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Influence of Groves on Daylight Conditions and Visual Performance of Users of Urban Civil Infrastructures

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Abstract: The control and efficient use of daylight is a difficult task due to its seasonal and hourly variation. Although it is matter of active research in indoor lighting due to the necessity to light human tasks at any hour of the day in a sustainable way, little attention has been paid to the impact of daylight on visual performance, safety and ergonomics of citizens, especially pedestrians in urban areas. This attention is even lower when dealing with the interaction between daylight and urban groves, which is an essential element in cities due to a wide variety of benefits like shadowing, CO_2 absorption, natural aesthetics, noise protection and many others. In this work, the interaction between daylight and typical urban trees in one city with high levels of insolation (Granada, in southern Spain) has been studied. The results, conclusions and proposals for a more sustainable urban planning are analyzed and presented.

Keywords: daylight; urban plantations; visual performance; insolation; civil infrastructure

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1. Introduction

Street and urban lighting are topics of the highest importance whose target is to ensure the safety of people and goods, as well as the well-being of people carrying out their tasks. One way or another, it has always been understood that all the concepts in urban lighting refer to artificial illumination during nighttime. Thus, the literature in the field of street lighting is extensive and deals with safety [1–4], energy and resource optimization [5–8] or a mixture of several aspects [9–11]. However, very little or no research has been carried out about the impact of daylight on visual performance of pedestrians in urban areas. This is an important gap that needs more research because safety, security and well-being are also matters of concern during the day.

Independently of the nature of the light source (the Sun or electrical lampa), most situations with indoor and outdoor lighting take place through a basic process that consists of the succession of the following steps [12]:

(1) Luminaries emit luminous flux, ϕ. The flux per unit of solid angle is the so-called luminous intensity, whose spatial distribution in different directions is expressed by the matrix $I(\theta, \varphi)$.

(2) The luminous flux received per unit of surface on the working planes from all directions, which is the illuminance, E.

(3) Different working planes have different capabilities to reflect the incident illuminance. This is the "reflectance", which depends on the material, the incident angle and the reflection angle, $\rho(\alpha, \beta, \gamma, \delta)$.

(4) The luminous flux is reflected by the working planes in all or some directions. The reflected flux in one given direction, such as the eyes of a typical observer, is the luminance, $L(\theta, \varphi)$.

(5) The luminous flux reaching the observer's eye, after refraction through the ocular media, will illuminate the retina (retinal illuminance, E_r) to initiate the visual and non-visual paths.

This process is typical when the working plane is not a primary source, but lighting is performed by reflection. This is the most common situation in outdoor and indoor lighting, where the configuration and reflective properties of a street and its environment [1,2] and a room and its furniture [12,13] have a deep impact on the visual performance.

Since human beings receive about 80% of sensory information through the visual system, optimal lighting is the key for safety, health, well-being and many other essential aspect of life [14]. Furthermore, the necessary orientation of human life and activities towards sustainable development according to the wide framework of the Brundtland Report [15] and Sustainable Development Goals [16] make accurate and sustainable lighting a critical must. In other words, light sources and lighting installations with low impact in energy consumption, raw material use, waste management and financial costs in both initial investment and maintenance, are some of the ways towards a sustainable world [17]. Although the Sun is the source fulfilling these requirements, the efforts to profit from its light have not been the same in the different branches of engineering and architecture. Thus, the models to use daylight in an ergonomic and sustainable way in indoor spaces are more and more sophisticated and exact [18–22], whereas little or no works on daytime outdoor lighting can be found in the literature.

In the following sections, some considerations about daylight, its interaction with urban groves (a key element in cities) and the results of a measures campaign to study this interaction between daylight and urban groves will be presented and discussed in order to optimize spaces and the well-being and safety of citizens.

1.1. Urban Daylighting: An Ignored Gift of Nature

In the development of urban planning studies, few modern architects and engineers have paid attention to the importance of daylight and have done so relatively late.

The architectural school of Chicago started considering the importance of daylight in new urban developments during the 1880s. In 1883, the revolutionary project of the Home Insurance Company office building was required to be "well lighted"—a new paramount feature. The developer considered that artificial lighting at the time was expensive and dangerous. John Welborn Root declared that the new skyscrapers' "great architectural problem" was the provision of daylight [23]. By the 1890s, lighting standards had been agreed among the members of the school of Chicago. The beginning of the new century brought extensive uses of the skeleton frame in the *Loop* skyscrapers, whose glass curtains changed the urban development and the architectural design paradigm. The Chicago school, with famous members such as Frank Lloyd Wright, remained an important global reference until the end of the 1920s, influencing the first famous wave of urban planning engineers in Europe. One of the main lessons learned to provide daylight indoors in architectural projects was that a new urban planning paradigm was required. Wider streets and roads, open spaces and plantations became interesting designs in new development construction projects, suggesting less dense urbanization distributions.

The most important European urban planners in the late 19th century developed this paradigm, considering the central importance of open spaces and daylight in their theories about projecting city transportation and building distribution. Arturo Soria's "Linear City" (1892) and Ebenezer Howard's "Garden City" (1898) are the most notable related projects—Sir Howard even lived in Chicago just after the 1871 "great fire", learning about the new influences of the city's reconstruction. Both of their projects partner open spaces' daylight with the plantation of urban groves.

This new urban planning paradigm, in Europe, is then assumed by architects and engineers alike in their construction projects. After the 1920s, Eduardo Torroja refers to "optic sensibility" as paramount in aesthetic design, and considers Gaudí as an important reference in this matter [24]. For Torroja, following nature in formal design is the key for aesthetic urban projects. In 1941, the first solution for commercially viable insulated glass is invented by Hopfield and Haven, providing new important tools for daylight-friendly design in contemporary architectural construction [25].

1.2. Urban Groves: Contemporary Design Considerations

Growing conditions for urban groves are inevitably different from those related to the natural environment. Traffic, space limitations, a dense pedestrian population, health conditions and climate specifics are some of the constraints that affect the design engineering problem when trying to ideate a new urban grove plantation [26].

Thus, a number of variables are usually considered: traffic lane distribution, aesthetics provided by different species, building and pavement repairs due to excessive growth of roots and branches, plantation spacing, allergic reactions due to pollination processes, soil requirements and preparations, ecological preference for native species, hydric requirements, etc.

However, one the main features of groves that urban populations enjoy is the shadow they cast onto the city lanes, roads and sidewalks, relieving pedestrians and traffic vehicles alike of an excessive level of illumination and heating, especially in summer months [27,28]. The reduction is carried out by a variety of physical phenomena, the most important being the reflection and the transmission of daylight rays, and heat absorption as a less relevant side effect.

The selection of adequate species for this purpose and the determination of variables such as tree spacing or the daylight/shadow reduction ratio are paramount, especially in areas with high levels of daylight insolation.

A case study has been carried out in Granada, southern Spain, to study the impact of each of the species frequently used for urban groves on sidewalks and in gardens, on the parameters related to visual performance of pedestrians. August was selected as the most notable month for insolation values, and measures were carried out around solar noon times.

2. Materials and Method

This research has been carried out in squares with intensive pedestrian daily life in the city of Granada (south of Spain, Figure 1).

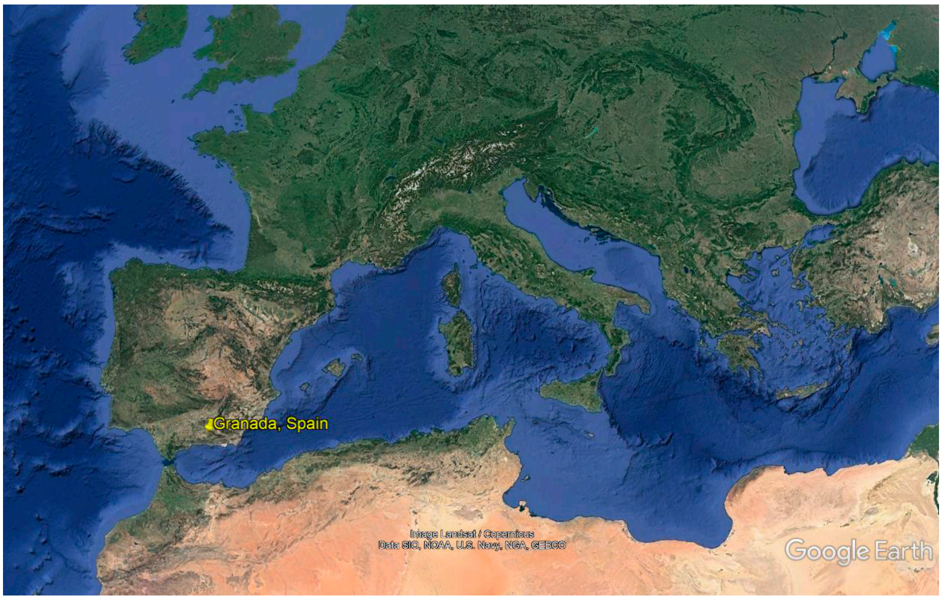

Figure 1. The city of Granada and its situation in southern Europe and the Mediterranean area. Source: Google Earth PRO v.7.3.4.8248.

The methodology followed can be summarized in the following steps:

(1) Bibliographic search of the literature on the impact of daylighting on visual performance of pedestrians in urban environments.
(2) Choice of typical urban squares with a high traffic of pedestrians incorporating the most common tree species in the urban environments of Mediterranean cities.
(3) On-site visual inspection and identification of species.
(4) Measurements of the photometric quantities involved in the visual process.
(5) Data analysis.
(6) Analysis of the results obtained and drawing of conclusions.

In particular, the data acquisition (identification of trees species and photometric measurements) was performed in five squares (locations 1 to 5). The groves of these urban road-adjacent squares consist in very common tree species in the cities of Spain: "Platanus Hispanica" (location 1), "Fraxinus Ornus" (location 2) and "Acer Negundo" (locations 3, 4 and 5). Figures 2–7 show the chosen squares, their groves and their location in the urban area of Granada.

Figure 2. Location 1 with "Platanus Hispanica" trees.

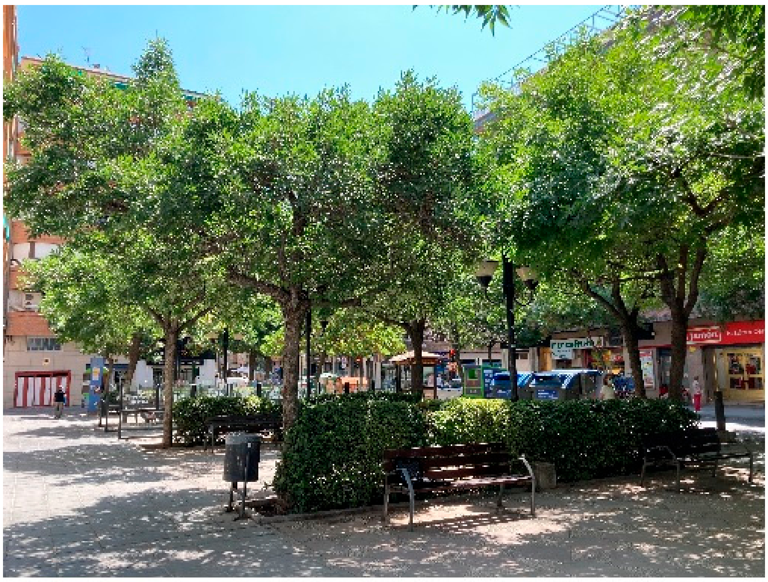

Figure 3. Location 2 with "Fraxinus Ornus" trees.

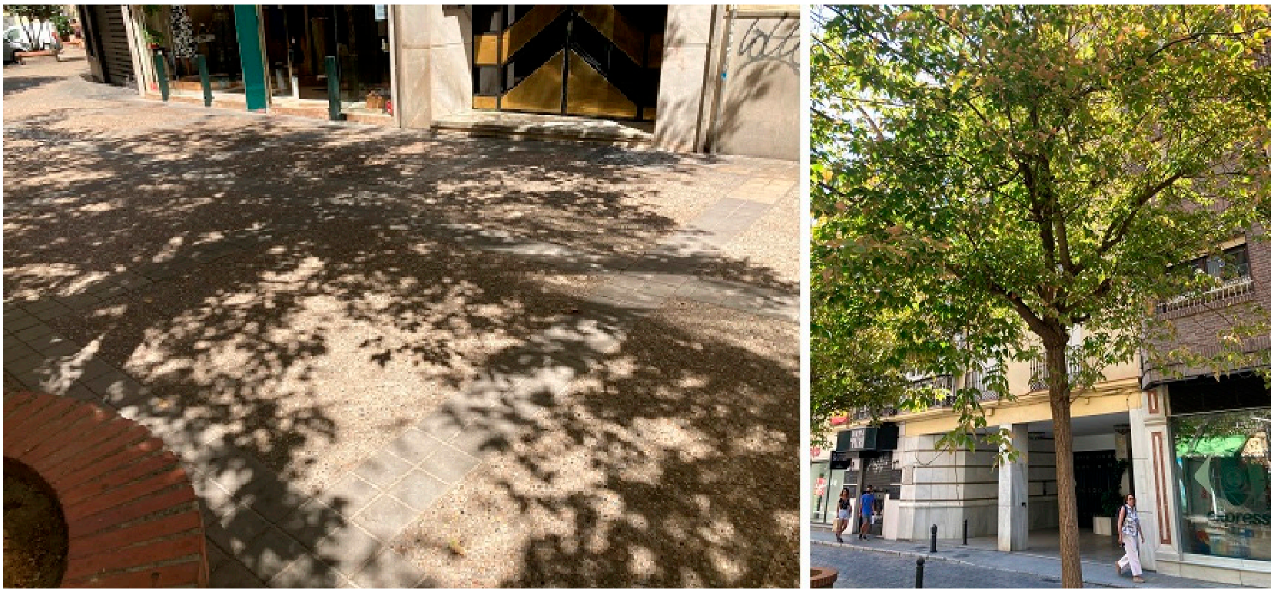

Figure 4. Location 3 with "Acer Negundo" trees.

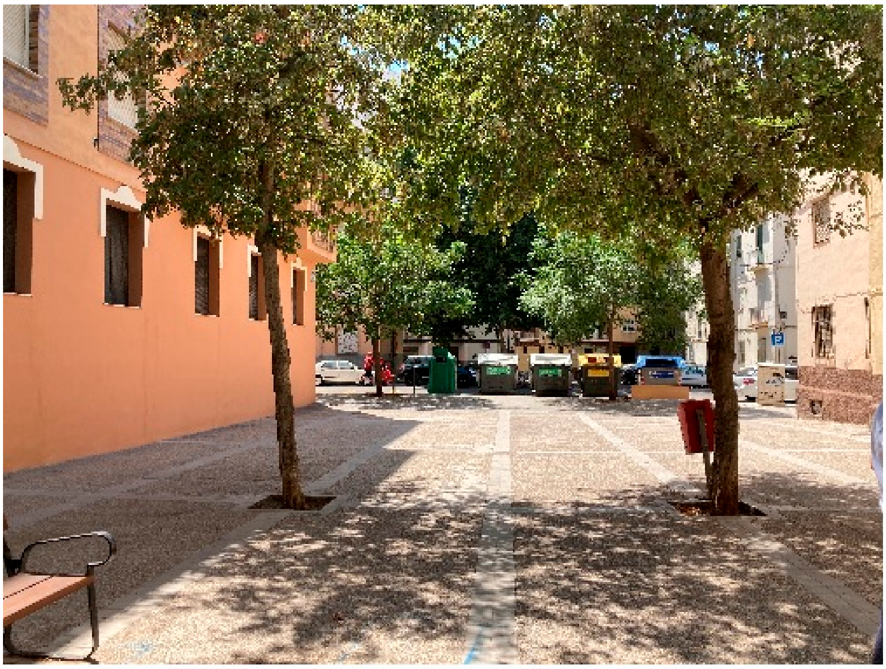

Figure 5. Location 4 with "Acer Negundo" trees.

The measures were carried out on a completely cloudless summer day (3 August 2021) between 13:00 and 15:00, the hours of maximal insolation in that region. This choice was not random, but intentionally made to study the effect of trees on daytime lighting conditions. At other hours, early or late in the afternoon, most of the solar illuminance is not direct but diffuse and the trees play a less important role.

The measured quantities were horizontal illuminance on the ground (main visual plane of pedestrians), vertical corneal illuminance on the eye of a typical 1.75 m pedestrian and luminance from the infinite measured along the horizontal line towards the pedestrian's eyes. From these data, average horizontal illuminance on the ground (E_m) average vertical illuminance on pedestrian's pupil (E_v), average luminance on the horizontal line of sight (L_{hls}) and average illuminance uniformity on the ground (U_m) were calculated.

The instruments used were a CL 200-A lux meter and a Hagner Universal Photometer S3 for illuminance and luminance measurements, respectively. In order to precisely focus the surface whose luminance is measured, the S3 Photometer incorporates a telescopic sight showing a black point which covers an angular extension of 1º.

Figure 6. Location 5 with "Acer Negundo" trees.

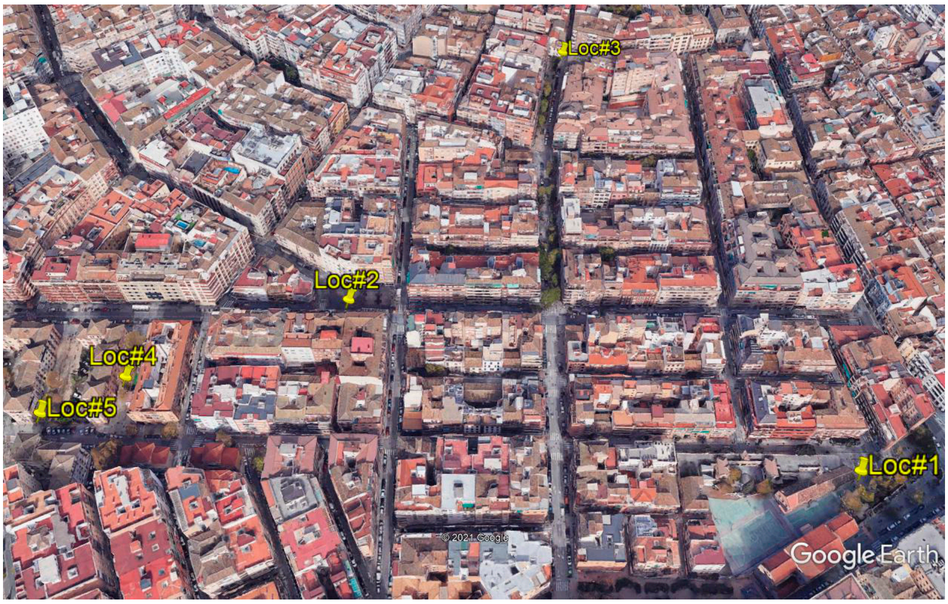

Figure 7. Situation of the squares in the urban area of Granada. Centered at 37°10′08.70″ N 3°36′06.81″ W–N oriented. Source: Google Earth PRO v.7.3.4.8248.

3. Results

The results of the measurements carried out have been considered from two different perspectives. Firstly, all the above mentioned average parameters have been calculated, including the most important quantity regarding visual performance in urban environments [1,29,30], road sidewalks and pedestrian squares, which is the horizontal illuminance on the ground. In Table 1, its average has been calculated including all the values.

Table 1. Total average illuminance and luminance in all the areas.

Location	Species	E_m (lux)	U_m	E_v (lux)	L_{hls} (cd/m^2)
1	Platanus Hispanica	17,760	0.3412	4537	2249
2	Fraxinus Ornus	15,246	0.0918	3269	627
3	Acer Negundo	14,621	0.2873	2773	683
4	Acer Negundo	18,398	0.2174	16,555	1867
5	Acer Negundo	18,674	0.1607	14,635	1658

Secondly, in Table 2, the average horizontal illuminance on the ground has been calculated considering only the zones under the trees' shadows. The reason for considering this last parameter is that the squares under consideration have wide shadowed zones and many visual tasks of the pedestrians can be carried out only in this zone. Table 2 also shows the percentage of illuminance attenuation by the trees. This parameter is very important because the high values (above 90%) highlight the remarkable role of the most common urban groves in urban environments.

Table 2. Illuminance depending on the considered zone (shaded or sunny), average uniformity in the shaded zone and attenuation of the trees.

Location	Species	E_m Shadow (lux)	E_m Sun (lux)	Attenuation (%)	U_m Shadow
1	Platanus Hispanica	7054	92,700	92.4	0.859
2	Fraxinus Ornus	4810	88,300	94.6	0.291
3	Acer Negundo	7239	66,300	89.1	0.580
4	Acer Negundo	7811	92,500	91.6	0.512
5	Acer Negundo	8541	89,600	90.5	0.351

It is also remarkable that the average illuminance uniformity in the shaded zones is relatively high, comparable in some cases with the required uniformity in nighttime lighting. This means that the well-known variability of natural illumination can be attenuated by introducing an appropriate grove. As demonstrated in this work, even the uniformity, which is one of the most difficult parameters to fulfill in nighttime lighting, can have high values in shaded zones during daytime.

"Platanus Hispanica" trees, present in location 1, allow a very high uniformity with one of the highest attenuations. This is due to their height and leafy crown, which also allows for covering a wide zone with just a few trees. Other species, such as "Fraxinus Ornus", give high attenuation with lower uniformity.

4. Discussion and Conclusions

A quantitative analysis of the impact of urban groves on the visual performance of pedestrians was based on the most common species in the Mediterranean area. It is the first one on this topic since other studies on urban groves were limited to other parameters, such as thermal comfort.

The results highlight that the synergy in the polynomial daylight–visual perception–urban grove–well-being, although accepted in a natural way, presents deep implications that must be seriously considered when planning new urban spaces or remodeling existing ones.

Some of the main items to consider are the following:

(1) The tree species in urban spaces such as squares must be chosen attending to several factors. Classically, these factors have been aesthetics, shadows, hydric conditions and potential interactions with buildings and other urban facilities. However, the visual performance and the accurate values of urban road and street pavements' average

illuminance and uniformity are strongly conditioned by the grove during daytime. Thus, they must be considered during the choosing of species.

(2) The photometric parameters, especially the illuminance on pavements, walls and pedestrians' eyes, are highly variable during daytime due to the apparent path of the sun across the sky (ecliptic). The seasonal variations in solar altitude and the changing weather conditions (clouds, aerosol charge and others) also impact on the visual conditions of pedestrians. This means that one species can be a good choice for a traffic area, or be more suitable for a pedestrian space. Climate conditions and air quality should also be considered as important factors in order to attain a rational design, a solution that combines aesthetics, perceived security, ecological value and solar protection as paramount target results.

(3) In spite of the abovementioned variability, an appropriate grove can produce high average uniformities in shaded zones. This is the case of "Platanus Hispanica", whose leafy crown and height make it one of the most common choices in cities in sunny countries like Spain.

In summary, the grove is an essential element in sustainable urban infrastructures, not only for the classical benefits of plants in terms of CO_2 absorption and others, but to modulate the daylight, especially in very sunny areas.

As potential limitation of this study, more measurements are necessary in other geographical areas with different tree species and daylighting conditions. It is clear that the levels of insolation in northern Europe are quite different from those in the location where this study took place (south of Spain, 100.000 lux on the ground at noon in summer). Consequently, the weather and thus the tree species used in urban environments and squares are also different. Furthermore, the strong contrast between sunny and shaded areas of the sidewalk or squares would be less acute in northern latitudes. But, although this research is location dependent, it is necessary to keep on mind that areas of high insolation like this one are the most sensitive, which makes the choice of this environment coherent.

Future studies in other locations with different insolation conditions and tree species will be able to adopt the results of this research so that daylight is definitively included when dealing with modern and sustainable cities.

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