9634	2007	0.9638
1981	0.9648	2008	0.9636
1986	0.9650	2009	0.9635
1987	0.9651	2010	0.9633
1988	0.9652	2011	0.9631
1989	0.9653	2012	0.9630
1990	0.9653	2013	0.9628
1991	0.9654	2014	0.9626
1992	0.9653	2015	0.9625
1993	0.9653	2016	0.9623
1994	0.9653		

Table 1. The fractal dimensions growth of urban green areas of Seville metropolis (1842–2016).

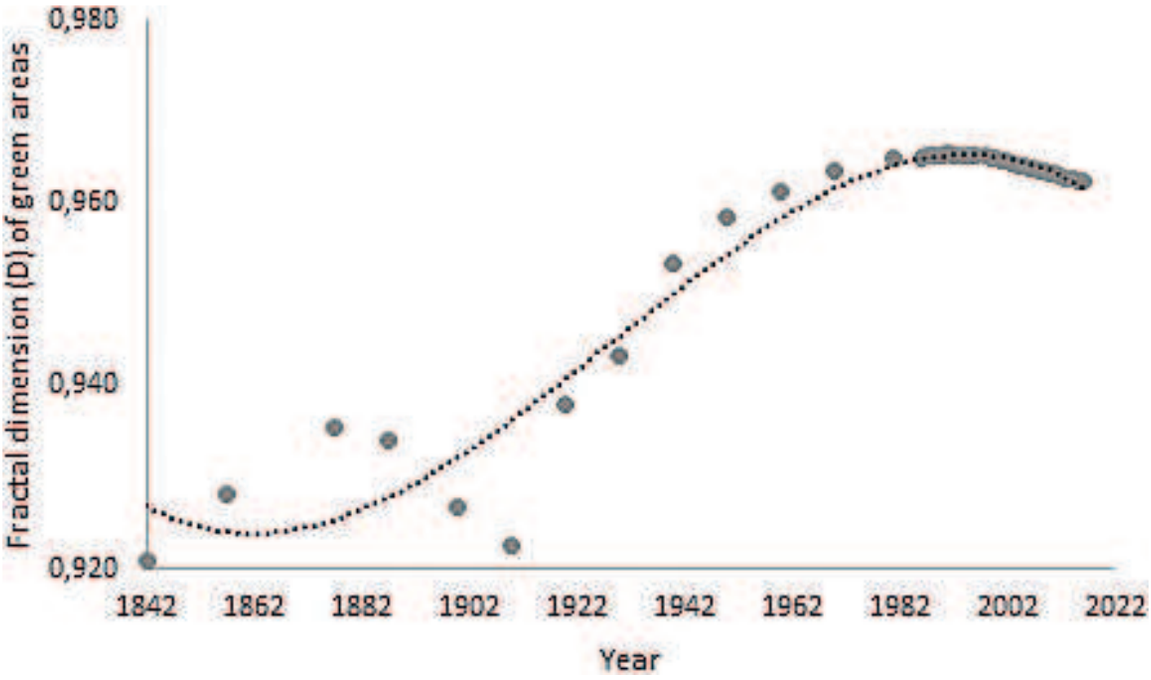

Figure 3. Logistic patterns of fractal dimension growth of green areas of Seville (1842–2016).

The results can stimulate new thinking on when and where an urban green area fractal is.

In urban green areas of Seville, the estimated value of the capacity parameter "D_{max}" is less than the Euclidian dimension of the embedding space and, therefore, is acceptable. Besides, the goodness of fit for urban green areas of Seville seems to suggest a proper fractal dimension estimation, so that can be inferred that the size of the study area has been adequate. In this sense, it is important to specify that in this study was defined a fixed study area whose advantage is that the fractal dimension values are more compatible for year-to-year comparison. However, and according to [12], for a fixed study area, the fractal dimension values of initial stages can be underestimated, while the dimension values of terminal stages can be overrated.

According to **Figure 3**, it can be seen that the maximum speed of fractal dimension growth appeared in 1930 when the city size is about 230,000 [2.01 m^2 of urban green area per inhabitant (**Figure 2**)]. This is very important due to do not differ from the speed of population growth.

On the other hand, special attention must be paid to 1995, since it is when both a greater green area per inhabitant is reached (6.34 m^2/inhabitant) as well as the greater number of inhabitants of the city (about 720,000). Otherwise, the greatest value of the fractal dimension, D_{max} = 0.9654, is observed in 1991 (6.21 m^2/inhabitant and about 705,000 people) as a consequence of that all the green infrastructure corresponding to the 1992 Universal Exposition was about to be finished. This suggests that when the population size reached about 705,000, both more buildings as more urban green spaces appeared in Seville so that the urban LUC became more intensive than ever.

In general, these LUC, and according to [2], can be observed using remote sensing images, as a consequence of industrialization processes (**Figure 4**).

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In relation to the growth of the urban green area, it should be borne in mind that, in social terms, the annex and diffuse urban growth would imply greater social segmentation, as well as an upward trend in housing prices, which would make more difficult the accessibility to housing. As a result, Seville can be defined, to date, as a compact city where the incorporation of the environmental variable in new urban design and development projects is facilitated, being, therefore, eco-design a key element in urban policies of the Sevillian city since the beginning of 1990.

Hitherto, in Seville, squares, gardens, parks (**Table 2**) or urban forest play a fundamental role in the environmental and biodiversity of the city, as well as being spaces for strolling, relaxing or leisure. At spatial planning level, they are part of its structure and symbolize a balanced and eco-designed city environment, where the building is cushioned by natural spaces.

As is known, the development of non-Euclidean geometry has given rise to the construction of an endless of new models based on fractal dimension.

Actually, logistic models of fractal dimension growth can be used to explain the process of urban green spaces evolution and predict the results of city development where green areas fractals are concerned. In this sense, logistic parameters can be used as an assistant criterion,

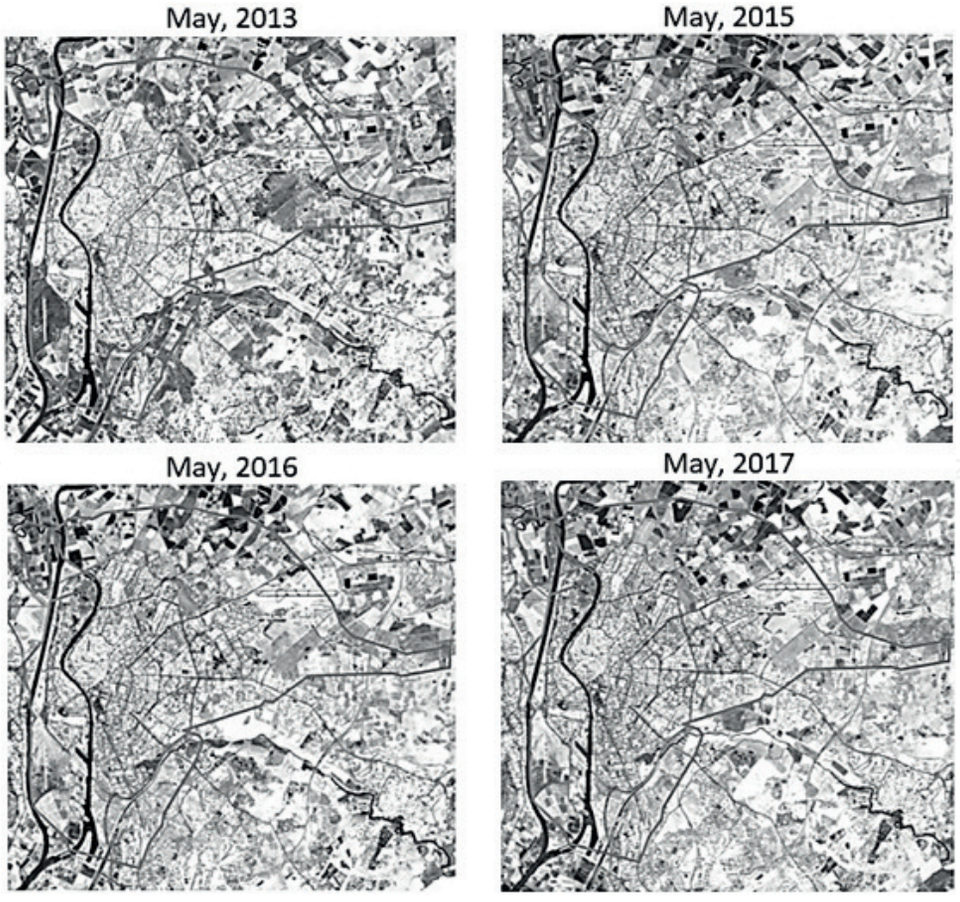

Figure 4. Landsat 8 LC satellite images showing the false color bands combination (764) to see urban areas in mid-May in recent years in Seville.

Name	Dated as a public park in	Area (m^2)
Parque Guadaira	2014	24,000
Parque Vega de Triana	2012	180,000
Parque de Los Bermejales	2010	135,000
Jardines de La Buhaira	1999	350,000
Parque Infanta Elena	1998	35,000
Parque José Celestino Mutis	1997	45,000
Jardines Prado San Sebastián	1997	58,384
Jardines Torre Los Perdigones	1997	20,294
Parque del Alamillo	1992	480,000
Parque de San Jerónimo	1992	148,677
Jardín Americano	1992	140,000
Parque Amate	1987	316,800
Parque Miraflores	1987	940,000
Jardines Federico García Lorca	1987	9240
Parque de Los Príncipes	1973	108,000
Jardines de Chapina	1969	39,760
Jardines de Villa Luisa	1925	5700
Jardines de Catalina de Ribera	1898	18,250
Parque de María Luisa	1893	340,000
Jardines del Valle	1866	10,554
Jardines de Murillo	1862	8500
Jardines de Cristina	1830	8100
Jardines de Las Delicias	1829	54,250
Jardines del Real Alcázar	1500	60,000

Table 2. Area of the main parks and gardens of Seville.

that is to say, if "$D_{max} > 2$," can be inferred that the study area is too small, and it will be necessary to define a larger study region in order to find a proper urban green area fractal spectrum over time. Moreover, if the lower limit value of a fractal dimension, "$D_{min,}$" can be obtained appropriately, it will be possible to make a space-time diffusion analysis for the urban green areas of the city.

On the other hand, urban green spaces evolution is associated with urbanization processes [2, 12]. According to [2, 5, 8], the intra-urban green areas growth process reflects the flow of interurban population to the city. In Seville, this process took place from the beginning of the 1980s until the mid-1990s, leading to a radio-centric growth of the metropolis and

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those satellite municipalities (Montequinto, Dos Hermanas, Alcalá de Guadaira, and Camas among others), besides its associated green areas, which are located a few kilometers from the Andalusian Capital.

5. Conclusions

The city of Seville has an average annual temperature about 19°C, that along with its average precipitation of 533 mm, concentrated between the months of October and April, as well as its nearly 2900 hours of sunshine per year, make it one of the main places of tourist visit around the world, not only for its climatic conditions, but also for its great monumental offer, urban green areas and restaurants among others.

In addition to the advantages offered by the parks and gardens of the city, the urban transport network allows tourists to move at low prices to the monumental areas or to the historic center. It cannot be forgotten that in the historic center of Seville there is an island of heat, although the pre-existence of narrow streets and high-rise buildings, give rise to a temperature decrease of a couple of degrees, enough to allow tourism on hot days.

The growth dynamics of the urban green areas of the metropolis has been a reflection of the diffuse growth of the city, giving rise to a series of disconnected areas with the central urban nucleus that little by little have been incorporated by the city, making possible the increase of demand for mobility and the appearance of new transport infrastructures, which has allowed Seville to be increasingly sustainable and eco-efficient.

On the other hand, the fractal dimension growth of urban green areas of Seville can be described with logistic models [16–20]. Besides, the uses and significance of the logistic models of fractal dimension, for spatial analysis of urban green spaces growth, can be specified in five main points:

a. Logistic models can be used to estimate the past missing fractal dimension values and predict the future unknown fractal dimension.

b. These models can be used to estimate the peak value of the fractal dimension growth rate.

c. The models can be applied to analyze where an urban green space fractal is.

d. Logistic models make a possible new approach to researching urbanization processes throughout the green areas dynamic of the city.

e. Finally, by means of the models, can be researched the spatial replacement dynamics of urban green areas.

For everything specified, and according to [21], for an adequate SEUD in Seville it would be necessary to take into account, increasingly, the importance of urban industrial polygons, as well as the design of their associated green areas, since their correct integration in the urban fabric of the city can lead to the plausible use of more open spaces, in addition to other facilities and infrastructure oriented to the community.

In relation to this, the application of the prevailing theories about the city of the twenty-first century and the processes of social agreement, which help the configuration of an urban scenario with new rules of use and design of urban green spaces, are the points to take into account in order to achieve the consideration of urban green landscape as a legal argument for local development, eco-design, social welfare, and the improvement of the quality of life of citizens within the framework of sustainability criteria [22].

Finally, it very important to emphasize the fact that green areas urbanization tends to generate fractal structures should, of course, incite reflecting about the underlying socio-economic processes.

Multi-scale concepts may also be of interest on the micro-scale of town sections (parks and gardens). Instead of rounding up the boundaries, fractal-like outlines of residential areas may be imagined: the consequent lengthening of the outline lets more house-owners benefit of the situation (urban green spaces enjoyment) on the edge of the settlement which seems to be rather appreciated.

When interpreting the results it becomes obvious that a fractal approach to urban green areas patterns helps us to make evident that green spaces patterns follow a particular type of spatial organization, despite their irregular aspect. According to [20], besides the purely descriptive approach, fractal modeling allows illustrating important features of these patterns and seems to provide a new approach for managing the consequences of the new lifestyle, which tends to claim good access to different kinds of both urban and rural amenities, and at the same time helps to reduce the risks of a diffuse sprawl which tends to weaken the environmental quality and to generate increasingly traffic flows.

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