Study of bioclimatic shading strategies in Seville: Habitability in open public spaces

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Abstract. It is necessary to adapt urban areas to climate change through solutions that combine tradition with innovation. This need is more pronounced due to climate change and the heat island effect. This work aims to design a mitigation technique that allows recovery life on the street through an adaptive solar control solution combined with vegetation. This technique will be designed and implemented in a square in the centre of Seville (Spain). The solution is defined as a green structure where the trees are the key part. However, the trees are planted small and are grow-slowly. Urban designs based on tree growth are estimated to reach design conditions 30 years after these trees are planted. That is why an innovative urban solar control prosthesis is required that adapts between winter and summer and that allows modifying its geometry according to the growth of the trees. The design of this solution has been made by studying in detail a real case with real problems. These problems have been characterized by temperature measurements, thermographies, transects for the evaluation of the heat island, level of incident irradiation, and actual use of space. Different alternatives for the rehabilitation of the urban fabric have been studied using computational fluid dynamics (CFD) simulations in ENVI-met. The optimal solution will reduce air temperature by 1ºC and surface temperatures by up to 12ºC, increasing the number of trees reaching close to 100% of the area covered to make them the natural mitigation solution in the future. The coverage developed in this work appears as a temporary solution until the trees reach a reasonable size that generates adequate shade to allow the use of the space during the summer months. The aim is to improve the habitability of cities and regain the prominence of people in them.

Keywords. Solar control system, greenery, habitability, open spaces.
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1. Introduction

The rapid growth of urban areas, coupled with the current health situation caused by COVID-19, highlights the need to use open spaces in daily life. Open spaces in urban environments provide benefits to pedestrians [1], however, the increase in heat waves puts people's health at risk, being of particular importance in pandemic outbreaks such as COVID-19 [2]. Most of the world's population will live in urban environments of low-quality environments by the middle of the century [3]. Therefore, it is necessary to act on open spaces through mitigation techniques to create sustainable and fresh spaces within cities, improving their habitability. These techniques include the reduction of air and surface temperatures, as well as the reduction of solar radiation. This study will focus on the review and analysis of solar control techniques.

Solar control techniques, based on the use of coverings, can differentiate between natural coverings through vegetation and artificial ones. The use of green infrastructure in the urban environment remains one of the most effective measures to cool the urban heat island [2], reducing air and surface temperature [4], as well as humidity and wind speed [5]. Artificial coverings, traditionally used as a shading strategy in the streets [6], behave in a similar way to the previous one in terms of improved comfort. The benefits of the natural technique will depend on the type of vegetation, height, and percentage of area covered, while its counterpart will depend on the optical properties, color, spatial distribution, arrangement, or size. Within this context, numerous authors have evaluated its impact on the urban microclimate. Thus, authors such as E. Chatzinikolaou et al. [7] study different bioclimatic scenarios of the vegetation plan through the ENVI-met numerical model, in Athens, highlighting the improvement in exterior comfort due to the inclusion of vegetation on the roadside, achieving a reduction of 5 in the PMV scale. Amiraslan Darvish et al. [6] study the impact of the configuration of trees and their species, comparing a real case with and without trees located in Iran, through simulations carried out with ENVI-met and DesignBuilder. They conclude that the case with trees manages to reduce the average monthly air temperature by 1.6ºC in July, while the average temperature in the cold months manages to remain 0.9ºC higher than the case without trees. Dalia Elgheznawy et al. [8] studies the effect of using artificial shading in the courtyard of a teaching center in Egypt. Through simulations in ENVI-met and Rayman 1.2, the results obtained show that adding 60% or more of sun protection, reduces the average air temperature by 1ºC, and the average radiant temperature by 24%. I. Lee et al. [9] compare both types, concluding that plant shading achieves better results than artificial shading in terms of temperatures and comfort level evaluated with the COMFA model.

As can be seen, the most used technique is the natural coverings, however, all studies evaluate the impact of the vegetation when the trees are mature, a phenomenon that only occurs when a high number of years have passed since its planting in the treated area. That is why it is necessary to use adaptive solutions to the growth of trees to achieve the objectives from the moment of planting, hence the interest of this study.

2. Case study

The area analyzed in this study corresponds to a square located in the urban center of Seville, with a surface area of 612 m^2 mostly covered by pavement. It is a consequence of the intersection of 3 streets, with high traffic density, that separate it from medium-sized buildings.

Fig.1 – Location

Seville is characterized by a warm climate, ranking within the Köppen-Geiger climate classification, as Csa, with hot and dry summers [10]. The average daily temperature of Seville in 2021 does not fall below 4ºC in cold months, being between 25-30ºC in the summer period, with maximum hourly temperatures of 43.7ºC in August. Therefore, the quality of the environment in the summer months is poor in the city center.
The current vegetation is scarce, made up of 8 small trees, which means that the square is in the sun almost all of the time. In order to know the current use of the square, a measurement campaign is carried out for 3 months through 2 cameras placed in the vicinity of the square. The results show that the use of the place at present is not high, serving as a passage area instead of a stay area. The area with the greatest influx is in the upper west part, corresponding to the entrance to the adjoining school. On the other hand, in order to know the current climatic situation, a monitoring campaign is carried out during the months of April to June 2021. Two fixed temperature and humidity sensors are installed with sampling periods of 5 minutes, for which a protective cover is designed to protect from rain and radiation.

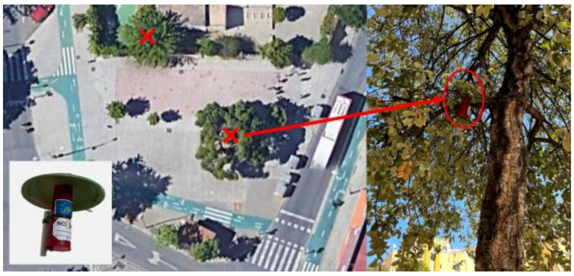

Fig.2 – Fixed monitoring

Fig.3 shows the temperature results for a week in May. It can be observed as the temperatures are between 15 and 35ºC, exceeding this temperature in several days. It shows again how in the intermediate months the temperatures remain high.

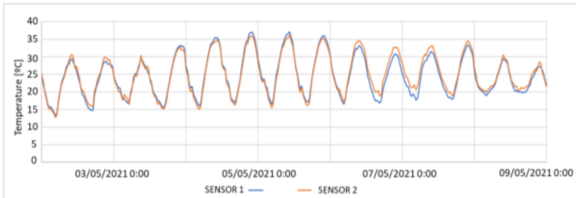

Fig.3 – Air temperature for a week in May

In addition to air temperature, surface overheating has a negative impact on human comfort [11], so knowing surface temperatures is an essential part of the city's sustainable design.
To find out the surface temperatures, measurements are carried out with the thermographic camera Testo 875-i during several days at different times of the day.

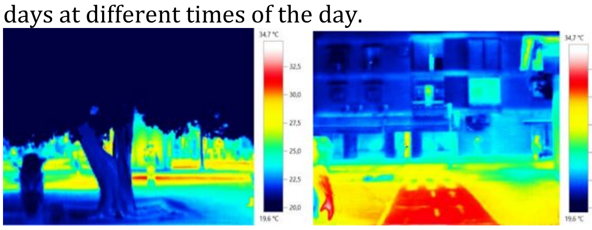

Fig.4- Thermographies of the square

Qualitatively, the temperature gradient between the sun and shade surfaces can be observed thanks to the existence of trees, demonstrating the need for them.

3. Intervention description

The intervention in this square aims to create a space within the city that enhances the relationship of the inhabitants with nature, in addition to achieving a natural coverage, lasting over time and with clear benefits in the environment, finally improving the habitability of the area. To do this, the aim is to generate a green cover made up entirely of vegetation, increasing the number of trees in the square by 500%, adding 5 new species to create a “green roof”. However, the trees are planted in their early growing season, so in the first years after the performance, there will not be the necessary shade to improve the exterior comfort of the area. The tree species used in the study are in their entirety of rapid growth, therefore estimating an average of years until reaching the adult size of 25-35 years. In the present study, the trees will be planted in the square with an average age of 5 years, so the average estimated time to reach adult size from their planting in the plaza is 30 years.

For this reason, as long as the trees reach the necessary size to provide the space with shade, it is proposed to create an "artificial green roof", defined as a green-structure, union of the existing vegetation, the new one of small size and an adaptative artificial cover. The artificial cover must be adaptable to the growth of trees and to the seasons of the year so that it provides shade in summer and lets in the sun in winter. According to the growth of trees, the intervention can be divided over time into 4 different scenarios:

1-Current scenario: The number of planted trees is small, without any additional shade element.
2-Green-structure scenario: The square has all the new trees planted, but with small dimensions. Artificial coverage appears.
3-Medium scenario: The trees have grown to medium dimensions, which allows the cover to be partially replaced.
4-Final scenario: The trees have reached maturity and their size is capable of shading the entire square. In this scenario, the role of the green-structure is no longer required.

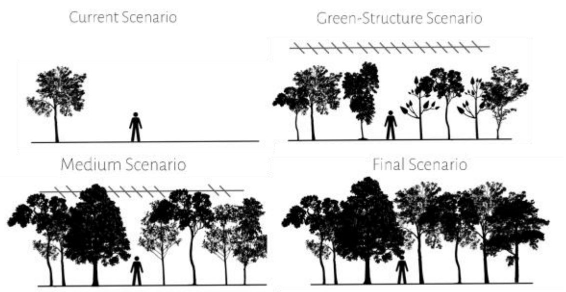

Fig.5 – Proposed scenarios

3.1 Adaptative cover design

The roof is made up of individual structures assembled. The design of each structure seeks to resemble trees in shape and size, however, to facilitate assembly and connection between them, they are designed in the shape of hexagons, formed in turn by six equilateral triangles independent of each other, with a height of 5 meters.

Fig.6 – Green-Structure

One of its main characteristics is the possibility of modifying its geometry in the short and long term. In the short term, it is possible to partially eliminate the triangular modules in winter months, allowing the increase in solar radiation, if necessary. In the long term, solar coverage allows adaptation to the growth of trees, permanently eliminating the necessary triangular modules when the tree reaches the required dimensions to cover that space. The modules eliminated in this case may be used occasionally in other parts of the city.

Each triangular module that forms the green-structure must allow radiation to pass in the winter months and block it in summer months. For this, slats are used as the structural system of the roof. To obtain the optimum geometry that achieves this objective, a sensitivity analysis of the different variables is carried out during summer days. Thus the distribution of slats is defined with an orientation (α) south-east, inclination (β) of -55º, width (w) of 0.1m and separation between them (s) of 0.1m (Fig. 7).

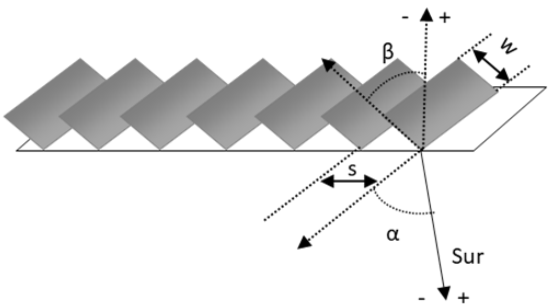

Fig.7 – Slat scheme

Therefore, it is achieved that, through adaptive artificial coverage, direct solar radiation decreases to a great extent, which will cause a reduction in surface and air temperatures, improving thermal comfort and habitability of the space allowing to recover life on the street.

3.2 Solution integration

For the vegetative shading strategy to achieve the expected cooling benefits, the correct location and arrangement of the trees is essential [8]. The mass of trees has both deciduous species that favor the entry of radiation in winter, and evergreen species, which guarantee shade in the summer period. It will be arranged in such a position that, given the solar path in the summer months, the entire square is shaded once the trees reach adult size (Fig. 8). In turn, the roof will be located in the western area marked by its predominant use.

Fig.8.- Square design

4. Impact assessment

4.1 Simulation

The different scenarios studied will be simulated following the ENVI-met microscale numerical model. The results obtained through ENVI-met simulations have been validated by real measurements in numerous studies [3], [12], [13], so in this document the climatic data of the tool will be used to evaluate the impact of the proposed intervention. The days selected for the simulation are April 16, and July 15, 2021, the latter being one of the hottest of that year. The initial values of the simulation, for each time of the year are shown in Table 1.

Tab.1 – Initial meteorogical conditions

Variable	Summer	Spring
Wind speed measured in 10 m height (m/s)	3	2.5
Wind direction (deg)	225	225
Min. temperature of atmosphere (ºC)	12	5
Max. temperature of atmosphere (ºC)	27	14
Min. relative humidity in 2m (%)	30	50
Max. relative humidity in 2m (%)	69	70

The vegetation will be modeled through ENVI-met database (Albero), modifying the dimensions of the species depending on the evaluated scenario. The albedo and transmittance values used are shown in Table 2.

Tab.2 – Vegetation propierties

Species	Albedo	Transmittance
Citrus x Aurantium	0.4	0.3
Platanus x Acerofilia	0.18	0.3
Ficus Benjamina	0.18	0.3
Celtis Australis	0.18	0.3
Coco plumoso	0.18	0.3
Paulownia	0.60	0.3
Cercis Siliquastrum	0.60	0.3
Albizia Julibrissin	0.60	0.3

Following the arrangement of the vegetation and taking into account its dimensions, as well as the location of the roof in those scenarios in which it is in use, the geometric modelling is carried out, presented in Fig. 9. The resolution of the grid is 1 metre per square cell, reaching a grid model of 60x70x40 meters.

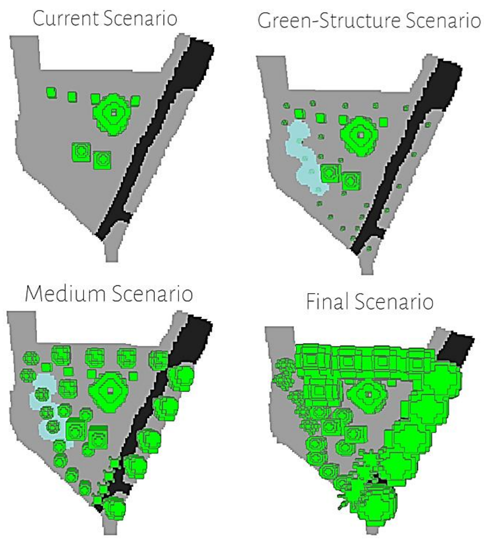

Fig.9 – Simulations models in ENVI-met

5. Results

In the first place, it is worth highlighting the final result of the plaza made through visual models that allow us to know the scale of the intervention.

Fig.10- Final realistc model of the square

On the other hand, the results obtained can be differentiated between results related to environmental changes in terms of air temperature, radiation incident on the square and surface temperatures and the consequent changes in thermal comfort.

5.1 Enviromentals variables

After the simulation carried out, the air temperature in the square at 1.5 meters from the ground is obtained, to know the conditions at an average height of the pedestrians both in summer and in spring at different times of the day.

As can be seen in Fig. 11.a, referring to the air temperature in the square for the four scenarios on July 15 at noon, the inclusion of the vegetation reduces the temperature by around 1ºC in the area with the highest concentration of vegetation for extreme cases. It also manages to reduce the negative effect of hot surfaces such as the asphalt that surrounds the square. The effect is similar to 6:00 p.m. on the same day (Fig. 11.b), where the temperature of the place is higher due to the accumulation of heat during the day, achieving temperatures close to 35ºC in the surrounding areas. Inside the plaza, the temperature reduction in extreme scenarios is 0.5ºC.

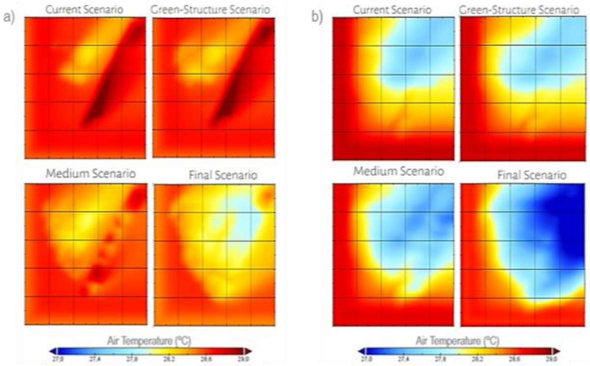

Fig.11 – a) Air temperature in the 4 scenarios for July 15 at 12:00h. b) Air temperature in the 4 scenarios for July 15 at 6:00 p.m.

For April 16 at noon, a reduction in air temperature of up to 1ºC is achieved again in extreme scenarios. The reduction of air temperature in the Green-Structure Scenario, where the vegetation still has a very reduced size and only the artificial cover appears, is reduced, showing the clear importance of the vegetation in the reduction of temperature. However, it is notable in both seasons of the year, as the artificial structure manages to slightly improve the thermal conditions.

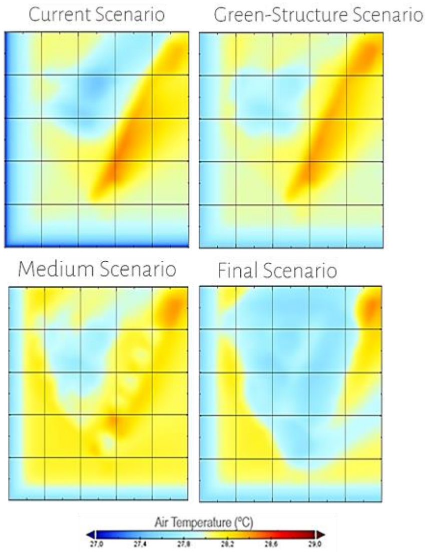

Fig.12 – Air temperature in the 4 scenarios for April 16 at 12:00h

Regarding the surface temperatures, the differences obtained are significant. On July 15 at noon, the surface temperatures are reduced by around 9ºC in the areas where vegetation is added. It is worth highlighting the improvement obtained in the asphalt area with a reduction of 12ºC thanks to the effect of the vegetation. During the afternoon, again, temperature differences of the order of 10ºC are achieved with a maximum of 12ºC. The effect of the artificial cover, in this case, supposes a reduction in temperatures of 6ºC, below that achieved through the vegetation.

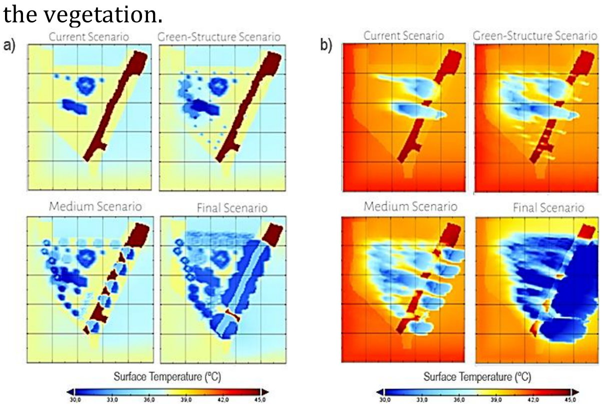

Fig.13 – a) Surface temperatures in the 4 scenarios for July 15 at 12:00. b) Surface temperatures in the 4 scenarios for July 15 at 6:00 p.m.

The variation in surface temperature on April 16 at noon, again, achieves a reduction in extreme scenarios of the order of 10ºC, with a maximum of 12ºC in the case of the asphalt area. For the intermediate season, the effect of the artificial cover is closer to the effect produced by the vegetation.

Finally, the effect of the intervention on incident radiation is remarkable. Thus, Fig. 14 shows the simulation results obtained for July 15 at noon, where the incident radiation on the square changes from 1000 W/m^2 until it is practically nullified in extreme scenarios. The use of artificial cover allows creating a meeting space where radiation is 60% lower, before the total growth of vegetation, improving the habitability of the area from the beginning of the intervention.

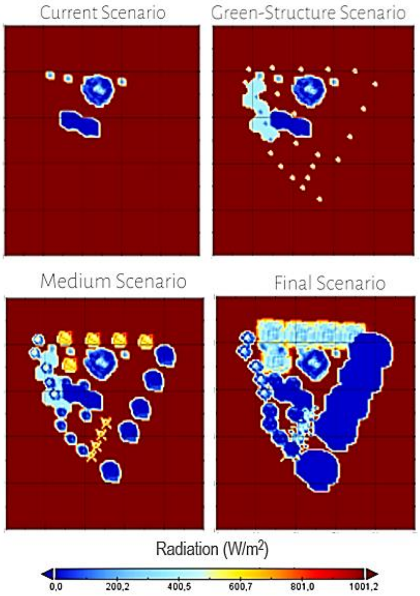

Fig.14 – Radiation in the 4 scenarios on July 15 12: 00h.

For this same time in the intermediate period, the results are very similar, managing to reduce almost all the radiation.

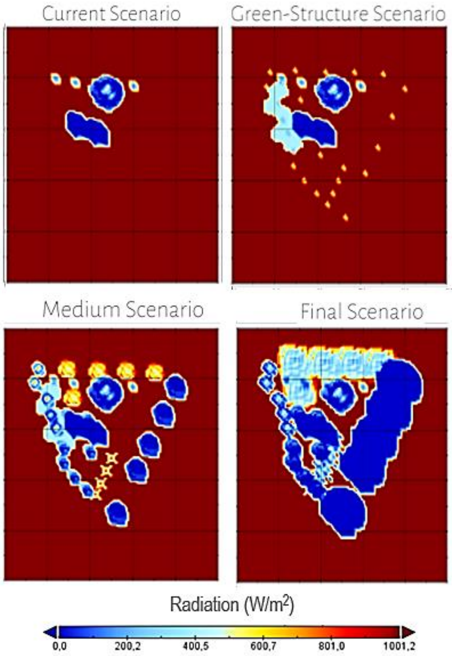

Fig.15 – Radiation in the 4 scenarios on April 16 12: 00h.

6. Conclusions

The innovative solution study has been carried out in a square in the center of Seville (Spain). The intervention based on the innovative integration of adaptive solar control solution combined with vegetation as a bridge between the current situation and the growth of the trees, achieves a place within the city throughout the year where climatic conditions improve considerably, thus improving the habitability of the area. A green and pleasant space is generated. It is possible to reduce the air temperature by up to 1ºC in the final situation, as well as up to 12ºC in the surface temperatures. On the other hand, the initiating radiation, the main cause of discomfort outdoors, manages to be reduced to almost its elimination. It is possible to highlight the necessary use of artificial cover as an intermediate step between the planting of the vegetation and its final growth, being an innovative solution that manages to improve the climatic situation of the square from the beginning of the intervention.

7. Acknowledgment

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8. References

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