SIMULATING DAYLIGHT PROPAGATION THROUGH COMPLEX FENESTRATION SYSTEMS IN A URBAN CONTEXT USING A VARIABLE SAMPLING SUBDIVISION SCHEME

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ABSTRACT

The use of Complex Fenestration Systems (CFS) within buildings can contribute to a significant reduction of cooling loads by the way of two assets: the redirection of daylight and the shading of sunrays. In order to back-up these features, daylight performance evaluations need to be performed individually in each case according to the geographical location, outdoor conditions, building orientation and design as well as indoor material properties. The use of computer simulations can make this assessment easier than on-site CFS monitoring requiring the availability of testing facilities, materials and equipment transportation as well as the physical installation of a CFS. Computer simulations can be carried-out using the RADIANCE lighting software, which allows the estimation of the daylight propagation through the CFS using monitored light transmission properties. Those features named BTDF data (Bi-directional Transmission Distribution Function) are assessed using a bidirectional gonio-photometer and stored in an internationally standardized format. In order to perform such simulations, BTDF data are assigned to a planar polygon that models the CFS and/or a window becoming a secondary light source in the virtual model. The accuracy of the simulation results is generally relying on the computer simulation parameters that drive the lighting calculation in the virtual model, as well as the BTDF data resolution assigned to the polygon mimicking the CFS. In an urban context moreover the shadowing effects due to adjacent buildings have a significant impact on the incoming daylight flux transmitted by the CFS. It is important accordingly, to subdivide such a polygon - which may be a large glazed area - in an optimal way in order to enhance the simulation accuracy. Computer simulations were carried-out for that purpose using a virtual model of an office room placed in an urban-context. The BTDF data of a Laser-Cut Panel (LCP), made of a 6 mm thick acrylic panel with 4 mm spaced parallel laser cuts, were applied for that purpose to: i) a single pane representing a full-size office window and ii) subdivided polygons of the size of the LCP sample benefitting from BTDF monitoring. All results are compared in order to determine the influence of the polygon subdivisions referenced to the BTDF data on the final computer simulation accuracy.

Keywords: Daylighting, Complex Fenestration Systems, Bi-directional Transmission Distribution Function (BTDF), RADIANCE Lighting Software, Bidirectional Gonio-photometer.

INTRODUCTION

The use of CFS in buildings signify important benefits for the users by allowing a more even redistribution of direct sunlight, improving the visual comfort and contributing to the mitigation of the final energy demand [1, 2]. The ideal way of obtaining an assessment of the daylight propagation through Complex Fenestration Systems (CFS) in a room would be to perform on-site evaluations in a full scale building. However, to test CFS in real buildings represents several difficulties such as the availability of a testing facility, materials and equipment transportation as well as the CFS installation. To overcome these drawbacks, the use of computer simulations based on virtual models provides significant advantages. Computer simulations are essential for making an effective selection of the CFS in every particular case. The ray-tracing software RADIANCE [3] allows the simulation of the daylight propagation through CFS [4] by applying BTDF data (Bi-directional Transmission Distribution Function) [5-7] to a previously selected planar polygon acting as a window in the virtual model. Two RADIANCE procedures are mainly applied today to perform such simulations. Both use the BTDF data of a CFS stored in an XML format to model the propagation of daylight in a room. A first procedure uses the pre-process mkillum to model the daylight distribution through the CFS; a second procedure uses the *bsdf* material function to perform such simulation [2, 8]. As a common practice, the BTDF data is applied to a single polygon representing the full pane of a window in the virtual model. However, when using the mkillum procedure, the calculation of the daylight distribution through the CFS is performed from the center of the polygon, taking into account its full area assigned to the BTDF data. This might lead to inaccuracies in the simulation results when the shadows of adjacent buildings are projected on the building's façade. The objective of this study is to investigate the impact that the resolution of the subdivision of the polygon assigned to the BTDF data representing the window, might have in the accuracy of the simulation in the presence of exterior obstructions. This study proposes that the use of a subdivided polygon leads to more precise calculations.

METHODOLOGY

An office room located in the city of Zacatecas, México (22° 783' N., 102° 583' W, Altitude: 2543m) was used to carry-out simulations using RADIANCE [3]. The room is part of a buildings complex of a public university dedicated to Humanities and Social Sciences. Its dimensions are typical of an office room (5.50 x 4.17m and 2.46m height). For the purpose of this study the equipped building façade was orientated to south in the virtual model. The interior material properties (reflectance and transmittance) were assigned to the latter using optimal values. Thus the surface reflectance's were based on the IESNA recommendations [9] (floor 0.40, walls 0.70 and ceiling 0.80), while the glazing transmittance was set to 0.75. The BTDF data [2, 6] of Laser cut panel (LCP) [10] was assigned to the polygon that accounts for the upper window in the office room. In order to test the accuracy of RADIANCE simulations regarding the resolution of the BTDF data, the latter were carried-out first using the full-size polygon that accounts for the upper window in the office room. Secondly, such polygon was subdivided into small sections of 10cm x 10cm, which are the dimensions of the original LCP sample monitored with the gonio-photometer [5, 11] to assess its photometric properties [12, 13]. In total, the east upper window was subdivided into 150 sections of 10cm x 10cm plus 6 sections of 6cm x 10cm for the remaining space next to the column located in the middle of the room; the west-upper window was subdivided into 72 pieces of 10cm x 10cm plus 6 sections of 4cm next to the west wall. Since the objective of this study is to test the accuracy of the simulated daylight propagation through CFS when external obstructions are present, three buildings were included in the virtual model, placed 7m away from the façade in order to create shadows in the office room.

When modelling the daylight distribution through CFS in a room, the pre-process mkillum performs the calculation from the center of the polygon assigned with the BTDF data. Therefore, when a combination of light and shadow falls over such polygon, the calculation might be performed taking into account the entire polygon as if it was fully lit or fully shadowed, which might lead to inaccurate results. In order to investigate that, a daylight situation in the virtual model was created with exterior obstructions partly projecting a shadow over the entire polygon; such situation was created for winter solstice at 11h 50. Simulations were then carried-out using first the mkillum procedure [2], and secondly using the *bsdf* material function [8], in order to compare the results obtained with the two RADIANCE procedures. The simulations were carried-out first with the full-size polygon and later with a subdivided polygon. Since the *bsdf* procedure reproduces the propagation of daylight through the CFS directly using the BTDF data stored in the XML file, the use of a subdivided window will not represent any difference in the calculation. Hence, when using the *bsdf* procedure the simulations were carried-out only with the full-size polygon. Three situations were then assessed: i) using mkillum with the full size window; ii) using mkillum with the subdivided window and iii) using the *bsdf* procedure. The final assessment was performed in two steps: a visual assessment was performed first by comparing visualizations in the interior of the room from three different viewpoints. A second assessment was performed by comparing the simulated daylight distribution through the office room on the basis of illuminance ratio (IR)[14]. Illuminance was estimated for that purpose by placing points in the middle of the room, every 10 cm from the window up to 2.5m and every 20cm from there to the back of the room, at task level height (0.75m).

RESULTS

Visual Assessment

A straight view of the larger window in the office room is shown in Figure 1. It shows that when using the mkillum procedure with the full-size polygon, the light is projected on the ceiling as if the entire area was lit (left). However, when using mkillum with a sub-divided polygon, the visualization shows that a more accurate calculation is performed (center): the light is redirected to the ceiling only for the lit area on the façade. In case of use of the *bsdf* procedure (right), the visualization shows that the calculation is performed taking into account only the lit area. However, when using the *bsdf* procedure, the CPU time is larger than when using the mkillum procedure using similar radiance parameters. In order to obtain simulation results in a reasonable time using the bsdf procedure, the values of the parameters have to be reduced and even so the quality of the pictures.

Figure 1. Visualization of the office room using mkillum with the full-size window (left); the visualization using mkillum with the subdivided window (center)and the visualization obtained with the bsdf procedure (right).

A second visualization shows the office room viewed from the back of the room. It allows the comparison of the modelling of the daylight distribution through the LCP in both windows (Figure 2). The picture shows a well-defined lighting redirection on the ceiling when the simulation is performed using mkillum with the subdivided window (center). A similar result is also achieved using the bsdf procedure (right). However, in the latter the redirected light shows a less defined pattern due to the low picture quality. This is due to the limited CPU time allowed to the bsdf procedure by the values of the rendering parameters. In this case the rendering of a picture can take from 20min to one hour in low quality with the corresponding simulation parameters (-ab 2, -aa 0.2, -ar 32 –ad 512); while when using mkillum it takes about 10 minutes in both cases (full-size window and subdivided window) in medium quality with the corresponding simulation parameters (-ab 6, -aa 0.1, -ar 64 –ad 1024).

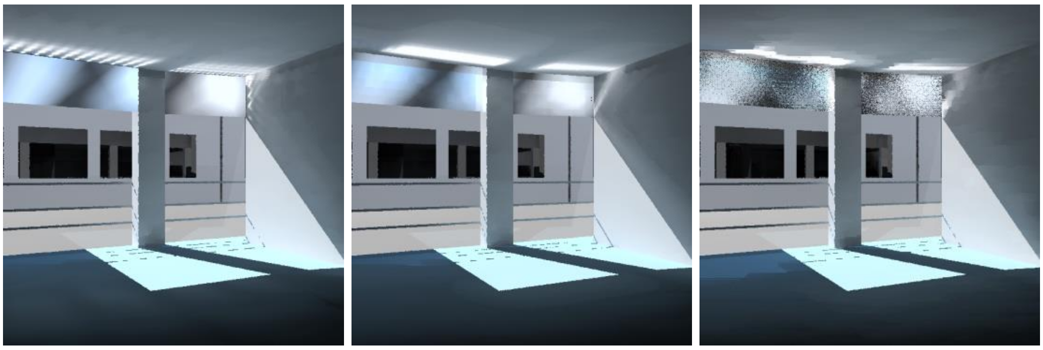

Figure 2. Visualizations of the interior of the office viewed from the back. Modelling of the daylight distribution through the LCP using mkillum with the full-size window (left), using mkillum with the subdivided window (center) and using the bsdf procedure (right).

A third visualization was obtained, which shows a closer view to the window as shown on Figure 3. It allows observing how daylight is redirected on the ceiling. When using mkillum with the subdivided polygon (center) the light pattern is regular and defined, while when using the full-size polygon it shows a discontinuous light projection (left). The simulation carried-out with the *bsdf* procedure shows an undefined light redirection due to the low quality of the picture (right).

Figure 3. Transversal view of the window allowing detailed observation of the daylight propagation through the LCP using mkillum with the full-size window (left), with the subdivided window (center) and with the bsdf procedure (right).

Assessment of daylight distribution through CFS in the office room

A second assessment was performed by analysing the daylight distribution through the room by comparing the illuminance ratio (IR) profile obtained in the shadowed area of the room (at the middle of the larger window). Different points were placed for that purpose at 10cm distance from the window up to 2.5m and from there at 20cm to the back of the room. The results are illustrated on Figure 4; they show a very similar IR profile across the room with values in between 9-10% next to the window. However, the IR profile obtained using mkillum with the full-size window shows larger values at a distance of 1m to 1.8m from the window. When calculations are performed with the mkillum process using the subdivided window and the *bsdf* procedures, the IR values shows a continuous profile, meaning that no daylight is modelled in the shadowed area of the façade. For all, the IR profile using the three conditions is within a range of 10% accuracy. The larger values obtained using mkillum with the full-size window are not considered as significant in regards to the daylight distribution. The CPU computing time using mkillum was equal to 2 hours when using the full-size window and about 14 hours when the window is subdivided. With the *bsdf* procedure, the CPU time is equal to 2 hours. The simulations were carried-out using the same simulation parameters in all cases (-ab 4, -aa 0.1, -ar 64, -ad 1024).

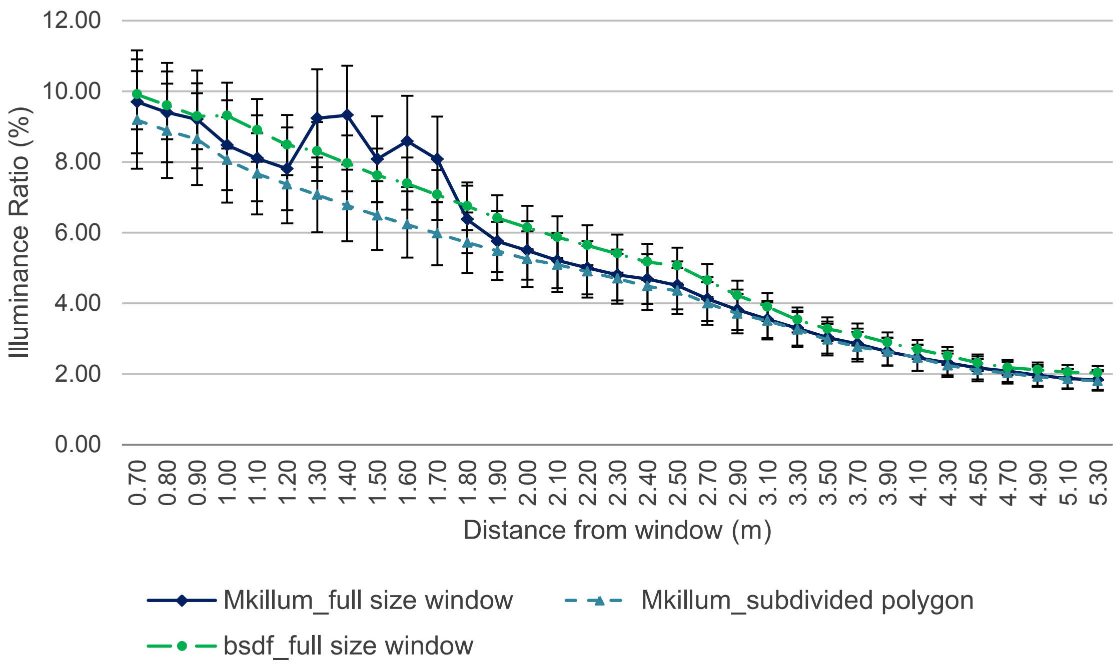

Figure 4 Illuminance Ratio through the room obtained using mkillum with the full-size, the subdivided polygon and the bsdf procedure at 11h 50 when shadows are projected on the façade.

CONCLUSION

The aim of this study was to investigate the impact that the BTDF data resolution assigned to a polygon representing a CFS has on the accuracy of simulations when exterior obstructions are present. Simulations were carried-out using two RADIANCE routines: the pre-process mkillum and the *bsdf* procedure. A full-size polygon was used first and then a subdivided polygon associated to the BTDF data of LCP, in order to compare the renderings and the illuminance ratio distribution. The former, showed that when simulations are carried-out with the full-size polygon, mkillum performs a calculation overlooking the shadow effect of the adjacent buildings, leading to inaccurate results. On the other hand, when the polygon is subdivided, the daylight distribution is calculated taking only in to account the areas that are not shadowed by the exterior obstructions; the same situation is observed when using the *bsdf* procedure. However, the assessment of the daylight distribution with the IR profile showed no significant differences in the simulation results when using the two procedures. In summary, if the daylight interior environment needs to be assessed regarding visual comfort, risk of glare, then the subdivision of the polygon assigned to the BTDF data of the CFS is advisable. If the quality of the interior environment requires a quantifiable evaluation, such as illuminance ratio (IR) or daylight factor (DF) [15], the subdivision of the polygon associated to the BTDF data does not lead to a significant improvement.

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