FACTORIAL EXPERIMENTAL DESIGN TO ANALYZE THE THERMAL AND HIDRIC PERFORMANCE OF SUBSTRATES USED IN EXTENSIVE GREEN-ROOF SYSTEMS IN MEXICO

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ABSTRACT

The use of naturation systems (or green-roof systems) provides several externalities, such as public and private benefits both architectural and urban scale, most notably its effect of termic control and stormwater management in buildings. Current studies about this technology have been restricted to regard it as a single element, which limited determine the action exerted by each one of its components. Therefore we have proposed a factorial experimental design to study the substrate, which has been considered one of the most important elements in naturation, and thus analyze the thermal and hydric performance that substrate contributes to the system.

The model relates the quality of the substrate, defined by five different types of substrates currently used in Mexico, with the depth of the substrate, with 2 thicknesses for extensive naturation system. Location, plant species *Sedum x rubrotinctum*, and type irrigate during plant establishment are the continuous variables, while the dependent variables are the thermal performance and hydric substrate analyzed by a series of tests in field and laboratory. Recognizing the influence of the substrate it could be set strategies and greater design possibilities in terms of resources, bioclimatic design and construction procedures, optimizing thermal and hydric performance in naturation systems as a basic tool in architectural work.

Keywords: naturation, substrate, experimental design, green roof.

1.- Naturation as enveloping

The excessive growth of cities has resulted in increasing hard surfaces and waterproof and the decline and deterioration of the vegetated areas. The lack of vegetation in the city life brings with it problems of various kinds, from environmental to psychological; for this reason have been sought new strategies that allow the incorporation of plant mass in those spaces that have been little valued as sites for the growth of vegetation. These spaces include the architectural envelopes [1].
A constructive technology that allows the incorporation of vegetation on built-up surfaces is naturation, in buildings envelopes highlights its use in covers.
His employment provides different types of benefits: environmental, architectural, constructive, aesthetic, economic, etc., all them private and public; these vary according to the type of green-roof system that is used [2].
It is necessary to know the functioning of the green-roof system as a whole and of each of its elements in order to understand its performance and optimize its benefits, which is why it has been decided to perform research on this technology.

1.1.-Components and classification of naturation systems

Green-roof systems comprise a series of elements that must perform specific functions as shown in (fig. 1), the materials used to cover these functions vary according to the region where it is built.

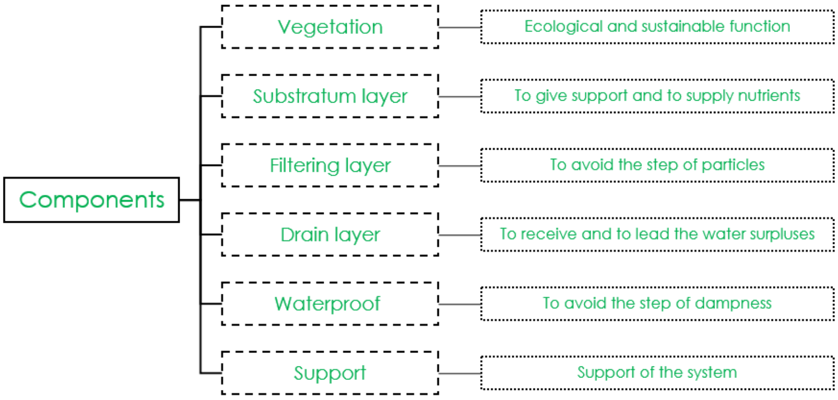


Fig. 1 "Green-roof system components". Reference: García, I. México, 2011.

There are different classifications for types of green-roof systems: according to the thickness of the substrate, selected plant species and required maintenance. However, in general they are divided into three types (Table. 1):

Characteristics / Type of naturation	Extensive	Semi-intensive	Intensive
Thickness of the substratum	6 – 12 cm	12 – 30 cm	+ 30 cm
Weight m^2	60 – 150 kg/m^2	120 - 250 kg/m^2	+ 250 kg/m^2
Irrigation	No	Periodically	Regularly
Maintenance	Low	Periodically	High
Height aprox. of vegetation	5 -50 cm	5 -100 cm	5 – 400 cm
Cost price	Low	Medium	High

Table 1 "Classification of green-roof systems"

The current environmental problematics has promoted the creation and investigation of sustainable technologies that they contribute to his improvement, vision that reaffirms the use of the extensive green-roof system, since it generates benefits to a low cost in comparison to other systems and with minimal or void maintenance, by which it is considered to be an ecological tool that offers royal improvements to the

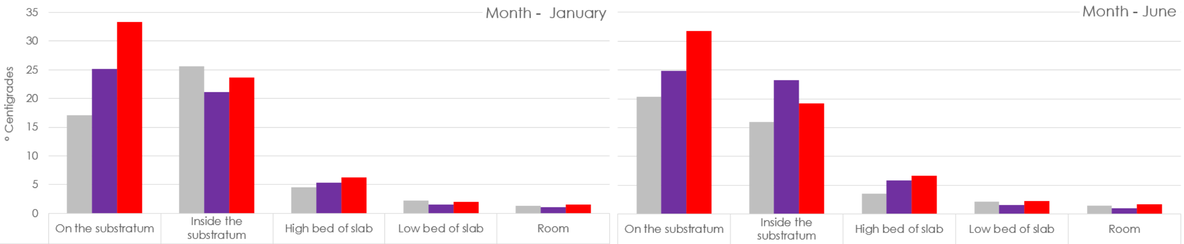
environment without demanding to waste resources. For these reasons, it has been selected the extensive system to be analyzed.
Research performed in Mexico about naturación has been restricted to consider it as a single element, limiting the determination of the action that each of its components exerts. For this reason, it has been decided to perform research on the substratum performance, that is considered to be one of the most relevant elements in the system, the analysis will consist in a factorial experimental design where heat and water performance that contributes to the system will be monitored, these studies form part of doctoral research "Hydraulic, thermal and acoustic performance of the substrate in extensive green-roof systems", performed in the program of master's degree and doctorate of the Faculty of Architecture of the Universidad Nacional Autónoma de México, UNAM.

1. 2. -Benefits of green-roofs

The naturation should be considered as a owning private in terms of property, but with a public purpose, since it produces effects for third parties or externalities that are not susceptible to be internalized. They also have the no-rivalidad feature, which means that the owning property does not diminish by the fact that it's been consumed by a great number of people.
The externalities are defined as side effects of an economic activity, can be positive or negative. The externalities of the naturation are predominantly positive, it is very difficult to find negative effects of these systems, just in case of public financing, naturation could "compete" for resources with other priorities in public investment. Between the positive externalities that naturación provides, there are several benefits [3], this analysis will discuss two of them: thermoregulation and management of stormwater.

1.2.1- Thermoregulation

Thermoregulation in green roof systems is given mainly by the substrate [4], there are data that indicates that the average of thermal reduction in a green cover with three different plant species (defined by their of color) and a substrate with 7.5 cm thick, records a daily temperature between a total fluctuation of the substrate of 18.08 °C in January and 14.13 °C in June [5], these values measure the difference inside and under the substrate. Records (fig. 2) shown that the greatest thermal reductions in the different layers of the roof system are given by the substrate.



	On the substratum	Inside the substratum	High bed of slab	Low bed of slab	Room	On the substratum	Inside the substratum	High bed of slab	Low bed of slab	Room
Gray color	17.12	25.59	4.49	2.21	1.31	20.34	15.99	3.55	2.16	1.40
Purple color	25.13	21.09	5.3	1.50	1.12	24.86	23.23	5.88	1.55	1.04
Red color	33.35	23.62	6.28	1.95	1.5	31.79	19.21	6.65	2.23	1.72

Fig. 2 "Comparison of daily thermal fluctuation in different positions in a green-roof in the months of January and June". Reference: García, I. Mexico, 2011

These thermal reductions achieve greater environmental comfort index inside, as shown by the data (fig. 2), the minimum daily thermal fluctuation in January was 1.12 °C and 1.04°C in June for a system with purple vegetation. The effect of thermoregulation brings greater environmental comfort as consequence, additionally it reduce energy consumption from air conditioning, reducing thus expenditure of economic resources.

1.2.2- Management of stormwater

Water that is deposited on a green-roof is captured by the substrate, hence a part of it is absorbed by the plants and then is returned to the atmosphere through the process of evapotranspiration, another part is retained by the structure of the substrate and the remnant is slowly drained from the system.

Is known that green-roof systems can reduce the runoff from a building, therefore decreasing the maximum flow rate and the volume of the sewerage system; all depending on the intensity of precipitation and characteristics of the substrate.

It is estimated a green-roof can absorb, filtrate, retain and store an average of about 75% of the annual precipitation falling on it [6].

Measurements of researchers of University of Kassel indicate that the backwardness of the drainage of rain water after a heavy rain with 18 hours in an green-roof of 12° of tilt and 14 cm in thickness of the substrate was 12 hours, and ended up draining 21 hours after it stopped raining (fig. 3). The stormwater drain amounted in that time period only to the 28.5% [7].

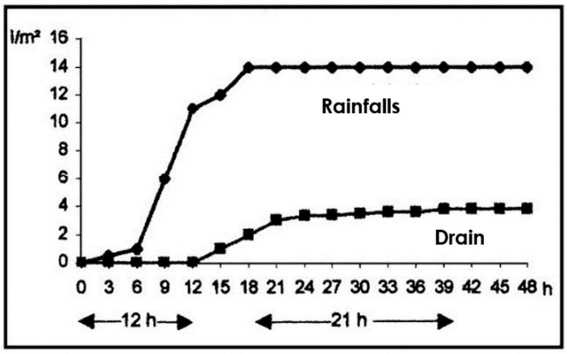


Fig. 3 "Volume of rainfall and storm drain in an green-roof after a continuous rain of 18". Reference: Minke, G. Cuba, 2014

2.- Factorial Experimental Design

A factorial experimental design relating different variables of analysis was designed with the objective of determining hydric and thermal performance of different substrates used currently in Mexico in extensive green-roof systems: independent, dependent, and constant variables are described below.

2.1.- Independent variables

Quality and depth of the substrate were selected as independent variables, which are related and create a matrix of different types of samples to be analysed (fig. 4).

The quality of the substrate is defined by five different types of substrates: three of them have been designed and tested by renowned academics from various institutions of higher education in Mexico, another is a substrate designed and used commercially in the Mexican market and the fifth substrate has been designed according to the recommendations of the NADF-013-RNAT-2007 environmental standard [8], which provides the technical specifications for the installation of green-roof systems in Distrito Federal, Mexico.

The depth of the substrate will be given by two thicknesses: eight and six centimeters, which are within the category of extensive green-roof systems. The objective of using two different depths is to record if there are significant changes in performance and the effect that has on the development of the vegetation on each substrate.

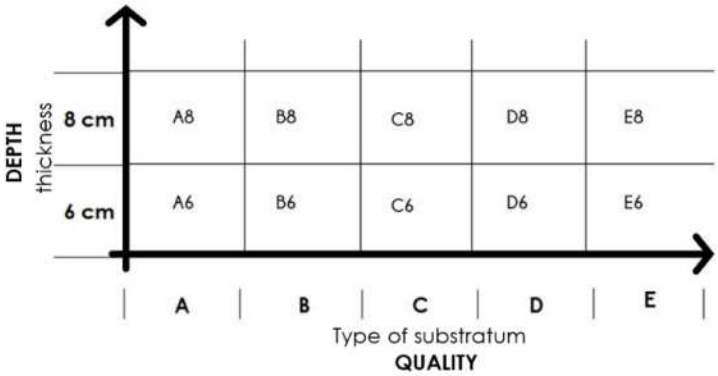


Fig.4 "Relationship between independent variables".
Reference: García, I. Mexico, 2014

Considering the five types of substrates with two different thicknesses, there are a total of 10 different samples, it's also consider four repetitions for each sample in order to validate analysis tests.

2.2.- Dependent variables

Dependent variables are heat and water performance and physical and chemical characterization of each substrate; in addition to the evaluation of plant development according to the type of substrate that is being used.

Analysis of the thermal performance will take place in laboratory and in field. Laboratory data of specific heat and thermal conductivity of each type of substrate and heat reduction in substrate with vegetation will be obtained, since there is no record of such data in Mexico, tests will be carried out at the Instituto de Investigación de Materiales at UNAM. Due to the characteristics and operation of the conductivimeter and the thermal camera, it is necessary to use containers for tests, it's being used silver plywood boxes with 15 mm thick, with a dimension of 0.30 m long x 0.30 m width, and two different heights of 0.08 and 0.06 m, corresponding to the two selected depths (fig. 5), each test will be performed by triplicate.

In field, heat will be measured in each type of substrate using temperature sensors, placed on each plastic module test, with a dimension of 0.60 m long x 0.30 m width and two different heights of 0.08 and 0.06 m (fig. 5).

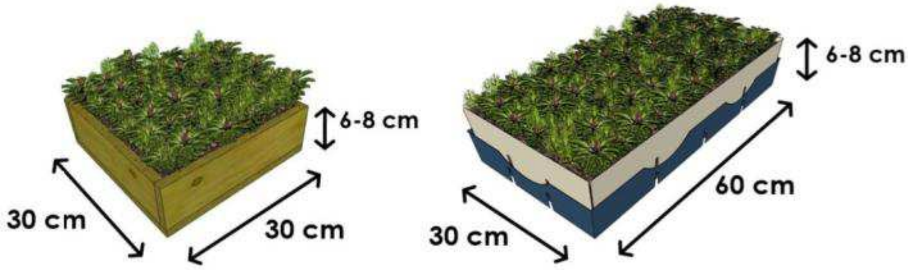


Fig. 5 “Modules for laboratory and field tests”. Reference: García, I. México, 2014

Analysis for hydric performance will consist in registering field capacity of each type of substrate in real time environmental conditions, using the same plastic containers for test (fig. 5) and four samples for each mixture, both for the substrate and substrate with vegetation. Additionally it will be analyzed the volumetric amount of fluid retained and drained by containers according to the amount of rainfall recorded, as well as the quality of the water that is drained by the measurement of suspended solids and total solids.

In order to perform the physical and chemical characterization of substrates, several tests will be made in the "Laboratorio de conservación del patrimonio natural y cultural" at UNAM, among them are:

- -Physical parameters: texture, density, porosity, humidity, field capacity, color and optical properties.
- -Chemical parameters: pH, organic matter and available nutrients determination.

The growth and development of the vegetation in each type of substrate is another dependent variable, in which is going to be measured the vegetation cover, taking in consideration the density and height of the vegetation in each module with relation to time.

2.3.- Constant variables

Constant variables are the field experimental model location, the plant specie and the kind of irrigation.

The experimental model will take place on the cover of the postgraduate unit J building (fig. 6), located in the cultural area of City University at Universidad Nacional Autónoma de México, to the South of Mexico City area, at coordinates 19° 20 01 North latitude and 99 11 54 ° longitude West, at an altitude of 2268 meters above sea level, the climate is temperate with rains in summer in concordance with Köppen climate classification system (Cw).

Fig. 6 “Experimental model location”. Reference: García, I. México, 2014

Other constant variable is the plant specie to use in tests with different substrates, in order to compare the growth of vegetation on each substrate. The selected specie is the *Sedum x rubrotinctum* (fig.7), this specie was selected due to their physical characteristics, its adaptability to extreme environmental conditions and that it requires a low maintenance.

Sedum x rubrotinctum has good coverage and survival in extensive green-roof systems [9], in addition its leaves turn reddish in nutrient deficiency conditions, suggesting the state of the substrate.

Fig. 7 “*Sedum x rubrotinctum*”. Fuente: García, I. México, 2014

Irrigation in different test modules be done only during the vegetal consolidation, the kind of irrigation will be a constant variable and it will be to field capacity on all substrates.

3.- Data logging

Although data will be registered on thermal and water monitoring over whole year on test modules, there have been determined specific periods of time to analyze each dependent variable according to environmental conditions; in addition statistical analysis will be required for validation of results obtained for each test.
For thermal performance, analysis will be focused in the month of January, which recorded the lowest temperatures of the year, and the month of May for higher temperatures. Water performance will be focused during the rainy season which corresponds to the months frome June to September; and the dry season from November to January, recording the quantity and quality of liquid retained and drained into the substrates.
The development of the vegetation will be monitored in each season of the year, registering time, difficulty or ease of growth according to weather conditions and type of substrate.

4.- Conclusions

The research is at the stage installation of the experimental factor design in the roof of the building (fig.8), while there have been obtained preliminary results in the substrates characterization tests.

Fig. 8 “First Assembly of the experimental model”.
Reference: García, I. México, 2014

This research will provide data about substrates that will allow a better understanding about its operation within green-roof systems, allowing a better selection and use of materials that compose them, obtaining higher quality and efficiency of the substrate in roof-green systems. This knowledge will allow a better prediction of thermal and hydric performance in green-roof systems, creating strategies and greater design possibilities in terms of resources, construction procedures and bioclimatic design, but mostly supporting naturation as a basic tool in architectural work.

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