The Architect Roberto Rivero and Daylighting Research

Jose M. Cabeza and Jose M. Almodovar

Escuela Tecnica Superior de Arquitectura. Universidad de Sevilla
Avda. Reina Mercedes 2, 41012, Sevilla. Spain
Tel.: 34-95 455 6556 / Fax: 34-95 455 6972
Email: crowley@arrakis.es
jmalmodovar@us.es

ABSTRACT: By the end of the 1950's decade, architect Roberto Oscar Rivero, who had been studying in England, returned to his native Uruguay and produced a revolutionary approach to daylighting techniques: he was able to relate lighting intensities with positions of points located underneath rectangular windows, plotting the result in a simple table. He could do so with the help of painstaking graphs that he drew manually.

To introduce the value of the transmittance in his methods he had to define an expression widely quoted by scientists around the world, the Rivero Transmittance Formula, which shows the relevance of directionality in a factor usually taken as scalar in most calculations.

This procedure also permitted the study of skies like the CIE overcast sky, which were strongly dependent on the angle of altitude and hence the performance of uniform and overcast skies could be compared.

With so many fortunate advances he was on the verge of finding a more general solution to radiative exchange problems, which intriguingly enough, he was not able to produce eventually. Roberto Rivero has passed away recently, and his original texts have almost disappeared as there was no re-edition of this material. Since the manuscripts were conveyed in Spanish, we have felt the necessity to explain his discoveries for an English-speaking audience. In order to do this, we will use a contemporary point of view, and we will discuss how far he could have reached and what he achieved in the daylighting field.

Conference Topic: Methods and tools for design assistance
Keywords: Daylighting. Rivero. Sky calculation. Configuration factors.

1. BACKGROUND OF THE RESEARCH

From the beginning of the 20th century, the science of lighting was slowly but surely established. The findings of J. H. Lambert and especially those contained in his treatise on Photometry of 1758, were rediscovered, distorted and finally applied. This process was mainly encouraged by the promoters of the new products that became available in the field of artificial devices and luminaires.

Then, among the many interesting efforts that took place, we could quote those of Pleijel, D. Spencer, P. H. Moon, Hopkinson and H. H. Higbie.

However, they did not seem to know each other's work, especially in what regards to the excellent papers by Higbie and Randall.

Rivero was familiar with what we could describe as the Nordic school of daylighting, which included English, Scandinavian and occasionally French studies, but not Germany or the United States, where a different approach might have prevailed as we will show.

Thus, Rivero was concerned with the problems posed by the uniform sky, which had been a main issue in Pleijel's work, and also with the new and more complex approach presented by cloudy skies as seen in the theories of Spencer-Moon, later adopted by the CIE (International Commission for Lighting).

We would say now that the CIE overcast sky, with its unequal luminance distribution is the archetypal case of non-diffuse emitters.

In this category of sky, the luminous distribution on the hemisphere is governed by the following physical considerations.

$$L(q, j) = L(q) \neq L$$

$$L(q) = L * \left(\frac{1 + 2 sen q}{3} \right)$$

2. THE CONTRIBUTION OF RIVERO

To integrate the quantity of illuminance received from a sky of uniform luminance, Rivero proved that this was equal in value to geometrical projections over a sphere, what is today more known as the projected solid angle principle (figure 3).

He developed an extraordinary spherical trigonometry to find accurate expressions for horizontal and vertical light factors, he was able to achieve this by means of application of the projected solid angle principle, a solution which avoided heavy integral calculus, paradoxically, such calculus had been provided by Higbie at a much earlier date and was apparently known in Germany, at least by those working with the architect Hannes Meyer, as we can see in figures 1 and 2.

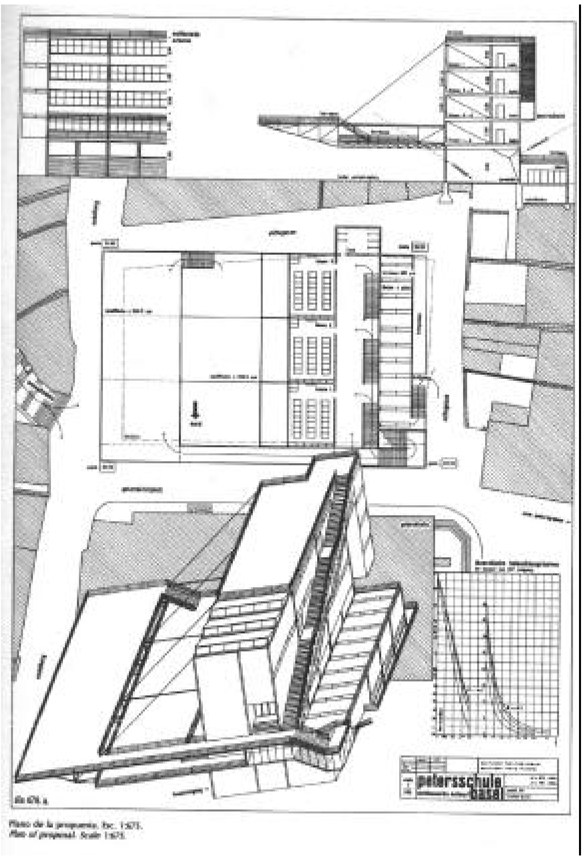

Figure 1: Unbuilt project for a School in Basel (Switzerland) by the architect Hannes Meyer, showing daylighting graphs in the right-bottom corner, to be compared with the graphs in figure 2.

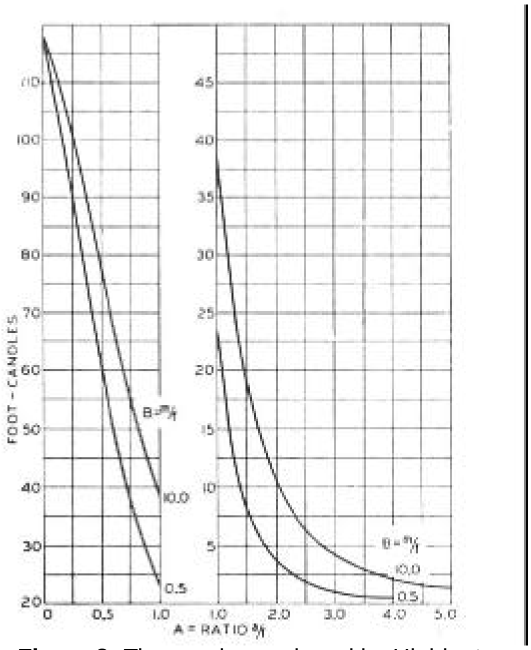

Figure 2: The graphs produced by Higbie, to calculate the light coming from tilted skylights, developed only two years before Meyer's project. (1926)

As expected, his solution coincided with the so-called surface-to-point configuration factor, which can be computed now in a much more general way than with the former attempts. Rivero was not aware of his finding, he thought that he was able to integrate a portion of the sky light, which in fact yields the same value but with a different meaning.

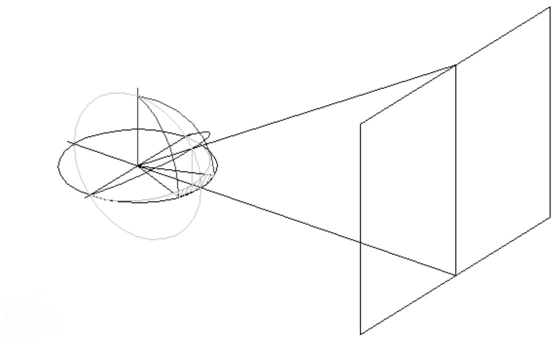

Figure 3: The projected solid angle principle

Higbie in turn, believed that he had found only the exchange of diffuse energy from rectangular windows to defined points, and admitted openly that his method could not be used with real skies or transparent windows, while in fact this is a perfectly possible thing to do. Both researchers had come to the **same solution** through diverse paths and **without realising of it!**

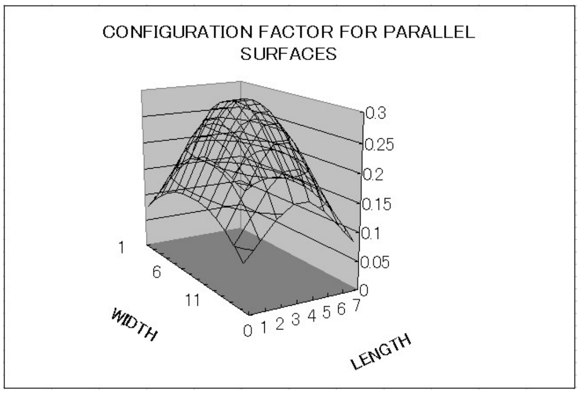

Figure 4: Display of the configuration factors as integrated by Higbie.

After that, Rivero considered that he could reduce lengthy computational work on either formulas or projections, which, at the time were deemed very difficult to carry out for architects and designers, by representing the light emitter as a rectangular grid form (spaced every 5 degrees in spherical coordinates) and then adding the projections of the so-divided fragments of the sky that were seen from the calculation point and through the window, in a kind of approach that reminds us of finite-element method.

In fact, a few "lighting protractors" produced in the following years at the British Research Station, worked in a similar manner. Once the specific dimensions of a window are known, they are averaged by distances to the study point, to determine their angles. Then those angular quantities were referred to clusters of fractions from the sky-vault, previously plotted in tables.

As the tables bore a homological relationship with the windows under study -a consequence of the aforementioned, they allowed for graphical as well as numerical use.

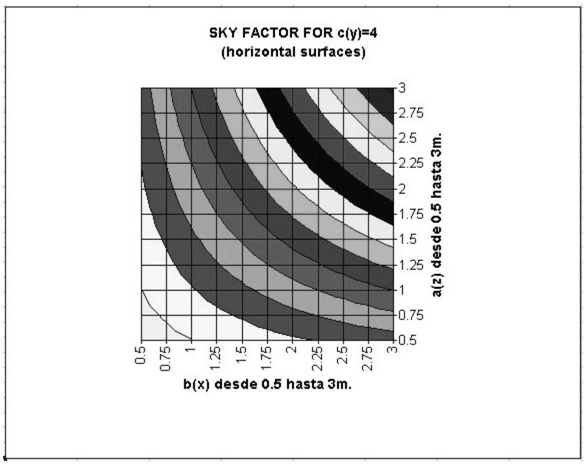

Figure 5: Example of output from Rivero's Tables

With a single nomogram he had resolved the main problems of the lighting science of the time, the tool was able to calculate the effect of windows without need of formulas, free from curved or complex projections, but still appropriate for drawing and visual access. And with another important feature, the tables, according to Rivero's view were totally independent from climatic data, i.e. they only displayed fractions of external illuminance regardless of its value.

Moreover, in the same structure, he worked to include the effect of the newly found CIE overcast sky. In order to do this, he increased -in proportion to the zenith, the values of the clusters previously obtained for the uniform sky. This is a numerical way of solving an otherwise complex integral.

Nonetheless, if the windows were glazed the problem of transmittance appeared to be a serious one, and here is where his world-wide quoted formula comes in.

He had to devise an expression for the transmittance that could be related to the angle q involved in the tedious calculations already organized. A single scalar quantity was not adequate as they were many rigorous studies on the value of transmittance and the whole procedure that had been followed, insisted on the differential quality of sundry regions of the sky. After comparing some of the available formulas he came up with the following equation.

$$T_q = T_0 * (\cos q + sen^3 q * \cos q)$$

Which produces a graphical result as above.

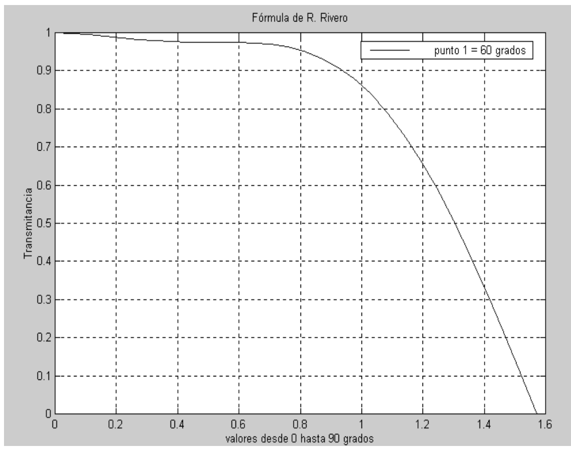

Figure 6: Cartesian plot of Rivero's transmittance equation.

It is remarkable that in such a simple but efficient way he could take into account all the important variables under the same tabular structure.

3. CONCLUSIONS

Regarding other aspects of both Higbie's and Rivero's work, we could add that they grasped the concept of vector analysis in lighting, but not in a straight way. Higbie, for instance, studied the configuration factor of inclined surfaces, whose numerical value could have been obtained in another way, making use of the already integrated values for vertical and horizontal factors. In the case of Rivero, to make comments on a graphical example, he describes the effect of a rotated rectangular window on a vertical plane.

Both researchers discussed to some extent the problems of skylights, the typical sawtooth section in Higbie's case was even treated in a rather detailed manner. Rivero composed a significant part of his tables for "horizontal windows". However, none of them argued on the particularities of sunlighting or direct light.

We could conclude by saying that their main lack if we could speak so, is that they did not dare to confront reality, they were not confident about the real availability of meteorological data or in the effort to predict daylighting they pursued safer assumptions, perhaps now we will never be sure.

Only we would have liked to pay homage to Rivero and the people who first discussed these problems in America. Their approach was probably the best possible and we can only wonder what course would have taken environmental design if all the aforementioned constraints would have been solved or envisaged by them.

Like other Uruguayan-born architects as Eladio Dieste or Gilberto Gatto-Sobral, Rivero is an outstanding representative of South-American genius in the respect of Architectural and Environmental Science .

Figure 7: The Atlantida Church, near Montevideo. Eladio Dieste. (1960). Dieste was extremely sensitive with the materials employed in his structural design, that can be described as ecologically-oriented.

Figure 8: The Public School "Mariscal Sucre" in Quito (Ecuador) designed by the Uruguayan G. Gatto Sobral to take into account ventilation, lighting and seismic effects, almost the same preocupations of Hannes Meyer 's school project some 30 years before.

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