# Case study: Green Roof Garden Concept for Smart Cities

**Abstract**

The new alternatives for construction designs seek to offer more sustainable alternatives through proposals, where the environment is integrated to generate comfort and well-being. The most innovative proposals in the construction are where the options of roof garden are integrated, as a new way of being sustainable in the buildings. This research uses the proposals of the roof garden and the application of the Cultural Algorithm for the analysis and the generation of experiments for validation. The results allow to determine the best proposal in a group, the designs generate similar groups of behavior and common characteristics. Finally, it is able to offer various proposals of buildings with roof garden as final results.

## 1. Introduction

The concept of sustainable development is established in a balanced relationship between economy, society and the environment. In April 1987, the Commission published and released its report, entitled “Our common future”, in which the concept of sustainable development is defined to give committed to meets the needs of the present without compromising the ability of future generations to meet their own needs." (Brundtland, 1987). In order to present advances towards sustainability there should be applied more efficient operational forms, where science and technology (S&T) become the key elements in order to have better results.

The changes generated to improve the results towards sustainability, caused modifications, knowledge wise, in all most every discipline, do to this science and technology allowed to approach more complex problems generating innovating solutions.

In this regard in the year 2002, The Economic Commission for Latin America (ECLA), raised the new challenges to the S&T, which indicated the generation of new analytical approaches, as results of the multidisciplinary becoming the main source of activities and priorities that serve as the basis of current S&T systems, worldwide (Gallopín et al. 2003).

Sustainability is a topic that directly influences the design, construction, technology and operation processes of any entity i.e. building, urban block, neighborhoods, networks, centers, cities, regions of the countries (Hernandez Moreno 2008). The influence is based on most of the types of materials, spaces in which it is built, the designs and distribution of the spaces, materials, equipment, attachments, and the application of S&T to generate better comfort.

Adhya, Plowright and Stevens in 2010 mentioned that in the urban areas growth is not uniform in many situations. But the growth is occurring in certain areas of the big cities. In addition, these authors state that although there is enormous cities growth but still there are disarticulation, deterioration, and devaluation of the inner core cities. As such these big cities present a scenario that provoke opportunities for improvements.

The problems of the growth of the cities were addressed by the different organizations i.e. Faculties of Architecture, Urban Planning, and Engineering, seeking to find new positions related to the topic of the population growth, pollution and environment. In order to solve these problems new opportunities should be explored.

## 2. Roof Gardens

The new proposals in the areas of Architecture and Engineering through the various projects of construction and redesign, is onboard the theme of re-use of roofs as a way to use new energy alternating to achieve the spare spaces. In this theme, Germain, Grégoire, Hautecoeur, Ayalon and Bergeron in 2008 defined a new guide to help others and designed the roof garden. The document specifies that in increasingly dense and extensive cities, it is necessary to look for new ways to take advantage of the spaces, as well as the way to recover those that are not used or underutilized, as well as those that by their nature are sterile. These last, are considered spaces that had not been given any usefulness, such as: roofs, patios and balconies. Besides, they are the most used to make transformations to make habitable spaces, with more comfort, through the exuberant, productive and purifying proposals. Roof gardening means taking an inspiring, ecological and productive activity, and developing new links with the food chain, the seasons, the environment and the community. The vision of their ideal locations is to turn the city into a garden and its inhabitants in gardeners.

New designs in urban and urban development face many issues related to the socio cultural, economic, environmental and technological elements and all of these must be combined to determine the best option to solve the issues related to design and the implementation of various garden model on the roof. Sustainable urban development is a concept that is applied in the visions of the smart city (economic, social, physical and environmental, including a smart roof garden), framed in S&T strategies that guarantee improvements the populations welfare. The main aim in the smart cities is to improve long-term welfare level, without compromising the development possibilities of the surrounding areas and helping to reduce the harmful effects of environment.

The constant growth of cities has caused a social-spatial segregation, to which designers, urban engineers and architects have contributed in the resolution of this phenomenon. Population has increased in both urban and rural areas, but urban growth lacks in sustainable strategies to be more environmentally friendly spaces, however, strategies have not been able to guarantee these attributes.

Due to inefficiencies in urban development strategies, there is a need to seek the integration of sustainability principles in the development of new growth zones such as: neighborhoods, economic zones, commercial plazas and public areas. Integrating the environment in new design proposal is the fundamental principle to reduce the inefficiency.

The constructions whether of the type of housing, areas, departments, business, institutional buildings, among others, must consider the climatic, cultural, social and economic variables of the environment where they are located. Furthermore, these constructions must be compliant with local, national and international regulations.

Also, according to national and international policies it should be taken into consideration the provision of materials, equipment, labor, technological innovations, use of alternative energies in order to create the welfare, and satisfaction of clients.

Based on the problems in the relationship between city, urbanism and sustainable development, this research is established in order to articulate sustainability elements through new technological proposals that allow better decisions in intelligence system in the roof garden.

## 3. Cultural Algorithms (CA)

Striphas (2015) indicated that algorithm comes from various languages also The Oxford dictionary (2019) points out the influence of many other languages. These definitions indicate the most common meaning of a formal process or procedures, often expressed in arithmetic forms. Additionally, it was designed as a result of long series of transformations before providing a result.

The development of CA can be attributed to Reynolds (1994) when he first developed an evolutionary algorithm, which is established on the basis that knowledge is not a technique integrated a priori, but that it is extracted during the same search process, which are known to this day as cultural algorithms.

Decision making depends on the inherited culture, as well as the beliefs of the current population. Its origins are established in the applications of sociologists and archaeologists when it is necessary to try to model the cultural evolution. There are several ways to apply the CA, Slaver (2017) researched cultural algorithms and defined tactics for the ethnography of algorithmic systems, likewise, Dourish (2016), established the algorithms in context to algorithmic culture. Yang, Wu, Zhang, Chen, Lou and Li (2012) created an efficient function 0ptimization algorithm based on culture evolution, and many others. All of them offering different perspectives of application of the algorithm that allows access to the different ways of learning and improvement in decision making and learning using technology.

Reynolds in 1994 mentioned the phenomenon of inheritance in cultural algorithms, with the aim of increasing the rate of learning or convergence, and in this way, the system is capable of responding to a large number of problems, through the components established in Figure 1.

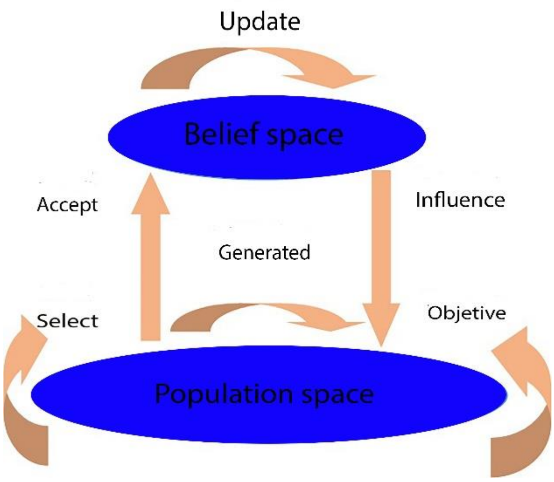


Figure 1. Spaces employed by the Cultural Algorithm, (based on Reynolds, 1994)

The figure 1, demonstrate the interaction between the space of belief and the population space where the relationship is bidirectional. The population space works in a similar way to that of an evolutionary algorithm, the population space consists of a set of individual's data where each has an independent feature used to determine their suitability (fitness). The interaction between the two spaces makes the cultural algorithm increases the complexity in the development and computation of the evolutionary algorithm.

A code description of the Cultural Algorithms is described by Yan et al. in 2012, as follow:

a. BEGIN

b. t=0

c. Initialize population P(t)

d. Initialize belief space B(t)

e. Repeat

f. Evaluate P(t)

g. Update (B(t), accept P(t))

h. Generate (P(t), influence B(t))

i. Select P(t) from P(t-1)

j. t+=1;

k. Until (termination condition)

l. END

## 4. ~~Analysis of Customer Behavior of installation related with an Urbanization in a great city~~ Relationship of variables in the construction of green gardens

The urbanization developed in a city applying the roof garden concept generates the construction of a structural equation based on the relationship of the variables and their incidences. To achieve this goal, the next structural equation 1 is considered, based on the data generated in the Table 1, in which is the value related to the viability of a specific roof garden and define with different aspects with the potential features of this.

$$V = \left\{\frac{CRG}{IRG} - \left(\frac{\#S * SRG}{PLA} RA\right)\right\} \pm SCA \qquad \text{(eq. 1)}$$

where

CRG = Cost of Roof Garden

IRG = Increase Roof Garden in the time

#S = Number of species in the Roof Garden

SRG = Size of Roof Garden

PLA = People accessing to Roof Garden

RA = Recreational Areas in Roof Garden

SCA = Social Cultural Aspects related to the location of the Roof Garden (Space to parking, access to smart farming, security and others).

Table 1. Multivariable analysis with the information related with each Roof Garden and its components

| **Model of Roof Garden** | **Roof Garden Increase Index** | **Commercialization** | **Services** | **Recreation and smart farming areas** | **Social Cost-Benefit in a Smart City** | **Equipment in the Roof Garden** |
|---|---|---|---|---|---|---|
| Barbados | 8 | 0.814 | 0.765 | 0.863 | 0.799 | 0.678 |
| Crimea | 14 | 0.795 | 0.811 | 0.835 | 0.847 | 0.715 |
| Djibouti | 5 | 0.747 | 0.838 | 0.842 | 0.817 | 0.818 |
| Macao | 8 | 0.816 | 0.794 | 0.803 | 0.858 | 0.902 |
| Pitcairn | 9 | 0.947 | 0.836 | 0.828 | 0.807 | 0.794 |
| Tahití | 12 | 0.877 | 0.819 | 0.842 | 0.805 | 0.816 |
| Tuvalu | 7 | 0.954 | 0.797 | 0.783 | 0.912 | 0.828 |

## 5. Methodology

The study is defined exploratory and descriptive research through a quantitative data analysis. The space was in the city of Queretaro, Mexico. For the study multiple matching method is used and a series of evaluations with different combinations of Roof Gardens (seven in total) is done. The study required a total of 50 runs of data using different scenarios and adding a variety of factors for its final result. Also, the study was generated a data base through the run of test.

The analysis of the Roof Garden needs to comply with the following indications:

a. Favorite will be given to those with more similarity

b. Classification and ranking of the results is generated to group of similarities result

c. All proposals are required to undergo the evaluations

The specifications for the economic evaluation phase are specified by the following requirements: the preferences will be given to those results with greater similarity, later these aspects will be selected to compete the final results. The most important specification is that each Roof Garden must be participate in the seven tests. All the Roof Gardens projects must be ranked using the result evaluation. According to the results after the tests end, then a final multiple matching evaluation is completed.

The hybrid CA is established by the following indications:

a. The rights are established for customers to evaluate according to the needs of the organization.
b. A comparison list of the results of the test will be generated before a new cycle begins.
c. Each evaluation will have all the Roof Gardens scheduled in a group of seventeen test.
d. The hybrid algorithm will be programmed to set the time for comparison of different similarities using a complete multiple match analysis based on the marketing assigned to s Roof Garden.
e. The Roof gardens are qualified for selection based on a model, which allows to choose by means of an established base that gives priority to the most indicated.
f. The organization for each Roof Garden need to matches for each round in the algorithm.
g. Roof Gardens must indicate their participation for their evaluation in each of the series. In case one of these Roof Garden refuses to participate in the series, the algorithm can nominate a Roof Garden to be established as a replacement and this Roof Garden should be ranked among the best Roof Gardens in the concentrate list.
h. On the basis of an average calculation of two decimals, the qualification list in the series of comparisons, before starting a new cycle, three qualifiers will be selected (excluding the seven Roof Gardens that will be compared in the matches).
i. In case Roof Gardens has the same average rating, the number of similarities

established for the match will be used to determine its classification.

j. To ensure active participation in the future, a minimum of twenty-five executions are recommended for the four ranking lists included and before the main classification list.

k. When a Roof Garden does not agree to play in a multiple combination series, then the selection process uses the average rating plus the number of runs played during the qualification period.

l. The algorithm repeats this process until reaching the required qualifiers of the series and the location of multiple coincidences for each roof garden and the real possibility of installation.

### ***5.1 Mathematical analysis by the loads exerted by the construction elements on the roof***

By means of the analysis of variables the first equation that allows calculating the total weight that will have, the roof garden, is presented, later presents a second equation whose improvement is a function of the accumulated precipitation for each cubic meter, where the units of kg / m$^2$ and that finally the expected result is expressed in kilograms (Guo et al. 2017).

$$Z = \frac{M * C}{D} \qquad \text{(Eq. 2)}$$

$$Z = \frac{M * C}{D} + \Delta ɣs \qquad \text{(Eq. 3)}$$

Where:

M= Reinforced concrete slab

C = Live load analysis Wp

D = Specific weights of organic layer

ɣs = Difference of specific weights.

Z= Total weight Roof garden

### *5.2 Experiments*

With a simulation of people, the result is presented in table 2.

Table 2. Value relation Z (in Kg)

| Minimum Z Values | Maximum Z Values |
|---|---|
| 401.9874 | 871.9874 |
| 896.1584 | 1366.1584 |
| 1467.3032 | 1937.3032 |
| 2115.4216 | 2585.4216 |
| 2840.5137 | 3310.5137 |
| 3642.5795 | 4112.5795 |
| 4521.6189 | 4991.6189 |
| 5477.6321 | 5947.6321 |
| 6510.6189 | 6980.6189 |
| 7651.1842 | 8121.1842 |

The above data refer to the possible results that the roof can have, for safety reasons the maximum Z values expressed in kilograms are taken whose last combination n exceeds 8 tons, Figure 2.

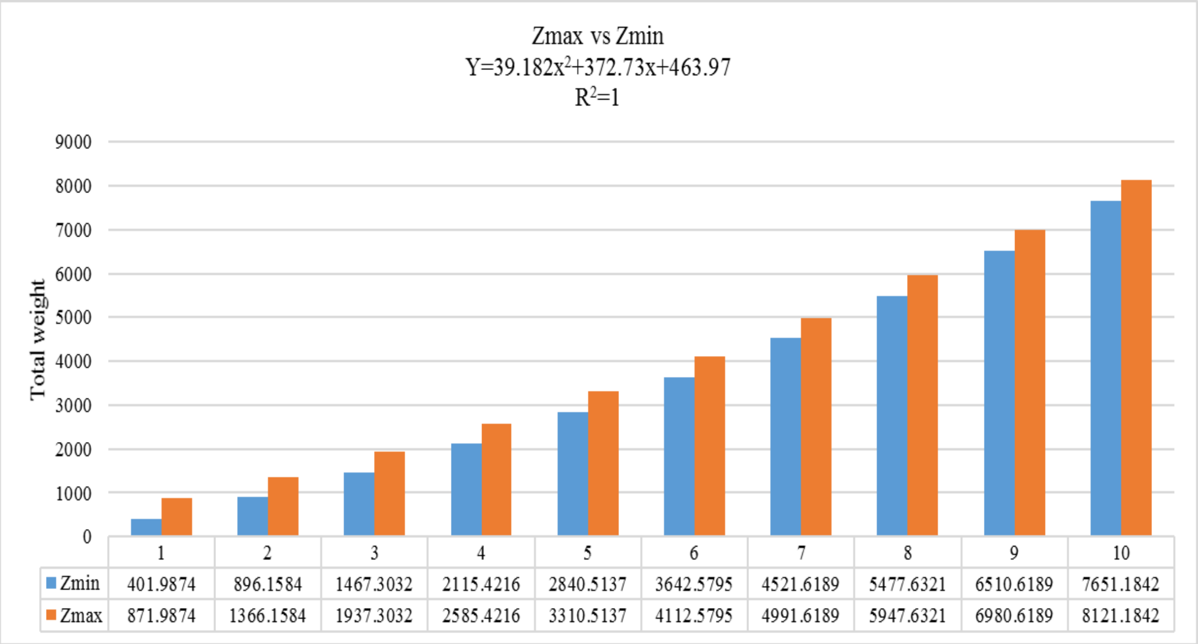


Figure 2. Minimum and maximum weight (w) comparison

The results of the $Z_{min}$ values correspond to eq. 1, which contemplates the specific weight of the dry organic layer (ɣ). Consequently, the values of $Z_{max}$ correspond to the equation and the specific weight of the humid organic layer is taken into account, whose equation expresses the addition of the difference of the specific dry and wet weights. The resulting equation $39.182x^2 + 372.73x + 463.97$ is a function whose result represents the total load, that can be on the top of the building contemplating the roof slab (WD), the average weight of people (WP), and the specific wet weight of the organic layer, Table 3.

Table 3. Analysis of the maximum weight (w) according to the roof area ($m^2$)

| Surface of buildings house room and department | | |
|---|---|---|
| $m^2$ | P | Support $W_{max}$ |
| 100 | 0.1 | 19000 |
| 200 | 0.2 | 38000 |
| 300 | 0.3 | 57000 |
| 400 | 0.4 | 76000 |
| 500 | 0.5 | 95000 |
| 600 | 0.6 | 114000 |
| 700 | 0.7 | 133000 |
| 800 | 0.8 | 152000 |
| 900 | 0.9 | 171000 |
| 1000 | 1 | 190000 |

According Building regulation of México City, it establishes the following living loads for Buildings:

| | | |
|---|---|---|
| Apartments and rooms in houses | 190 | $kg/m^2$ |
| Meeting places with fixed seats | 350 | $kg/m^2$ |

In the above relation, the main experiment occurs with the condition of not exceeding 95 tons for example: in the case of the habit area Towers in Juriquilla, Querétaro, which have an architectural design whose roof area is designed by the following dimensions: 35x14 m=490 $m^2$, which works for P=0.5 of the Table 3.

## 6. Analysis of results

To represent the growth of the loads, it can be observed in this graph that the values grows in an increasing way, as a result it obtains a polynomial equation of degree 2, which is in function in the data described in Table 4.

Table 4. Array with final organic layer and the live load expressed to maximum support

| $m^3$ | Wt (Kg) | Number of Users | Wp (Kg) | Maximum Weight (Kg) |
|---|---|---|---|---|
| 10.55556 | 19000 | 231.99023 | 19000 | 38000 |
| 21.11111 | 38000 | 463.98046 | 38000 | 76000 |
| 31.66667 | 57000 | 695.97070 | 57000 | 114000 |
| 42.22222 | 76000 | 927.96093 | 76000 | 152000 |
| 52.77778 | 95000 | 1159.95116 | 95000 | 190000 |
| 63.33333 | 114000 | 1391.94139 | 114000 | 228000 |
| 73.88889 | 133000 | 1623.93162 | 133000 | 266000 |
| 84.44444 | 152000 | 1855.92186 | 152000 | 304000 |
| 95 | 171000 | 2087.91209 | 171000 | 342000 |
| 105.55556 | 190000 | 2319.90232 | 190000 | 380000 |

In the previous arrangement, in the first column (from left to right) the amount of $m^3$ of organic layer is shown, which is equivalent to the total weight of each value of the second column (Wt) expressed in Kg. Similarly, the third column shows the number of users whose equivalences in Kg are expressed in the fourth column. The resulting equation is: $81.9x-1800y = 0$, where: $x$ = No. users, $y = m^3$ organic layer, Table 5. Using JavaScript was designed a weight simulator associated with the roof garden of the building, it determined the ideal weights that could withstand the building in function of the proposed roof garden. The weight is modified and the weights were indicated in table 5, in order to determine if the ideal values can be adapted.

Table 5. Balance of variables x, y: 50% to 50%.

| Approximation | Organic layer | Number of Users | Accumulated |
|---|---|---|---|
| -0.0040815 | 5.27778 | 115.995115 | 19000 |
| 0.0008370 | 10.555555 | 231.99023 | 38000 |
| -0.0028350 | 15.833335 | 347.98535 | 57000 |
| 0.0020835 | 21.11111 | 463.980465 | 76000 |
| -0.0019980 | 26.38889 | 579.97558 | 95000 |
| 0.0029205 | 31.666665 | 695.970695 | 114000 |
| -0.0011610 | 36.944445 | 811.96581 | 133000 |
| 0.0041670 | 42.22222 | 927.96093 | 152000 |
| 0.0000855 | 47.5 | 1043.956045 | 171000 |
| -0.0039960 | 52.77778 | 1159.95116 | 190000 |

In table 6, 50% of both the organic layer and the number of users is obtained, with this the purpose of achieving a balance between the variables and thereby obtaining the left column of approximations. The results of the left column represent the approximation to 0 that meets the equation $81.9x-1800y = 0$; however, the kilograms of the organic layer and the number of users must be rounded to the nearest smaller integer for the purposes of real loads.

Table 6. Equilibrium coefficient to find the optimal point

| Equilibrium coefficient | Rounding Down | |
|---|---|---|
| 418.5000000 | 5 | 115 |
| 918.9000000 | 10 | 231 |
| 1419.3000000 | 15 | 347 |
| 119.7000000 | 21 | 463 |
| 620.1000000 | 26 | 579 |
| 1120.5000000 | 31 | 695 |
| 1620.9000000 | 36 | 811 |
| 321.3000000 | 42 | 927 |
| 821.7000000 | 47 | 1043 |
| 1322.1000000 | 52 | 1159 |

The equilibrium coefficient is obtained after having rounded the variables x, and the nearest integer down. Then, applying the equation $81.9x-1800y = 0$ corresponding to the number of users and the weight of the organic layer, the aforementioned coefficient is obtained as represented in figure 3.

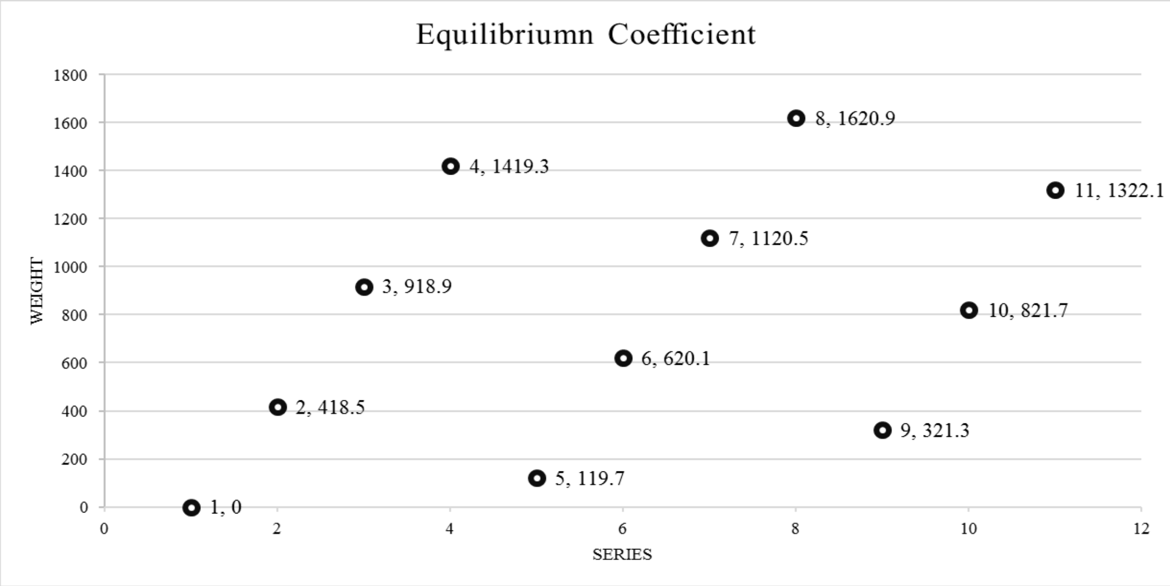


Figure 3. Dispersion diagram of Equilibrium Coefficient Distribution

Finally, in the lower part of the diagram has the lowest point marked with the number 4 which corresponds to the distribution coefficient 119.7, see Table 7. This indicates the number of people that can be on the roof of a building is 463, see Table 6. To do this can add the own load of the garden up to a maximum limit of 21 tons/m$^3$ (see Table 7), because the weight of 463 people is 463 x (81.9) =37,919.7 and 21 x (1800) =37,800, the sum of the products is 75,719.7 Kg and does not exceed level 4 (see Table 4). In the table 4 the area is in m$^2$, where 400 m$^2$ corresponds to 76,000 Kg.

As a result of the research and using Unity software for virtual reality, the prototype was designed according to the data obtained in the previous calculations, which is shown in the Figure 4, (the use of the software is for representative purposes only). The previous figure is a proposal of a roof slab with roof garden and Smart farming, whose area = 400 m$^2$, which can hold up to 463 people, that in essence is the optimal point that was sought.

Figure 4. Roof garden proposed in a Smart City including smart farming and organic layer.
Source: Own Elaboration, design using Unity

## 7. Experiment

The experimentation was done according with the following specifications:

a. Satisfactory evaluation is to obtain the most efficient arrangement of Roof Gardens, to do this, is necessary to construct a cluster for keeping the data of each of the representative individuals for each Roof Garden.
b. The description is made with the purpose of distributing the best form of each
c. the main experiment defined needs to have approximate 500 agents and 250 creations into the space.
d. The stop condition is reached after 75 runs; this allowed generating the best selection of each kind and their possible location in a specific model.
e. A location is obtained after comparing the different cultural and economic similarities of each Roof Garden and the evaluation of the Multiple Matching Model as in (Ustaoglu 2009).
f. The vector of weights employed for the fitness function is Wi= [0.6, 0.7, 0.8, 0.5, 0.6,

0.7], which respectively represents the importance of the particular attributes i.e. roof garden increase index, commercialization, services, recreation and green areas, cost-benefit and equipment's on the roof garden.

g. The algorithm will choose the location of each roof garden based on the attribute's similarity.
h. Each attribute is represented by a discrete value from 0 to 7, where 0 means absence and 7 the highest value of the attribute.

The experiment design involves series steps:

a. An orthogonal array test with interactions amongst the attribute variables; these variables are studied within a location range (1 to 400) specific to a coordinates x and y.
b. The orthogonal array is L-N (2-5), in other words, 6 times the N executions.
c. The value of N is defined by the combination of the 6 possible values of the variables.
d. The values in the location range.

Table 7 demonstrate the list of the possible scenarios as the result of combining the values of the attributes and the specific location to represent a specific issue (roof garden).

Table 7. The orthogonal array tests

| Roof Garden Increase Index | Commercialization | Service | Recreation and Green Areas | Cost-Benefit | Equipment on the Roof Garden |
|---|---|---|---|---|---|
| 4 | 1 | 2 | 2 | 3 | 4 |
| 3 | 1 | 2 | 2 | 3 | 3 |
| 2 | 1 | 3 | 2 | 4 | 4 |
| 5 | 1 | 3 | 2 | 5 | 2 |

The results of this table permit to analyze the effect of the variables in the location, and the selection of all the possible combinations of values. The orthogonal array test and the array aids (Harrell 2001) specify the possibilities to adequate correct solutions (locations) for each Roof Garden. For the first data to be organized it is necessary to determine the essential attributes.

Different attributes were used to identify the real possibilities of improving a roof garden set in a particular environment, and to specify the correlations with other Roof Gardens with similarity necessities (see Figure 5). The locations were choosing based on the orthogonal test array, because provides representative (uniformly distributed) coverage of all variable pair combinations.

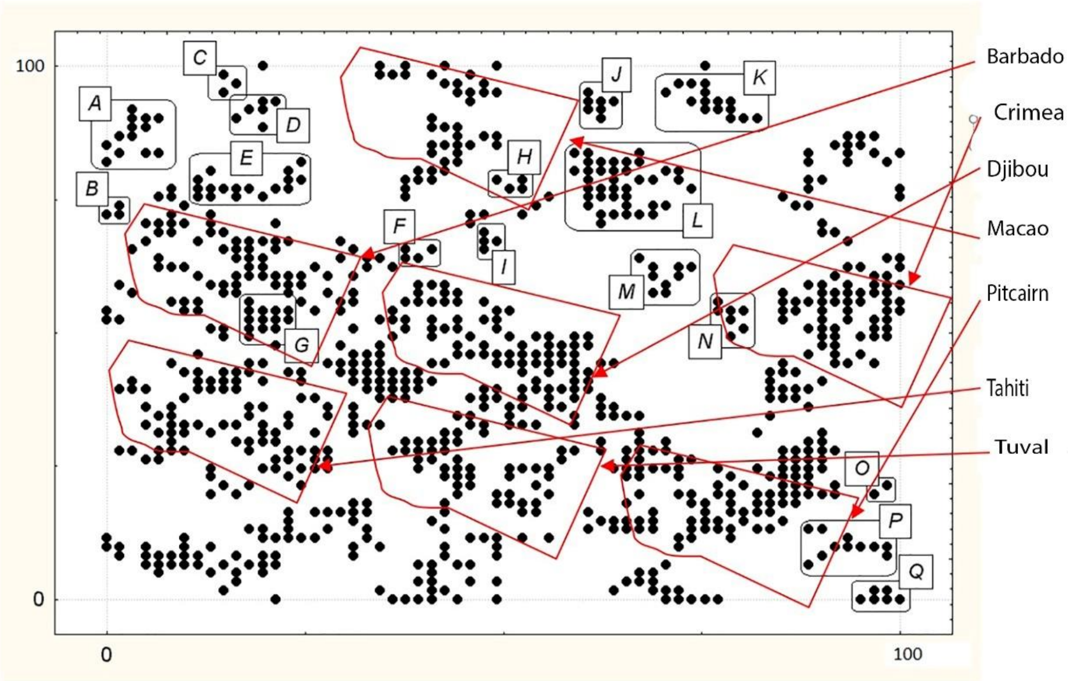


Figure 5. Location of Roof Gardens installation in the urbanization
Source: Own Elaboration, design using Xpedia

The cluster B, C, D, F, H, I, M, N, O, and Q are more related with people in families (brothers, sisters, uncles, aunts) whom likely more make smart farming, the clusters A, E, G, J, K, L and P, are clusters more related with social groups in a recreational roof garden. The x axis represents a sustainability model and y axis represents a facilities fun model to interact with another people. Using a dataset of 297 buildings with 4 more levels and the possibility to adapt a roof garden.

The result is related to the behavior of the community with respect to an optimization problem (to culturally select 5 similar roof gardens). The descriptive information allowed to identify changes in the increase time related to one or another Roof Garden. The use of CA substantially increased the understanding in the obtention of the paradigm from the total group. This after the classification of agent communities was made based on a relation that keeps their attributes. After the experiments it is possible to emphasize the importance of calculating the possible loads that can be had on the roof. That is why it is a priority to know the maximum number of people that can be occupied without compromising the structural safety of the building. It is very important to this research the integration of a virtual model associated with the final model, in our research we propose a Unity model, as is shown in Figure 6.

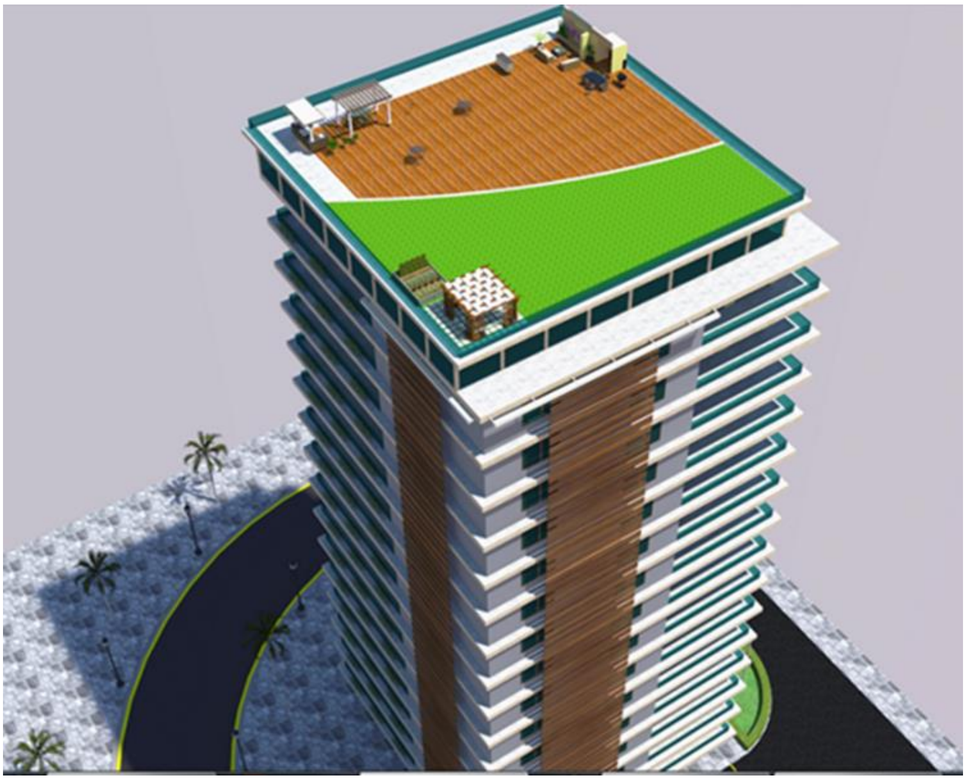

Figure 6. Roof garden final
Source: Own Elaboration, design using Unity

In a building of 17 levels, 90 m of height and 20m x 20m to dimensions based in final results (400 $m^2$). It can support 463 people even whit smart garden.

It is necessary to review the calculation memories of the building where the Roof garden is going to be built and specially to emphasize the reinforced concrete elements such as beams and columns. As a last recommendation, it’s important to review and be sure of the correct distribution of these elements to facilitate the development of the proposal where the live load is balanced with the organic layer, Figure 7.

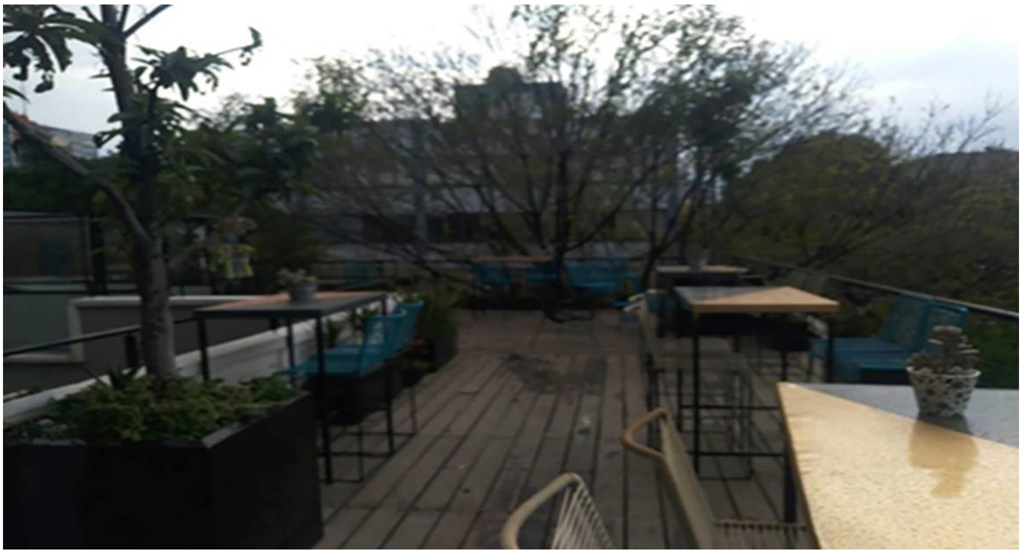

Figure 7. Proposal of space distribution in a Roof Garden in Averanda complex, Cuernavaca, Morelos, Photo taken by Ochoa in 2018

The number of people at the same time must be carefully analyzed to avoid problems both with the spacing and recreation of the people, and not to affect the group of plant species in it. In our model, 27 different species were chosen, which may exist between them, (Waris & Reynolds, 2018).

Another future work is to collect samples of 77 buildings and analyze those that are under construction or as it is also known as "projection", since these present characteristics that incorporate the category of intelligent buildings as: resistant to earthquakes, fires, and with new loads such as the installation of solar panels and intelligent control systems, Figure 8.


Figure 8. Map of representative buildings of Querétaro.

Where the yellow points represent the buildings constructed, the blue points symbolize the buildings under construction and the red points the buildings projected.

In the city of Querétaro, there has been an even greater need for corporate offices and housing complexes that is manifested in the current Vertical Construction Boom. There are 28 buildings built exceeding 40 m in height and 2 of the highest are Juriquilla Towers B and Juriquilla Towers A, both with 30 floors, with a height of 116 m and 115 m respectively. There are 30 buildings under construction, where the highest is not strictly the one that has the most floors. The San José Moscati hospital is 130 meters high and 28 levels, while the High Park Corporate 1 is 92 meters high and 29 levels. Finally, there are 19 projected buildings. The Westin Querétaro Hotel is 170m with a total of 40 floors, this being the tallest building the city has.

For the Design of Experiments (DOE) there are 77 data files and it will be indicated as A =

Constructed, B = under construction, C = Projected to establish a null hypothesis and an alternative hypothesis. With this, a design of complete blocks can be established at random, one block factor and by means of the ANOVA statistical technique with two classification criteria, (Table 8).

Table 8. Higher buildings grouped with two classification criteria: for the height and the number of floors that each building has.

| HEIGHT (m) | LEVELS |
|---|---|
| 116 A | 30 |
| 130 B | 28 |
| 170 C | 40 |

In this way, the DOE makes it possible to find the factor to compare the different levels that each building has, and if there are significant differences with respect to its height in order to select the buildings that are optimal for the design of a roof garden. As a result, according with the recommendations to realize consultations to obtain the acceptance function to propose an alternative location for the rest of the roof gardens (Dennis 1991).

## 8. Conclusion

Cultural Algorithms have a wide variety of applications, for example in the field of engineering and areas of innovation technological, applications in the field of robotics, where it is sought to have in various forms social interaction and adaptability in the taking of decisions, for example Nolfi, Floreano, &Floreano (2000) organize group of robots for collaborative tasks. Another future work using Cultural Algorithms is related to the distribution of workgroups, social groups or social networking to support in diverse problems related with Smart Manufacturing. Finally, Cultural Algorithms can be used in pattern recognition in a social database, for example: fashion styling and criminal behavior and improve models of distribution of goods and services as in (Guo et al. 2017) and (Waris & Reynolds 2018).

With the design of experiments, it was possible to establish the importance holistic and systemic analysis related to the diversity of the established economical patterns for each Roof Garden, like strategy to support the indices of sustainable development. These patterns represent different technology applications and a unique form of adaptive behavior that solves a computational problem that does not make clusters of the Roof Gardens in a Smart City.

The final conclusion was to achieve the application of the Culture Algorithm in the recognition of the behavior of the different proposals of the designs of the roof garden, to obtain the best results of a group of proposals and to find a balance between the variables that are involved in the distribution of the slab, otherwise they would become point loads and will bring as consequences fracture points, the latter are analyzed in the diagrams at the time and cutting forces.

With this work and the designs of the experiments it is achieved to have better ways of deciding on related proposals of the roof garden and make a support in the urban sustainability indexes in any city where they are applied.

**Future investigation**

For further research is necessary to intend and analyze the level and degree of cognitive knowledge for each Roof Garden –especially with space to Smart Farming- as is shown in Figure 9.

Figure 9. Roof garden in a Smart City (Based on Google Images 2019)

Also, is recommended to create a groups of proposals of roof gardens allow to understand the similarities shared by the designs, the common characteristics and the diverse methods used to generate more sustainable proposals. Another recommendation is to apply the proposal of Vukčević, Ochoa & Djraguljovič (2005), that indicate the small variations were beyond phenotypic characteristics and are mainly associated to tastes and related characteristics developed through the time.

Another recommendation to made innovative proposal is the example of roof garden in the city of Monterrey, Mexico, this case study presents various forms of use of the roof garden, this proposal is through garden, businesses, economic and social activities, see figure 10.

Figure 10. Roof Garden in Monterrey, NL, Mexico, (Based on Google Images 2019)

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