Methods of quantifying the visual filtering of vegetation to minimize the impact of buildings on the landscape

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Abstract:

Vegetation is used by landscape planners and designers to reduce the visual impact of buildings. The choice of the species to be used depends on the characteristics of the crown canopy filtering. Nevertheless, the information on crown canopy filtering is scarce. This work examines the degree of filtering in canopy architecture of *Quercus pyrenaica.* The district of the Ambroz Valley, in Cáceres Province was chosen as the experimental area for the purposes of this research, and here *Quercus pyrenaica* were chosen as the most representative species. Two methods were selected for this study: hemispheric photography and vertical photography. All data was gathered during the summer as this is when the canopy of the species analyzed reaches its maximum leaf area index. The main aim of this research is to compare the hemispherical photographic method for calculating the amount of light that passes through the canopy, with that of vertical photography to obtain filtering percentages in plants.

Key-Words: Vegetation; filtering; visual impact; landscape integration; photographic treatment; Quercus pyrenaica

1 Introduction

1.1. Vegetation as an element in building integration

There have been several attempts to deal with this topic since the appearance of various articles in the 1980s on the role of vegetation in the perception and aesthetics of the surroundings (Smardon, 1988).

One way of integrating buildings in the surroundings is to create plant screens that totally or partially hide the buildings (Smardon, 1988; Bosanac, 1990). To hide the buildings totally is not necessarily always the best solution. Sometimes a partial covering may be preferable in order to create a variation of the visual characteristics of the building. Thus, the form, line or scale of the building are modified by the vegetation, resulting in better integration in the surroundings (Jaeger & Reffye, 1992).

The existing relationships between the building's visual elements and those of the surroundings may produce visual continuity, diversity without contrast, compatible contrasts, or poorly compatible contrasts (Smardon, 1986; Barthelemy et al., 1989; Steinitz, 1990). The vegetation will be used to eliminate or reduce as far these contrasts as possible, since the less the contrast, the better the integration will tend to be (García et al., 2003).

Firstly emphasis should be placed on hiding the building completely with plant screens when, due to the building's morphological characteristics, it is impossible to attain good integration in the landscape (Lewis, 1999).

The vegetation screens for partial concealment can modify the perception of certain characteristics which define the building, such as line, form and scale.

Both line and form are elements which are defined by their complexity and orientation (Español, 1998). Furthermore, line is affected by another parameter which is clarity, while form is affected by geometry. Meanwhile, scale is defined by scenic occupation and scale contrast. The influence of vegetation on the above parameters could have an indirect influence on perception of line, form and scale of the building. Consequently a reduction in the contrasts could be attained and, therefore, a possible optimal integration solution (Barthelemy et al., 1989; Steinitz, 1990).

The parameters which define the line are: clarity, complexity and orientation: (Español, 1998; García et al., 1999; García et al., 2010).

Clarity refers to the line's degree of definition. The more intense and continuous the line, the clearer it is. Silhouette lines tend to be clearer, and generally possess greater definition than boundary lines. There are lines insinuated by a succession of similar objects in series, of minimal clarity. The clear lines tend to overrule the insinuated lines (Neufert, 1982; Español, 1995).

Complexity is the simplicity of the line, to changes in direction, breaks or marked undulations in the continuity of the line. In a scene, the simple continuous lines prevail over the more complex discontinuous broken ones (Neufert, 1982; Español, 1995).

Orientation is the arrangement of the line relative to the horizontality of the landscape. It can be studied by measuring the angle the line to be studied makes to the horizontal of the photograph. Verticality predominates over all other directions in visual perception (Neufert, 1982; Español, 1995).

Form is defined by its geometry, complexity and orientation (García & Hernández, 2001; García et al., 2010).

Geometry is the make-up of the form, ranging from pure, classical, regular shapes such as the square, the sphere or the prism, to irregular or amorphous shapes. The fact that the observer is attracted by pure shapes means that these tend to predominate in the scene over irregular forms (Humphreys et al., 2000).

Complexity is the degree of simplicity in any shape; visual perception is dominated by simple elements which are easily understandable (Neufert, 1982; Español, 1995).

Orientation is the situation relative to the overall horizontality of the landscape. Verticality of form tends to draw the viewer's eye, particularly if this verticality surpasses the skyline and is visible against the background of the sky. It can be quantified in the same way as the orientation of lines (Neufert, 1982; Español, 1995).

The greater the difference between the lines of the surrounding and those of the buildings, the greater the contrasts will be. The surroundings do not usually present intermediate lines, and buildings usually present clear lines. When vegetation is introduced which partially hides the buildings, the clear lines that make up the buildings manage to become intermediate lines (since the vegetation makes us perceive these lines as having less length and saturation, so diminishing their clarity). As a result, the "break" is reduced between the clarity of the lines that form the surroundings and those that compound the rural buildings. Therefore, the contrasts could also be diminished. (Smardon, 1986; García et al., 2010).

Contrast is essential for the control of visual effects and perception (Langer, 1953). It is vital for shedding light on the contents and the communication (Langer, 1953). The contrast between the surroundings and the creation may be compatible or of low compatibility (García et al., 2010):

- Compatible contrasts: The creation of adequate contrasts is one of the most important aspects in landscape quality; the value of the landscape increases when these contrasts are compatible and create unity in the scene.
- Non-compatible contrasts (PCC): The design guidelines or criteria must have three characteristics: efficiency, appropriateness and feasibility. This is not easy when an innovative touch leads the building to clash with the natural landscape.

The buildings introduce very regular prismatic shapes into the surroundings. This can cause contrasts with the generally irregular shapes of the elements that make up the natural landscape (Oppenheimer, 1986; Berezovskaya et al., 1997). The vegetation hides the excessively pure form of the buildings, giving a certain sense of irregularity which would produce compatible contrasts between the building and the landscape (Hernandez et al., 2003).
The predominant orientation of the lines that make up the surroundings is the horizontal (Español, 1998). Buildings introduce isolated vertical lines which may give rise to contrasts. When vegetation is added, new elements of reference are included in the scene, which, with their verticality, harmonize the whole by probably reducing these contrasts (Luttik, 2000).
The addition of natural vegetation elements, whose forms display an orientation similar to that of the building, means that the building attains better integration in the surroundings, by diminishing the contrasts (Español, 1998; Henderson et al., 1998).
The screens are to be of appropriate size and leafiness, so as partially to hide lines and forms (Muhar, 2001). Furthermore, if necessary, the screens of vegetation are to be staggered, using native trees and bushes, of varying sizes, leafiness and speed of growth (Purcell & Lamb, 1998). These screens are to be placed in front of the arrises or, in the case of the ends of the building, behind them too. This avoids the impression of the building standing out against the skyline.
Scale is the relationship which exists between the dimensions of a building design and the landscape elements around it. In a landscape two basic kinds of scale are to be observed: (Español, 1998).

- Absolute scale: this refers to the absolute measurements of the objects in the landscape, understood in relation to the size of the observer.
- Relative scale: this refers to the proportion relations as a whole which exist between the dimensions of an object in a scene.

The characteristics of scale defined by Español in 1998 are as follows:

- Scale contrast is the size distribution of all the objects in the scene. Scale contrast can be lowered when the scales are staggered (i.e. when there are small, medium-sized and very large objects). It can be high in the case of highly contrasted scales (i.e. only very small and very large objects); or it can be non-existent when the scales are unitary (i.e. all the objects are of similar dimensions).
- Scenic occupation is determined by the dimensions of a certain object in relation to the dimensions of a real landscape space. It could be stated that large, heavy objects within an enclosed space, tend to dominate delicate, light, small objects in open spaces.
- The dominion of the visual field is the proportion of visual plane of the observer that is occupied by a particular object. It depends on the observer’s view point.

Therefore, in order to reduce the negative visual effects that a large scale building can have on the scene, it is crucial to bear in mind parameters like scenic occupation and scale contrast, which have such a great influence on the scale.
As for scenic occupation, it should be mentioned that the greater the occupation, the greater the importance of the element in question. In this sense, vegetation can “cover” a building that gives excessive scenic occupation in such a way that this occupation is not so obvious (Jakle, 1987; Zonneveld & Forman, 1990; Hernández et al., 2004a).
As for scale contrast, the size distribution of the elements that form the surroundings can give rise to marked visual discrepancies (Español, 1998). Hence the need to compare the height of the building with that of the other dominant elements. If there should be contrasts, they can be solved by including vegetation as a dominant element, so as to provide new heights for comparison. Their value would be to harmonize the scene (Henderson et al., 1998), without needing to hide the building, but rather to use staggered vegetation screens. By incorporating new reference heights, the contrast produced by the various scales present in the scene would be softened (García et al., 2010).

2. Methodology

3.1. Determining Factors of the Species

Vegetation, like every living thing, presents certain genetically defined structural and growth patterns (genotype). But as an element which is part of an environment, it is greatly affected by this: either by abiotic agents like meteorology and physiographic conditions, or by anthropic agents such as human activity. Its vegetative structure may show variations due to the severity of these external actions (phenotype) (Herrera, 1992).

For the generalization of the method and the search for experimental plots, a search was carried out for the vegetative structures that were present in great numbers in Spanish context. The National Forest Inventory (ICONA, 1994) provided data on the phenotypes of Pyrenean Oak in all the woodlands where this species were dominant. Thus information was gathered from the Spanish provinces where this species grow.

The species, which are the object of this research, show tree conformations broadly defined according to the growing system in which man has used them.

Oak can be found in Form A, providing they are spindle-shaped trees. These have timber-bearing trunks of 4 meters or more, branching at the top. Another variant is Form B in fruit-bearing production, wherein the main trunk branches lower than the height of 4 meters. These belong to the group of species mentioned in the National Forest Inventory (ICONA, 1994).

The research was completed with data-gathering from young oaks. This provided growth sequencing from youth to maturity in Forms A and B.

2.2. Research Area: Municipality of Hervás

The rural research area under study is the municipality of Hervás. It lies at 40º 16' 38" Latitude North and 5º 51' 25" Longitude West in the District of the Ambroz Valley, in the north of Cáceres province, in the foothills of the Gredos and Béjar ranges.

Once the species to be studied had been chosen, as well as their tree architecture and conformation, a search was made for experimental plots which, within the study area, met the criteria laid down.

Data from the Third National Forest Inventory (ICONA, 1994) is used for Forms A and B with the aim of locating places where the trees adapt to the dasometric averages of the trees under study. Ten examples were chosen for species studied: Oak in Form A and B, were selected in order to complete the research and the series of data from youth to maturity in Forms A and B that means a total of 30 trees under study. Each tree had its relevant dasocratic measurements taken using a VERTEX Laser Hypsometer (height, branching height, canopy diameter and width of canopy) as well as the UTM coordinates for its subsequent treatment in a Geographic Information System collected by GPS.

Thus, two experimental plots were obtained within the municipality of Hervás for developing the research methodology in rural environments for Form A, B and C tree conformations.

2.3. Photography in the field

The photos in the research were taken on a CoolPix 995, Nikon digital camera. Four photos were taken for each tree, pointing North, South, East and West. They were always orientated towards the Magnetic North in order to verify the cardinal direction being photographed, and to standardize the field method and subsequent analysis (Valladares, 2006). So as to get the degree of filtering of the trees, the photos were also taken following the two methods below, but using the same camera, for subsequent comparison and standardization of results.

As mentioned earlier, the use of a hemispherical lens is accepted and widespread in the scientific community. Vertical photography was also used in this study as this is the vision that the average observer has of the landscape under normal conditions. Both methods provide data from different viewpoints on tree canopy filtering.

A. Method 1: hemispherical photography

This method allows us to obtain images of the ground projection of the whole canopy. A 180º fish-eye lens is required to generate these images. This must be mounted on a digital camera set horizontally on a tripod at a certain distance above the ground. In this study the height above the ground was 1.5 m. so as to clear the scrub. Also the tripod and camera was set up at 40 cm from the tree trunk, in order to obtain the most complete information about the canopy. Lastly, the photos were taken at times when the sun was not at its zenith, so as to avoid refraction and flares in the pictures taken, which could partially distort the amount of foliage to be analyzed (Fig 1).

Fig. 1. Hemispheric photo of a Form A oak

After taking the photos, the next step is to analyze digitally the canopies photographed to work out an average value for the filtering of each tree.

At this point, a quick and simple way of measuring this parameter is by quantifying the number of pixels in the photo which are occupied by foliage.

Turning the photos into black and white (negative image) is standard procedure (Montero *et al*., 2008) which facilitates this quantification process. For this step to be as objective as possible, the transformation threshold to black and white cannot be set at random at the whim of the analyst. Generally speaking, this procedure must be standardized to minimize the counting errors. The methodology proposed by Nobis & Hunziker (2005) has been chosen for this reason. The authors prove that the best way to achieve a threshold for converting the photos into black and white is by working in the blue channel of the visible spectrum. Moreover, they have developed software (SideLook v.1.1) which makes this procedure automatic, and which is used in this work for the reasons given.

Once the threshold has been obtained for all canopies of the trees to be studied, the next step is to carry out a count of the pixels in the canopy in each of the four orientations per tree, using the Adobe Photoshop® CS3 computer programme.

To simplify and speed up the field work, the canopy is divided into three main filtering zones:

- Minimum filtering: corresponds to the zones of the canopy with approximately 100% of opacity, usually close to the main trunk.
- Edge filtering: corresponds to the outer zones of the canopy with 30% opacity.
- Medium filtering: these are the zones of the canopy that do not belong either to maximum filtering or to edge filtering.

Once the pixels related to the three types of filtering with sky background have been measured, this information is extrapolated to the rest of the photo and each filtering zone measured is weighted, using the real total area in pixels that each category takes up in the total canopy. To these ends, in the digital process, the same zones mentioned above (minimum, edge and medium) are established for the overall foliage of the tree

Each orientation provides three figures corresponding to the three filtering zones established. The filtering coefficient in each one is the weighted sum for the surface occupation of the three filtering zones. The final filtering coefficient of each tree will be finally the average of the four orientations.

B. Method 2: Vertical Photogaphy

The decision was taken to contrast the results obtained with the method above by repeating the process with vertical photography. In other words, to attempt to quantify the degree of filtering from other orientations: observing now from the frontal viewpoint of an average observer of 1.70 m. The four cardinal points (N., E., S. and W.) were used again for their best comparison with the cases above, and for their importance from the point of view of the vegetation growth.

The photos taken for this method were taken with the same camera as was used for the hemispherical photos (CoolPix 995, Nikon), at the height of the average observer, on a tripod and at a distance of 10 m. from the tree trunk, so as to capture all the canopies in the study.

As opposed to hemispherical photography, in which the result was a ground image of the canopy against the background of the sky; in vertical photography, the background is often taken up by other trees or objects. This makes it hard to perform an isolated count of the foliage pixels in each study canopy. To avoid photographing this effect, or interference, a white screen was placed during the acquisition of each image.

The screen is set on lengths of PVC tubing at 1.50 m. The maximum height ranged from 8 to 9.5 m, according to the height of the tree canopy. Once unfurled, the screen is 2.40 m. wide by 1.40 m. high.

The photos taken in the field are next analyzed using the SideLook v.1.1. programme, for transforming into black and white. Then the pixels are counted using Adobe Photoshop® CS3, as explained in the previous method.

As explained in the previous section, to simplify and speed up the field work, the canopy is divided into three main zones of filtering: minimum filtering, edge filtering and medium filtering.

On the other hand, the size of the white screen used does not permit the complete capture of the foliage of each canopy. Therefore, once the pixels related to the three types of filtering with the screen background have been measured, this information is extrapolated to the rest of the photo and each filtering zone measured is weighted, using the real total area in pixels that each category takes up in the total canopy. To these ends, in the digital process, the same zones mentioned above (minimum, edge and medium) are established for the overall foliage of the tree.

This is performed because it is impossible to cover all the canopy with a screen as it would be too tall and wide and utterly unmanageable in the field (it could not be held vertical without sagging; the slightest breeze would bend it like a sail etc).
Each orientation provides three figures corresponding to the three filtering zones established. The filtering coefficient in each one is the weighted sum for the surface occupation of the three filtering zones. The final filtering coefficient of each tree will be finally the average of the four orientations, as in the previous method.
Finally for this study, a total of 360 photographs were taken of Quercus pyrenaica in the area of the inventory in the north of Extremadura. The measurements of the degree of canopy obstruction by both methods ranges from 0 (zero obstruction), to 1 (total obstruction).

3. Results

3.1. Quercus pyrenaica

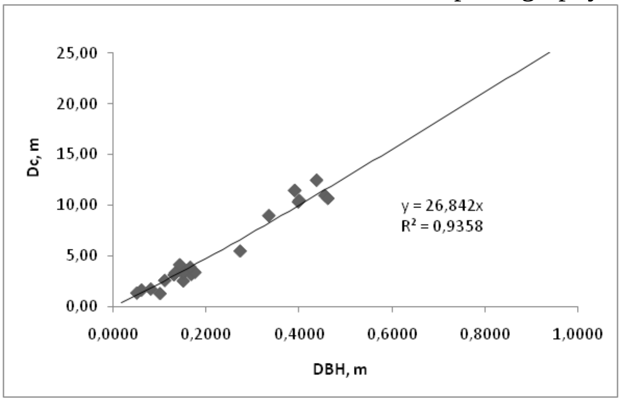
Table 1 shows the treated data for Oak. For every tree measured, the allometric variables are represented (total height of trunk [Ht], diameter of crown [Dc] and trunk diameter at breast height 1.30 m. [DBH]), and the measurements of the degree of canopy obstruction by both methods (vertical photo or with screen [O_vert], and hemispherical photo [O_hemis]).
The first step is to ascertain which allometric relations carry more weight from the point of view of tree growth, and which ones can be of use to modelize the plant structure.

Table 1. Data gathered per tree, form and method of acquisition (species: Quercus pyrenaica). The last two columns show the average obstruction in oak canopies for each Method and Type. The degree of obstruction is from 0 (zero obstruction), to 1 (total obstruction).

ID	Form	DBH(cm)	Dc_1(m)	Dc_2(m)	Dc_average(m)	Ht(m)	O_Vert(average)	O_hemis(average)
1	A	14,75	3,10	3,700	3,40	11,50	0,64	0,63
2	A	13,00	2,30	4,00	3,15	11,00	0,62	0,66
3	A	16,75	3,40	3,00	3,20	9,50	0,62	0,66
4	A	15,00	2,80	2,30	2,55	8,30	0,56	0,62
5	A	17,50	3,30	3,50	3,40	9,70	0,60	0,63
6	A	14,00	3,60	3,70	3,65	8,30	0,61	0,63
7	A	14,25	4,30	4,00	4,15	9,80	0,64	0,60
8	A	13,25	2,80	3,90	3,35	9,60	0,64	0,62
9	A	15,00	4,00	2,70	3,35	10,90	0,68	0,66
10	A	16,50	3,80	4,00	3,90	12,70	0,68	0,67
1	B	35,25	9,60	9,60	9,60	9,40	0,86	0,88
2	B	45,50	11,00	11,00	11,00	9,80	0,89	0,86
3	B	27,25	5,50	5,50	5,50	7,60	0,88	0,85
4	B	39,00	11,50	11,50	11,50	7,60	0,90	0,87
5	B	43,70	12,50	12,50	12,50	11,20	0,90	0,86
6	B	40,00	10,50	10,50	10,50	9,60	0,91	0,87
7	B	39,00	11,50	11,50	11,50	10,30	0,90	0,87
8	B	39,78	10,35	10,35	10,35	8,00	0,89	0,85
9	B	33,42	9,00	9,00	9,00	7,70	0,90	0,90
10	B	46,15	10,70	10,70	10,70	10,80	0,90	0,88
1	C	6,00	1,50	1,80	1,65	6,20	0,55	0,51
2	C	5,00	1,40	1,30	1,35	4,20	0,49	0,49
3	C	8,00	1,80	1,70	1,75	6,40	0,50	0,54
4	C	10,00	1,30	1,30	1,30	8,00	0,57	0,54
5	C	11,00	3,10	2,10	2,60	7,00	0,63	0,56
6	C	8,50	2,00	1,90	1,95	5,00	0,57	0,55
7	C	7,50	1,75	2,10	1,93	5,60	0,56	0,52
8	C	5,00	1,40	1,40	1,40	4,20	0,59	0,53
9	C	6,00	2,10	1,05	1,58	5,40	0,57	0,52
10	C	10,00	1,80	1,70	1,75	8,60	0,55	0,55

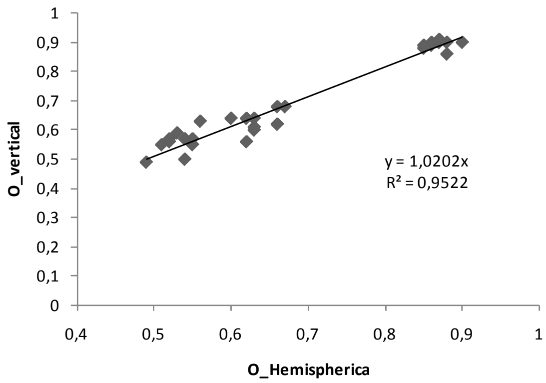
In this sense, DBH is the variable which most biological importance has had in other works consulted (Montero *et al*., 2008), and it is one of the main variables in this study. The relation of this parameter with the rest of the variables with an acceptable degree of correlation will allow us to forecast the growth of the tree throughout its life. Of all the analyses performed, it is the diameter of the crown which has the closest biometric relationship to the DBH. On the other hand this is to be expected, compared to other parameters such as height – more closely linked to the growth conditions of the mass as a whole (tree density), or forestry activities. Thus, the allometric relationship makes it possible to determine the DBH equation and canopy diameter and reaches the highest percentage of explained variance, giving the best results in model generation (Montero *et al*., 2008)
The most significant allometric variables which best explain the modelization of the crown in its growth are the DBH and Dc, as can be appreciated in Fig 2.

Fig. 2. Comparison of degree of obstruction obtained for oak with both methods of photography



In the validation analysis of the acquisition method for vertical photograph, there has turned out to be a direct link (R^2=95%) (Fig 3) between the data for degree of obstruction for this method and those results for hemispheric photography. Thus, once more, both methods have been shown to be valid, and the methodological proposal is seen to be effective for measuring degree of obstruction.

Fig. 3. Exponential trend of the allometric variables of significance in the growth of the tree canopy in oak

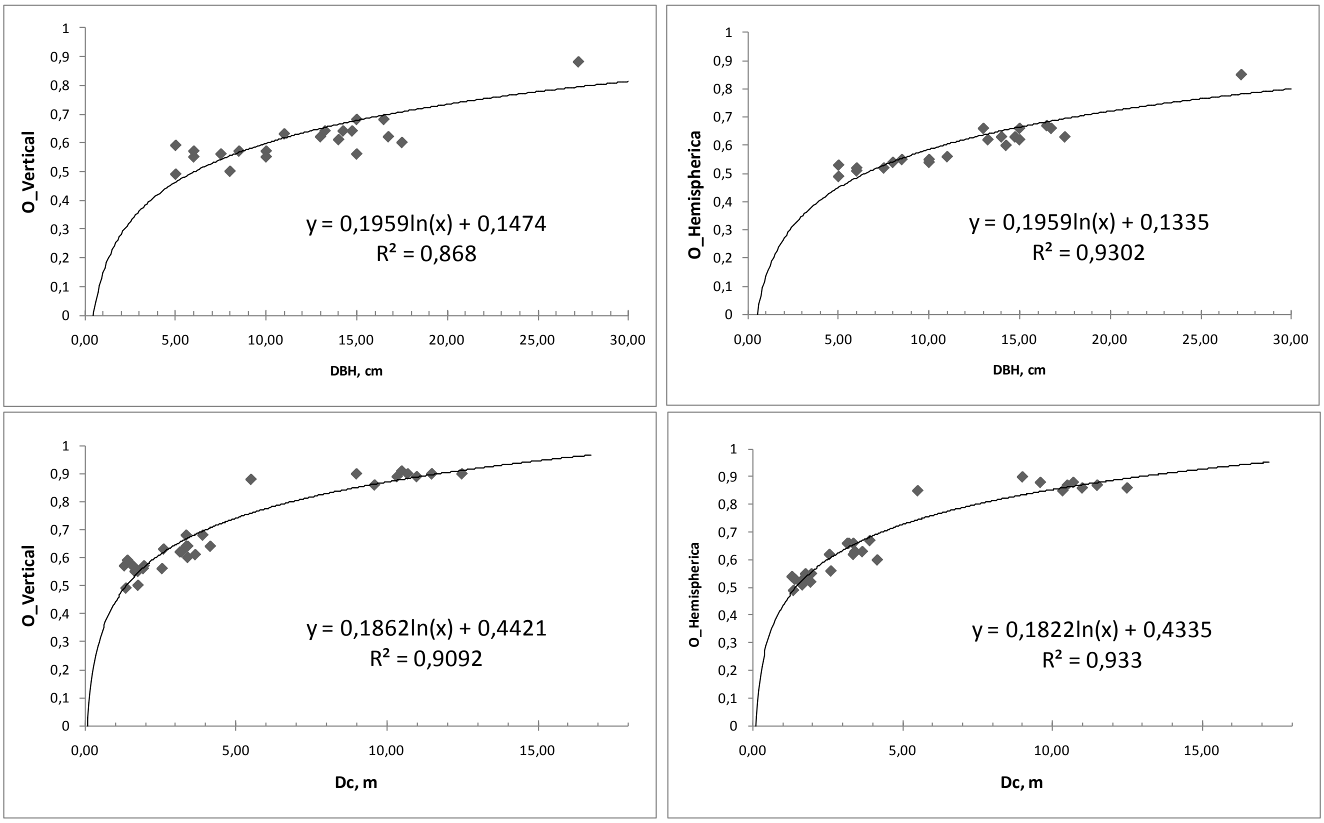


Finally, the predictive model for degree of obstruction with tree growth once more shows a direct correlation for the variables DBH, Dc in both methods of measuring the obstruction (Fig 4). This reinforces the idea of its usefulness in integration research.

4. Discussion and Conclusion

Hemispherical photography is far easier to take in the field than vertical photography, as well as requiring half as many photos for the subsequent analysis. However, to develop this research it was essential to take vertical photos, since the views obtained of the trees are the same view that an observer of average height sees. This is not the case with hemispherical photography, which gives us a view of the tree canopy seen from below, as explained previously.
In light of the results obtained, among the allometric relationships compiled, the one that relates canopy diameter to trunk diameter (Fig 2), is that which reaches the highest percentage of explained variance. Therefore, it is the equation which will give best results in the generation of the obstruction model for this species.

Fig. 4. Logarithmic relationship of the models to estimate the filtering capacity of chestnut, starting from DBH and Dc, for both types of photographic acquisition



Tables 1. show that the greater the trunk diameter (DBH), the greater the canopy diameter (Dc) of the tree, and consequently the greater is its degree of obstruction (vertical obstruction and horizontal obstruction) and viceversa.

The figures obtained from the statistical analysis of the comparison of the average obstruction of the tree canopy in both methods, which were explained in the previous section, give us the result R^2=0,952 for oak. These results are statistically consistent and they show that both methods make it possible to obtain a similar opacity index, and therefore the protocols set out in the measuring and calculating of this coefficient are validated.

In this study, the results obtained through the analysis performed on the photos by the two methods are very similar. Thus it can be deduced that the two methods would be valid for measuring opacity of Quercus pyrenaica.

The proposed method, based on hemispherical photography for the determination of the degree of obstruction per species has turned out to be consistent enough and easy to utilize to for its use to be recommended in works with similar aims, from the point of view of building landscape integration.

Thus, treatment of vertical photos and hemispherical photos of tree canopies allows us to predict what their capacity is to minimize visual impacts caused by ongoing activities which interfere in the landscape.

The work of authors such as Rich, (1990), Roxburch & Kelly, (1995) and Valladares (2006), estimate the acquisition of light and its distribution in forestry systems. The articles of Smardon, (1988) Hernandez *et al* (2003) García, (2003) contemplate that the use of vegetation improves the integration of building in the landscape, but they do not calculate the capacity of visual filtering produced by the species around the building. Therefore, these results constitute a step forward as far as visual filtering of trees to minimize landscape impact is concerned, in the natural environments studied.

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