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Modeling a Roof Garden to Buildings in a Smart City using Equation Weight to Calculate Distribution of Load Live and Weight Maximum on a Roof Top

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Abstract. This research presents an intelligent model related with the modeling of a roof garden in buildings in the center of the country of Mexico and, in general, the buildings are located in Mexican national territory, taking in consideration the legislation in such delimitation. We analyze the behavior and features of a roof slab from the point of view of the constructive conception that was designed to complete the building and that does not have the specifications of a slab of mezzanine that from the beginning are established in the calculation memory of the construction. For that reason, it is important to determine the optimal parameters for the development of the roof garden and thus begin to transform the cities with the characteristics and conditions to be a smart city. The intent of the present research is to apply mathematical tools, computational as well as artificial intelligence software for roof garden modeling, based on a mathematical model that allows to integrate the dead load to live load, and the specific weights of the dry stratum and the wet stratum since the use of smart farming is incorporated in the roof top design.

Keywords: roof top, intelligent garden, buildings in a smart city, load live, smart farming.

1 Introduction

The Roof Garden are born from the idea of using spaces in cities where one of the main problems is lacking of farmyard, reduced to create a garden or at the time natural conditions for developing crops spaces, where the aesthetic and environmental benefits of gardens on rooftops and roofs have been recognized for decades. In this way, the quantification of these benefits has not been investigated deeply in the US, but in other countries such as Germany and Canada [1].

Green roofs provide a large range of benefits from amenity to ecological and technical advantages to financial aspects [2]. The California-based study by Simpson and Machpherson [3] shows that tree shades have potential to reduce annual energy use for cooling 10-50% (200-600 kWh) and peak electrical use up to 23% (0.7 kW).

At present, there is a lot of literature that describes the importance of family gardens for stress prevention, leisure and personal issues and social identity [4].

The inclusion of mathematical tools has been increasing over time but it is a relatively a new topic in which it is being given great importance in different aspects. Kumar and Kaushik (2005) performed a mathematical model to evaluate the cooling potential of garden areas on the roofs of buildings exposed to solar energy [5].

2 Structural Equation Model

The structural equation models show the dependency ratio between the variables. For example, by integrating a series of connections for the electric line for the case of the people who depend on it or in its independent case, the one that is within the same model of the variables that can be independent in the same way they can be dependent on others [6], this is how they become a useful tool [7].

The reason why the Structural Constructive Factors (FCE in Spanish) were taken is because they were considered to be the most important for the analysis of loads on the roof. Given that Ergonomic Environmental Factors (FEA in Spanish) are considered secondary factors, since they represent variations where the most significant is precipitation; this is considered in the specific wet weight of the land for garden. A wind = 0 m/s is taken into account since in conditions to evaluate loads it does not represent a significant value, nevertheless it is for trees of more than 1 meter and mainly for future metal or wood structures that are incorporated above the rooftop.

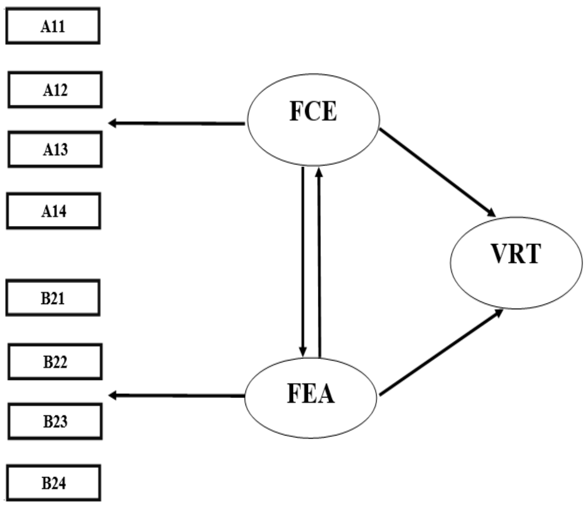

Fig. 1. Relationship of factors

Figure 1 shows the relationship between the factors:
A11 (Reinforced concrete slab),
A12 (Slab and beam slab),
A13 (Live load) and A14 (Dead weight),

B21 (Specific weight of the dry layer),
B22 (Specific weight of the wet layer),
B23 (Wind), and B24 (Precipitation).
where:
FCE means (Structural Constructive Factors) and FEA means (Ergonomic Environmental Factors).

2.1 Structural Constructive Factors

According to a study carried out by the National Chamber of the Clothing Industry published in 2012 (CANAIVE, 2012) shows that Mexican body size and its weight respectively are less than the Americans and Mexican Americans. These measurements were taken with a sample of 17, 364 Mexicans of legal age. The study was carried out in October 2010 to June 2011.

Table 1. Tabulation and normalization of values, given the weight of a Mexican-American equivalent to 81.9 kg average.

No max. Of users	P	Wp
0-24	0.1	1965.6
25-49	0.2	4013.1
50-74	0.3	6060.6
75-99	0.4	8108.1
100-124	0.5	10155.6
125-149	0.6	12203.1
150-174	0.7	14250.6
175-199	0.8	16298.1
200-224	0.9	18345.6
225-250	1.0	20475 kg

2.2 Dead Weight of Concrete Slabs

The calculated deadweight of normal weight concrete slabs cast in place will be increased by 0.2 KN/m² (20 kg / m²). When a layer of normal-weight mortar is placed on a pre-cast or pre-cast slab, the calculated weight of this layer will also increase by 0.2 KN / m² (20 kg / m²) so that the total increase will be 0.4 KN / m² (40 kg / m²) [3].

The value of the resistance of concrete from de f´c=250 kg/cm^2 [15] is used for slabs and columns of houses, social centers and schools. As well as the concrete with f´c=350 kg/cm^2 is used for slabs and columns of buildings [10]. The following table shows the standardized values of the strength for conventional concrete slabs, since the compressive strengths (f'c) is greater than 499 kg /cm^2 are considered as high resistance concretes [11].

Table 2. Standardized values of reinforced concrete roof slabs. Considering: thickness of 10 cm, revoked, flattened, waterproofing and the safety factor.

kg/cm^2	P	W_D
271.5-294.14	0.1	272
294.15-316.79	0.2	297
316.8-339.44	0.3	322
339.45-362.09	0.4	347
362.1-384.74	0.5	372
384.75-407.39	0.6	397
407.4-430.04	0.7	422
430.05-452.69	0.8	447
452.7-475.34	0.9	472
475.35-498	1	497

ɣd	ɣhum
1330 kg	1800 kg

Fig. 2. Specific weight of the dry and wet organic layer respectively (kg / m3).

3 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 / m2 and that finally the expected result is expressed in kilograms [13]

$$Z = \frac{M * C}{D}, \quad (1)$$

$$Z = \frac{M * C}{D} + \Delta\gamma s, \quad (2)$$

Where:

M= Reinforced concrete slab

C = Live load analysis *Wp*

D = Specific weights of organic layer.

ɣs = Difference of specific weights *ɣd* and *ɣhum*.

Z= Total weight Roof garden

4 Experimentation

Table 3. 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 exceeds 8 tons.

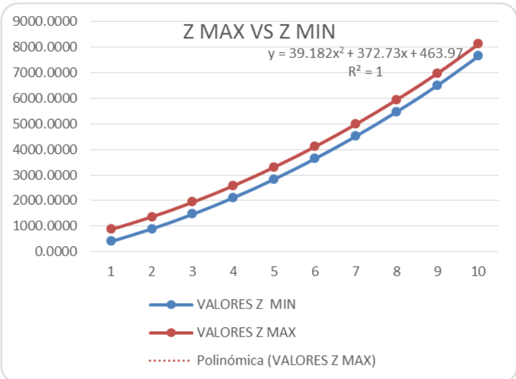

Fig. 3. Minimum and maximum weight (w) comparison.

The results of the Z_{min} values correspond to eq. 1, which contemplates the specific weight of the dry organic layer (ɣd). 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 39.182x2 + 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 (W_D), the average weight of people (W_P), and the specific wet weight of the organic layer (ɣhum).

Table 4. Analysis of the maximum weight (w) according to the roof area (m^2).

Surface of buildings house room and department		
m2	P	Support Wmax
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 relation to the above, the main experiment occurs with the condition of not exceeding 95 tons for example: with the case of the Habitárea Towers in Juriquilla, Querétaro (grupoacerta.com/project/habitarea-towers/), 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. Is in this way that the following question arises to which we must answer, for what amount of people is it permissible to add *Wp* load without overloading the roof? and for what amount of area?

5 Analysis of Results

To represent the growth of the loads, it can be observed in this graph that the values are increased in an increasing way, as a result we obtain a polynomial equation of degree 2, which is in function in the data described previously in Table 1.

Table 5. Array with final organic layer and the live load expressed to maximum support.

m^3	Wt (Kg)	No. users	Wp (kg)	Maximum weight
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

Fig. 4. Polynomial Graphic maximum value z.

In the previous arrangement, in the first column (from left to right) the amount of m3 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 = m3 organic layer.

Table 6. Balance of variables x, y: 50% to 50%.

Approximation	Organic layer	No. 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 are obtained, this with 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 7. 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

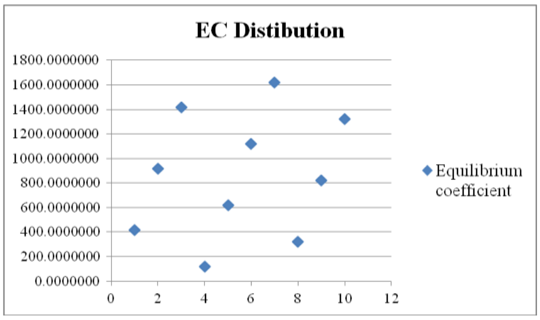

Fig. 5. Dispersion diagram of Equilibrium Coefficient Distribution.

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, we obtain the aforementioned coefficient.

Finally, in the lower part of the diagram we have 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 are 463, see Table 6. To this you can add the own load of the garden up to a maximum limit of 21 tons/m3 (table 7) because the weight of 463 people is 463(81.9) =37,919.7 and 21(1800) =37,800, the sum of the products is 75,719.7 kg does not exceed level 4 (see Table 4). In the table 4 refers the area in m2, where 400 m2 corresponds to 76,000 kg, that´s the reason why that amount of area is chosen.

Fig. 6. Roof garden proposed in a Smart City including smart farming and organic layer.

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 6 (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, which in essence is the optimal point that was sought [12].

6 Conclusions and Future Work

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 high priority to know the maximum number of people that can be occupied without compromising the structural safety of the building. In the study, we reach the conclusion of finding a balance between the variables since they are loads that must be distributed on the slab, otherwise they would become point loads and bring as consequences fracture points, the latter are analyzed in the diagrams at the moment and cutting forces. Is very important to this research integrates a model of virtual reality associate with the final model using virtual reality, in our research we propose a Unity model, as is proposed in Figure 10.

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, you have to review and be sure of the correct distribution of those elements to facilitate the development of the proposal where the live load is balanced with the organic layer.

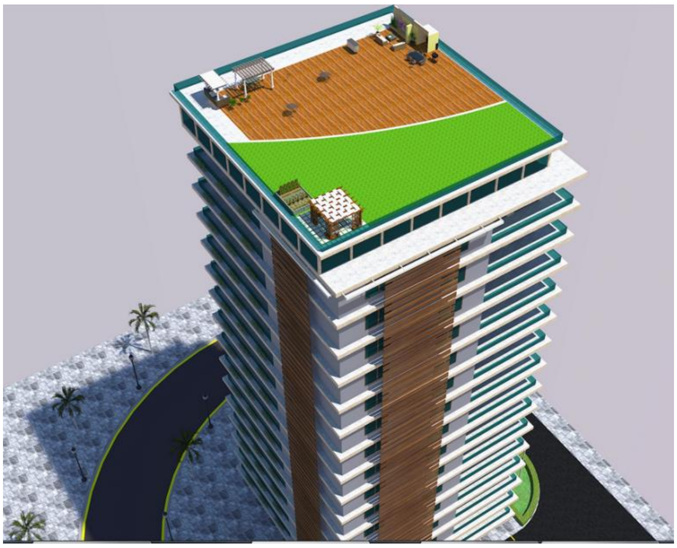

Fig. 7. Roof garden final in a building of 17 levels, 90 m of height and 20m x 20m to dimensions based in final results (400 m^2). It can support 463 people even whit smart farming.

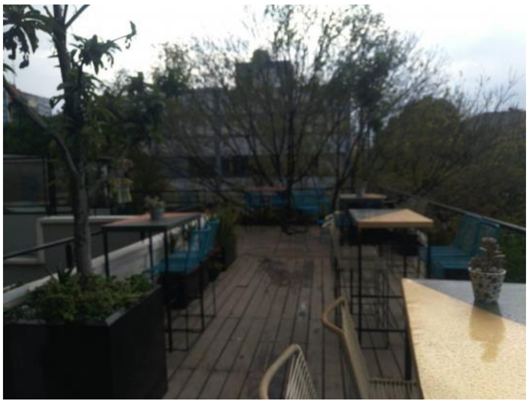

Fig. 8. Proposal of space distribution in a Roof Garden in Averanda, Cuernavaca, Morelos

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 [15].

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

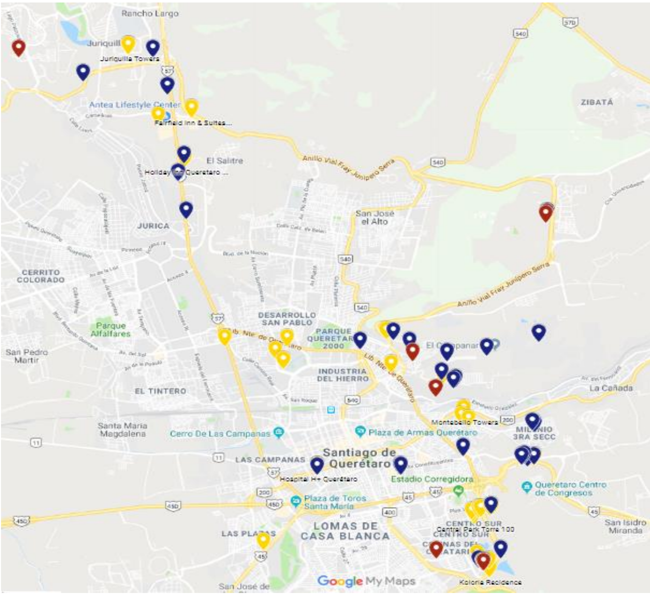

Fig. 9. Map of representative buildings of Querétaro. Where the yellow points represent the buildings constructed, the blue points symbolize the buildings under construction and the red points the buildings projected.

In the city of Querétaro, there has been an ever 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, of which the Westin Querétaro Hotel will be 170m high with a total of 40 floors, this being the tallest building the city will have.

For the Design of Experiments (DOE) we have 77 data and it will be denoted 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, 1 block factor and by means of the ANOVA statistical technique with two classification criteria.

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, it is possible to make a DOE of a factor, first to compare the different levels that each building has and if there are significant differences with respect to height in order to select the buildings that are optimal for the design of a roof garden.

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References

1. Monterusso, M.A., Rowe, D.B., Rugh, C.L.: Establishment and persistence of Sedum spp. And native taxa for green roof applications. Hortscience 40 (2), 391–396 (2005)
2. Johnston, J., Newton, J.: Building green: a guide to using plants on roofs, walls & pavements. London Ecology Unit, London (1995)
3. Simpson, J.R., McPherson, E.G.: Potential of tree shade for reducing residential energy use in California. Journal of Arboriculture 22(1), 23–31 (1996)
4. Syme, S.P., Campbell, E.: Predicting and understanding home garden water use. Landscape and Urban Planning 68(1), 121–128 (2004)
5. Kumar, R., Kaushik, S.C.: Performance evaluation of green Roof and shading for thermal protection of buildings. Building and Environment 40(11), 1505–1511 (2005)
6. Mejía, M., Cornejo, C.: Aplicación del modelo de ecuaciones estructurales a la gestión del conocimiento. In: Arequipa: LACCEI (2010)
7. Casas, M.: Los modelos de ecuaciones estructurales y su aplicación en el índice europeo de satisfacción al cliente. Madrid: Universidad San Pablo-CEU (2002)
8. Ochoa A. et al.: Baharastar–Simulador de Algoritmos Culturales para la Minería de Datos Social. In: Proceedings of COMCEV (2007)
9. Ochoa, A. et al.: Dyoram's Representation Using a Mosaic Image. The International Journal of Virtual Reality (2009)
10. Acme Concretos. Use by resistance. Consulted in: http://www.acmeconcretos.com/ index.php/en/usos-por-resistencia (2018)
11. Concretos, Lima. Concretos Lima S.A.C. (2018)
12. Rudomín, I., Vargas-Solar, G., Espinosa-Oviedo, J., Pérez, H., Zechinelli-Martini: Modelling Crowds in Urban Spaces. Computing and Systems 21(1), (2017)
13. González Barbosa: Construction of an Optimal Solution for a Real-World Routing-Scheduling-Loading Problem. Computing and Systems 13(4), 398-408 (2010)
14. Raisa, S., Micó, M.: Efficient use of Pivots for Approximate Search in Metric Spaces. Computing and Systems 17(4), (2013)
15. Luévanos, A., López, S., Medina, M.: Optimization of Reinforced Concrete Beams for Rectangular Sections with Numerical Experiments. Computing and Systems 22(2), (2018)