"SHADING": ANALYZING MUTUAL SHADING AMONG BUILDINGS

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ABSTRACT

A method for evaluating solar rights and shading requirements in an urban environment is presented. The method is embedded in a CAD tool developed and adapted for this purpose. With this tool, one can analyze the mutual shading between buildings and other objects like trees. The purpose of this CAD tool is to allow the designer to plan efficiently the various functions of spaces among different structures, like buildings, as well as determining the location of the passive and active solar collectors. The method is a general one and allows a fast and efficient calculation of the ratio between insolated and total surface areas of any given examined object that is shaded by other irregular and nonplanar elements. The calculation of this ratio is carried out for all the months and hours for which either shading or insolation is required. The information obtained may serve as hourly input data for any dynamic simulation model, which evaluates the thermal performance of the different external or internal shading systems. For a visual and a qualitative evaluation of the shadows among buildings, the model permits a very realistic representation. This is achieved by defining the light source according to the azimuth and the altitude of the sun, at the particular time of examination. The self-shading and brightness of the different surfaces and the shadows cast by the various elements at the designated time are then generated and can be evaluated visually.

INTRODUCTION

Mutual shading between buildings and other elements, like trees, may determine if a place will be pleasant or uncomfortable during the different times of day or throughout the year. It is also important to be able to determine the optimal window shading system (Shaviv, 1980). This is because shading of windows in summer and insolation of windows in winter, are among the most important design parameters to achieve good indoor climatic conditions with minimal energy consumption (Shaviv and Capeluto, 1992). Moreover, overshading of the windows reduces daylighting, which results in increased energy use for artificial lighting or internal heat gains (Shaviv, 1980).

The above important effects of proper shading design were recognized by Olgyay and Olgyay more than thirty years ago (1957). The energy crisis of 1973 accelerated attempts to find advanced CAD methods and tools for the design and evaluation of shading solutions (Shaviv, 1984a, McCluney, 1984) on one hand and for proper insolation on the other (Arumi, 1979, Shaviv, 1984b).

Most of the evaluative CAD tools that were developed before the last decade were designed for mainframes and lack a graphic, user-friendly interface (Kroner and Abrey, 1985). Therefore, many design tools, in the last decade, were developed for personal computers, taking advantage of graphics facilities and creating more friendly tools. However, they were limited to simple objects as they were based on algorithms governed by the limitations of existing personal computers (Peckham, 1988). Hence, they could not provide a comprehensive evaluation of a variety of complicated and nonplanar shading elements.

In this work, we present an evaluation tool, "SHADING". With this tool, one can analyze any given design with regards to solar rights or shading requirements. The method is a general one and allows the examination of the mutual shading between buildings and other objects like trees. It can perform an accurate evaluation of the design of any external or internal windows' shading devices as well. These shading systems may have an arbitrary shape like a pyramid, as was recommended by Shaviv for certain orientations (Shaviv, 1980). They can be venetian blinds or even rough curtains, such that their shading ability depends on the angle of incidence of the solar radiation. The analysis offered in this model can be carried out visually and quantitatively.

We use the term "Geometrical Shading Coefficient" (GSC) to express the ratio between shaded and total examined surface areas. We find it necessary to have a new definition, because the term Shading Coefficient (SC) is defined as the ratio of solar radiation that enters through a fenestration system relative to that of a standard reference glazing composed of a single-pane. Moreover, there are doubts today whether it is appropriate to continue and use the term SC (McCluney, 1991). The term GSC suggested here does not include the glazing materials and therefore, is not limited for use only in the context of fenestration systems. It depends on the geometry of the obstacles that block the sun from the examined surface. The GSC is not constant but depends on the angle of incidence of solar radiation. Therefore, it should be given as a function of the date and hour. We can also use the term Geometrical Insolated Coefficient (GIC) to express the ratio insolated/total examined surface areas.

The model SHADING was developed on a graphical workstation taking advantage of the advanced technology available today. The emphasis in this work is to present new ideas that show how modern concepts and hardware in computers allows us, using a very simple algorithm, to analyze quantitatively the ratio between insolated and shaded areas. Thus, we can create efficiently a data file of hourly, monthly or seasonal GIC of any given surface. The file can be read later by a dynamic simulation model ENERGY (Shaviv and Shaviv, 1978) for the determination of the thermal performance of buildings.

The visual evaluation is performed by using commercially available software ISM for three-dimensional representation. This enables the user to apply a Ray Tracing algorithm to present the mutual shading between buildings as a function of the date and hour. It also presents the brightness of the different surfaces of all objects as they appear at the particular time of examination.

The methodology and the design tool are demonstrated by a case study based on an actual design of a new five hundred-room hotel building. The solar rights requirement was a determining factor in the design of the new building in close proximity to an existing one.

PERSPECTIVE FROM SUN'S POINT OF VIEW

The simplest way to figure out the insolated and the shaded areas is by drawing an orthographic projection from the sun's point of view (Kroner and Abrey, 1985). The area exposed to the sun is clearly the part that is seen by it. This means that the sun's position at a particular geographic location and at a particular time (month and hour) should be used to define the point of the eye in the orthographic projection to be drawn. One should use an orthographic projection to simulate properly the solar rays that are projected from infinity in parallel lines, instead of using perspective.

Although this method is very simple, it takes a long time to evaluate a project with many entities, since a hidden surfaces removal analysis should be carried on for each view. Today, workstations with a Z buffer are quite common. The Z buffer performs the hidden surfaces removal analysis in hardware. Therefore, the determination of orthographic projection from the sun's point of view is accomplished very quickly and efficiently.

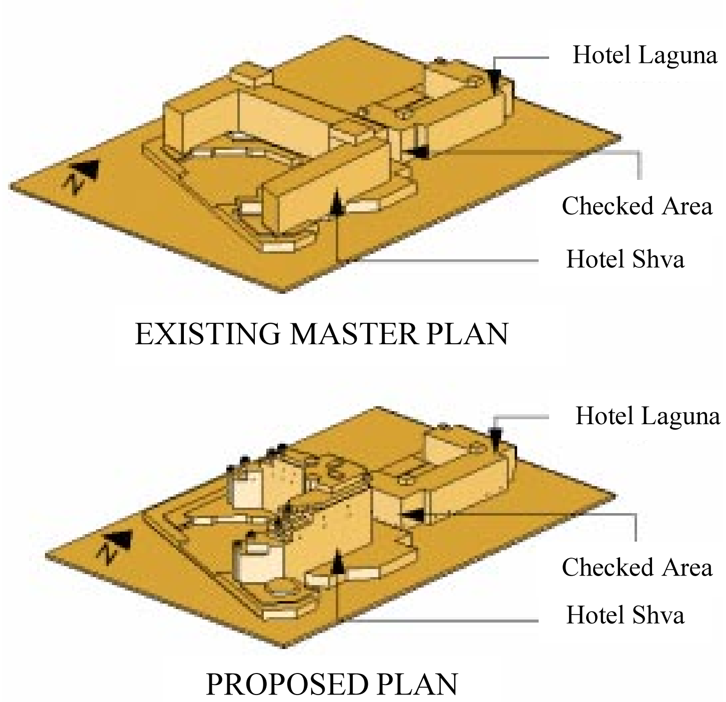
The longitude and latitude of the place and the difference between local time and Greenwich Mean Time are introduced by the designer using a questionnaire menu, as well as the building azimuth. The designer has also to determine the examined time (month and hour), or may ask for a whole year evaluation. Based on this input data the required orthographic projection from the sun's point of view at different examined times is presented instantaneously. If a whole year evaluation is required, the user will see all views almost as in a movie.

QUANTITATIVE EVALUATION

Often we would like to evaluate solar insolation quantitatively. To achieve this we take advantage of the graphical workstation's double buffer used to perform smooth animation. However, we apply the double buffer in a different way and for a different purpose.

The principle of the double buffer is as follows: The computer stores two pictures; one, stored in the front buffer, is displayed on the screen and the other, stored in the back buffer, is hidden. To create a smooth animation the picture in the front buffer is displayed, while in the back buffer the next image is created. Only after the complete generation of the new image, the displayed buffer is switched, so that the previously stored image is displayed. This is done to avoid the flickering caused by showing incomplete images.

For calculating the GIC of the examined surface, we do not need animation and can use the back buffer for a different purpose. The idea is to apply it for drawing an orthographic projection with no shading elements. Thus, we create simultaneously two orthogonal projections from the sun's point of view, the first one, shown in the front buffer and seen by the observer, is drawn with all elements, as one can see in Fig. 1. The second orthogonal projection, also from the sun's point of view, is drawn in the back buffer without the shading elements, and is not seen

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**************************
TOTAL CHECKED AREA:654.10
INSOLATED AREA:    199.22
SHADED AREA:       454.88
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***************************
ON DEC 21 AT 9.00 AM
30.46% OF THE TOTAL CHECKED
AREA IS INSOLATED
***************************

***************************
TOTAL CHECKED AREA: 654.10
INSOLATED AREA:     459.17
SHADED AREA:        194.93
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***************************
ON DEC 21 AT 9.00 AM
70.20% OF THE TOTAL CHECKED
AREA IS INSOLATED
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Fig. 1. Orthographic projection from the sun's point of view on December at 9.00 am and a quantitative appraisal of the solar insolation of Hotel Laguna's southern elevation
(The checked area is the southern elevation closed to the other building.)

by the user. The examined insolated area is calculated twice, once as is seen on the front buffer ($A_{insolated}$), and again, as appears on the back buffer, where all shaded elements were removed (A_{total}). As both orthogonal projections are drawn from the same point of view, the distortion is the same and the GIC of the examined area is obtained as the ratio $A_{insolated}/A_{total}$.

To calculate the superposition of all shadows, cast from diverse elements, we need first to determine what objects hide the examined surface from the sun, and then to find the shadows cast on the examined surface. As both objects may be irregular and nonplanar, these calculations may be very tedious if a vector technique is used. To avoid complex calculations, we use a bitmap technique for calculating this area. The area exposed to the sun is found simply by counting pixels according to their color. As the pixels of the shaded area get the color of the shading elements, these pixels are not counted. The shading elements can be deciduous trees, or rough materials, that give only partial shading. Such shading elements are painted with any chosen texture that does not fully mask the background. In this case, the pixels of the examined area, which are seen through the translucent objects, are counted as well. Thus in almost no time, we calculate the GIC, of any complex shading elements including translucent elements that give only partial shading.

The calculation of the degree of insolation of the surface can be repeated for all the months and hours for which either shading or insolation is required. This information is saved for further use in a simulation model for evaluating the thermal performance of the building. Such information is particularly important if the examined surface is a solar element or a window. The results can be also presented graphically for visual appraisal (see Fig. 2).

Taking advantage of the Z buffer and the Double buffer, and by using bitmap technique for calculating the insolated and the total examined areas, allows us to compute very quickly the GIC of any arbitrary complex and nonplanar elements shading any given examined surface. Moreover, it always take the same time to calculate the exposed area to the sun, as we only have to count the pixels with the original color that was assigned to the examined area. The examined area can have any shape, or can be divided into many elements. The time required for carrying these calculations does not depend on the complexity of the project at hand. To construct a whole year file, which means to create and evaluate about 150 views (12 months and from sunrise to sunset) takes less than 15 minutes.

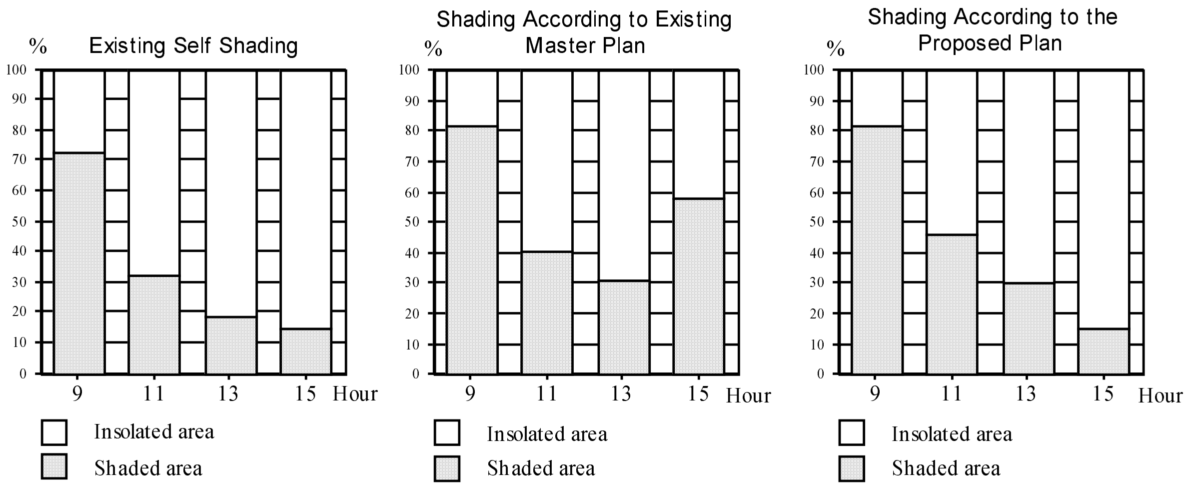

Fig. 2. A graphical presentation of the calculated insolated and shaded areas, at different times in December. (The checked area is the Hotel Laguna's swimming pool and plaza).
Left: existing self shading. Middle: shading according to existing master plan.
Right: shading according to the proposed plan.

VISUAL EVALUATION

To appreciate visually the appearance of the building under changing solar illumination, it is sometimes desirable to view the shadows at a particular time from a specified point of view. To realize this, one needs to create a perspective with mutual shading created by a light source that is in the sun's position. No simple algorithm can be found for accomplishing it. Therefore, we decided to use a Ray Tracing algorithm that is available in existing commercial 3D CAD software. In our case, we used ICEM Solid Modeler (ISM), developed by Control Data (1987).

The perspectives created by the ISM can be performed from any chosen point of view. Only the light source is defined at the location of the sun at the particular time of examination. The user of SHADING can select a view. This is done by choosing a free mode viewing and selecting the eye location by moving around, or by changing the height or distance of the eye. As SHADING uses the Z buffer, each view is created instantaneously. Once a desirable view is created, the user can send this view to the ISM software defining the sun location by pointing to the month and the hour of examination. The user of the SHADING software, does not need to know how to use ISM, or how to define, in ISM, the correct perspective views with a light source representing the sun, as can be seen in Figures 3 and 4. The integration of SHADING with ISM is presented elsewhere (Yezioro and Shaviv, 1994).

The ISM software provides realistic pictures with mutual shading between the buildings. It also provides automatically the momentary brightness of each surface (according to the angle between the vector representing the direction of the light source and the normal to this surface). Thus, the user can appreciate visually the brightness of each surface (see Figures 3 to 5). It might be that the examined area is shaded at a time that the solar irradiation is very weak anyhow.

A CASE STUDY

The methodology and the design tool are demonstrated by a case study based on an actual design of a new five hundred-room hotel building. The solar rights requirement was a determining factor in the design of the new building in close proximity to an existing one.

Figures 1 to 5 summarize the results of the case study. In this case study there are two buildings; The northern one is an existing hotel named "Hotel Laguna" (see Fig. 3), while the southern building is a new proposed hotel named "Hotel Shva" (see Figures 1, 4 and 5). The team selected for designing the Shva hotel proposed new plans, which were not based on the existing master plan. Hotel Laguna opposition to the construction of Hotel Shva was on the basis of Solar Rights determination, saying that: "Hotel Shva will shade completely the Swimming Pool of Hotel Laguna during December from 9.00 until 10.00 am". Also, they claimed that "the Laguna's south elevation, the swimming pool and plaza will be shaded more heavily if the new hotel would be built according to the proposed plan, than the existing master plan

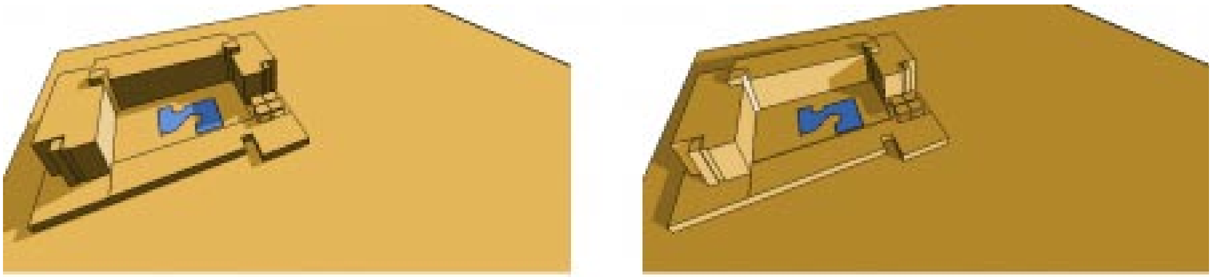

Fig. 3. Visual and qualitative evaluation of the self shaded Hotel Laguna's swimming pool and plaza.
Left: December 11.00, Right: December 15.00.

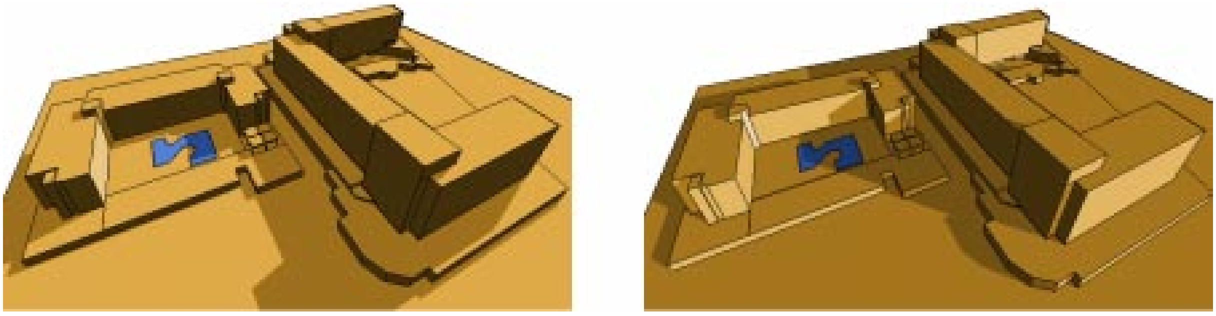

Fig. 4. Visual and qualitative evaluation of the insolated and shaded areas according to existing master plan.
Left: December 11.00, Right: December 15.00.

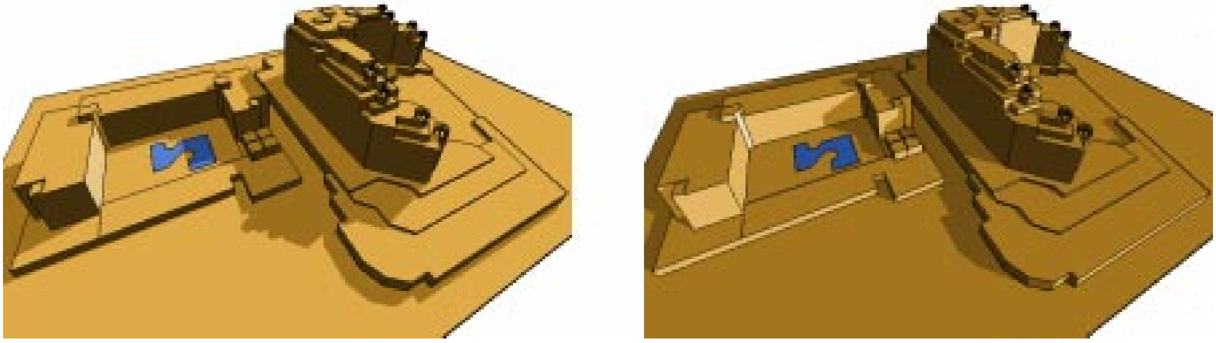

Fig. 5. Visual and qualitative evaluation of the insolated and shaded areas according to proposed plan.
Left: December 11.00, Right: December 15.00.

allows". The shading evaluation was carried out to find the validity of these claims.

Fig. 1 presents an orthographic projection from the sun's point of view on December at 9.00am. Note that in this Figure the areas seen from the sun position are insolated by it at the particular examined time and those areas that are not seen are shaded by the surfaces that hide them. Fig. 1 shows that Hotel Laguna shades completely its own swimming pool area during December at 9.00. Similar situation was found to prevail at 10.00 am.

Fig. 1 presents also a quantitative appraisal of the solar insolation of Hotel Laguna's southern elevation. The checked area was selected in this example to be only the south elevation that is in close proximity to the new proposed building of Hotel Shva, which should be built south to it. The Figure shows that at the particular examined time, the building based on the existing master plan, shades the Hotel Laguna's south elevation more heavily than the proposed design. Similar results were obtained for most examined times.

In Fig. 2, we present the results of the calculated insolated and shaded areas at different times in December. The examined area is the Hotel Laguna's swimming pool and plaza. Three checks were carried out; (a) the calculations of the existing self-shading of Hotel Laguna (left), (b) the shading according to existing master plan, which includes also the existing self-shading (middle), and (c) the shading according to the proposed plan including the self-shading (right). Again, one can see that in general, in December, the existing master plan shades the Hotel Laguna's swimming pool and plaza areas more heavily than the proposed design.

Figures 3 to 5 present visual and qualitative evaluation of the insolated and shaded areas on December at 11.00 (left) and at 15.00 (right). The visual and qualitative evaluation indicates that the few sunspots that are lost in the new proposed plan at 11.00 compare with the existing master plan are not significant. On the other hand, the new proposed plan offers a sunny plaza and swimming pool in the afternoon (at 13.00), a feature that is only partially achieved in the existing master plan.

The case study shows:
a. The simplicity in usage of SHADING. The geometrical input data may be easily introduced by SHADING graphics user interface describes in (Yezioro and Shaviv, 1994), or by using AutoCAD and SHADING DXF translator as was carried on in this case study
b. The simplicity and ease in comprehensibility of results.
c. The ability to analyze in a short time the mutual shading between complex buildings.

SUMMARY AND CONCLUSIONS

A method, a model, and a system for evaluating solar rights and shading requirements in an urban environment are presented. The model can evaluate mutual shading between any arbitrary elements. The method for this analysis is based on modern concepts and computers that allow the use of a very simple algorithm to analyze quantitatively the ratio between insolated and shaded areas. The examined area and the shading elements may be irregular and nonplanar. The shading elements may be partially translucent as well.

The model was evaluated by comparing CAD image of a case study with actual shading obtained in reality and good agreement was found (Yezioro and Shaviv, 1994). The methodology and the design tool is demonstrated, in this paper, by a case study based on an actual design in which solar rights requirement was a determining factor.

We can summarize that the model allows the designer to plan efficiently the various functions of spaces among buildings in an urban environment, as well as determining the location of the passive and active solar collectors. The model and the system developed may serve as a link between three types of software; 2D and 3D graphics representation and an energy simulation, which are currently used by architects.

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