INVERSE SIMULATION OF SUNSHINE, VISIBILITY AND REFLECTION IN ARCHITECTURAL AND URBAN SPACES

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ABSTRACT

This paper presents an "inverse" reasoning to solve problems of sunlighting, visibility and solar reflection in architectural and urban spaces. We propose a numerical model which enables to mix these parameters. Inverse simulation considers the relation between a given observer or an area and environmental elements. This relation represents a volumetric constraint. The CAD tool which is developed (SVR software), helps the designers to display architectural and urban constraints and also better take into account solar and visual impact of urban projects. Our model enables to find solutions in order to satisfy these solar and visual constraints and to manipulate geometrical volumes.

Keywords : inverse simulation, CAD tools, visibility, sunlight, solar reflection.

1. INTRODUCTION

The physical constraints of the architectural and urban environment impose strategic choices on the urban planners and require specific tools.

Currently the models of solar and visual simulation are direct, that is to say that they allow only the analyse and the expertise when the architectural project is ended. At CERMA laboratory, we work on a graphic "inverse" method to solve solar constraints [Siret 97] and visual constraints [Nivet 99]. These methods enable a 3D manipulation of physical constraints, as soon as possible during the project.

We present a new research on "volumes of solar or visual constraints". This research is based on a new constructing method of "volume of constraint" which use pyramids unions, unlike previous works which used algorithms. Furthermore our model calculate as well convex "volumes of constraint" as concave ones.

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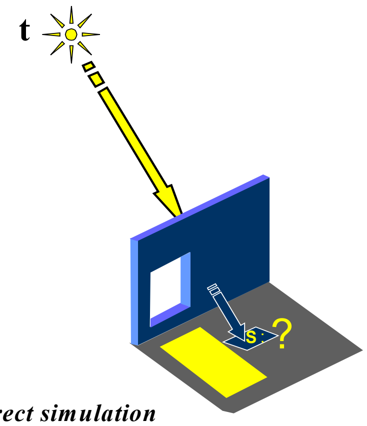
2. THE DIRECT SIMULATION OF SUNSHINE AND VISIBILITY

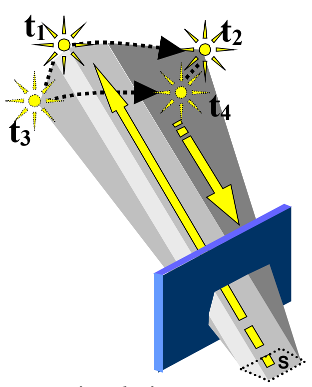
Generally, architects and urban planners use direct graphic methods to solve visibility and sunlighting constraints [Dourgnon 61] [Twarowski 62] [Olgyay 63] [Etzion 92] , but they must repeat this method until they find the best solution to solve these physical problems. (***Figure 1***).



Direct simulation

Figure 1 : *Conceptual diagram of direct simulation (one simulation = one try to know if "S" is or isn't in the sunlight at time "t")*

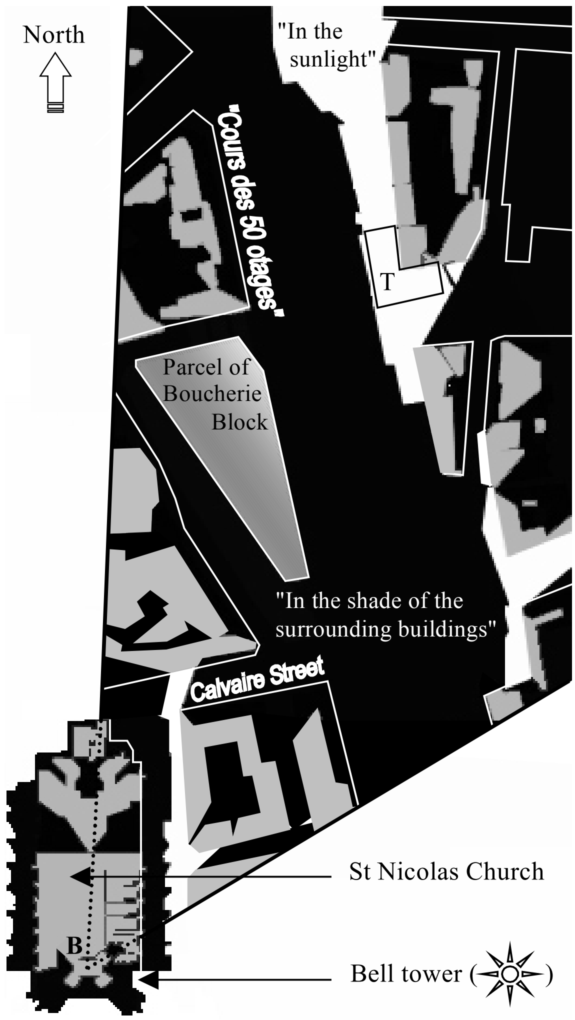
Architects and urban planners also need general tools to achieve sets of constraints. The solar constraints always are not separated problems (for example : "to be in the sunlight at 9 a.m. the 21st December 2001 and in the shade at 3 p.m. the 21st June 2001"). They can be also seasonal or periodic (for example : "to be in the sunlight from 8 a.m. to 1 p.m. during the winter" – ***Figure 2***).



Inverse simulation

Figure 2 : *Conceptual diagram of "inverse" simulation (one simulation = one set of solution to put "S" in the sunlight or in the shade between the instants t_1, t_2, t_3, t_4 ("S" = base, $[t_1t_2t_3t_4]$ = target, for example t_1 = 8 a.m. the 21st March, t_2 = 1 p.m. the 21st March, t_3 = 8 a.m. the 21st December t_4 = 1 p.m. the 21st December)*

The ***Figure 3*** illustrates one direct method to solve visibility problems. The visual constraint is comparable with solar problem. Indeed, both of them involve the same type of answer, that is to say a Boolean solution. In other words, the constraints are always : "to see or not to see the sun" or "to see or not to see a target".



Boucherie block project, Nantes, France.

Figure 3 *: Direct simulation of the visibility in comparison with a direct solar simulation. The steeple ("B") "is the sun", the terrace T is "in the sunlight of the steeple".*

Limited, generally, to the analyse of shadows of 3D spaces and direct visibility, the current graphic models don't take periodic and dynamic constraints into account. The volumetric resolving of 3D constraints on architectural objects and urban blocks, constitutes the primal axis of our inverse SVR model. On the contrary, the direct simulation doesn't allow volumetric solutions.

3. THE "INVERSE" SIMULATION OF SUNSHINE, VISIBILITY AND REFLECTION (SVR MODEL)

SVR model is based on a inverse graphic reasoning to solve architectural and urban problems between two given areas. It solves as well the sunlighting as the visibility or the reflection between a base and a target [Houpert 01]. The model was implemented in *AutoCAD* (VBA macro).

The base or the target could be a point (a given fixed observer for example) or a convex or concave closed polyline (a moving observer or an area in the sunlight or in the shade for example). The solution of the calculations is a solid 3D volume : a volume of solar or visual constraint. This complex volume represents the whole of the rays (sunbeams, visibility, reflection…) between the two surfaces (***Figure 4***).

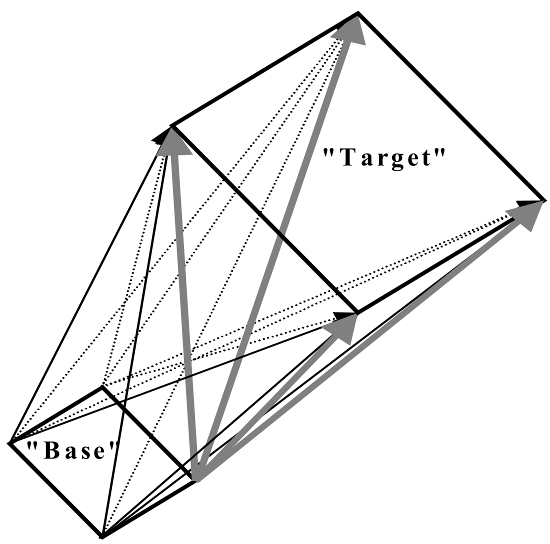


Figure 4 : *Conceptual diagram of SVR model : A set of "basic pyramids of beams" to join the "Base" with the "Target"*

The volume of solar constraint is a complex volume. The base of the volume is the surface which we want to be in the shade during summer for example (or in the sunlight during winter). The target is not a plane polyline but represented by a part of the sky-vault (or more exactly a period of the "solar vault") to simulate annual period of sunlighting (***Figure 5***).

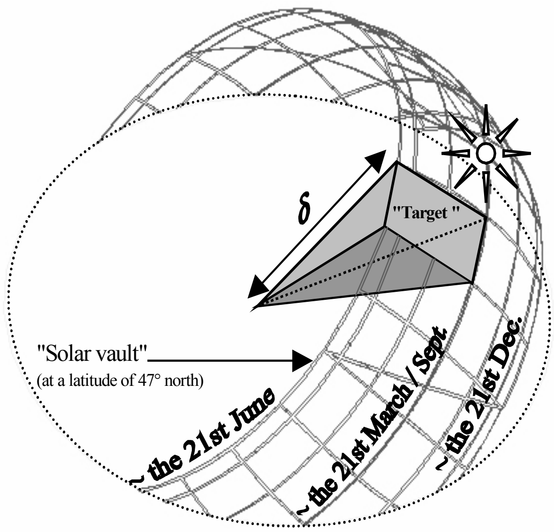


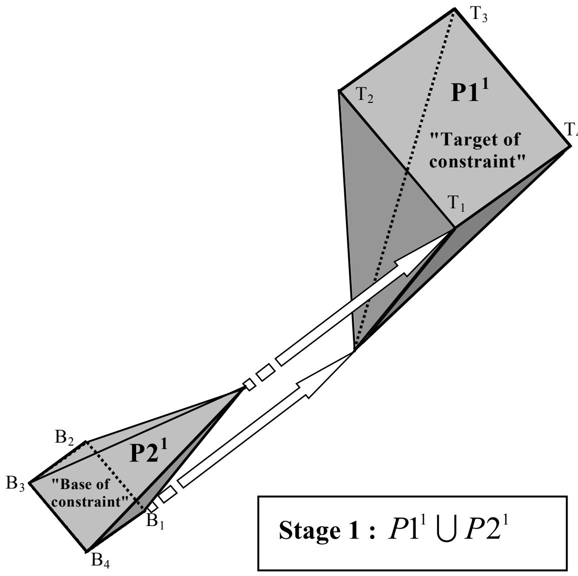
Figure 5 : *Construction of a "volume of solar constraint" from a model of the "solar vault" : the base of this volume is the surface which we want in the shade during a period of the summer for example. The target is represented by a non plane polygon to simulate this annual period of sunlighting. The sky-vault model is a half sphere 100 kilometres high (that is to say 100000 drawing units). Thus, the solar beams are considered as parallel.*

The architectural or urban problems of reflection are a mix of visual and solar constraints. Therefore, the reflection constraints are also solved with a visual or solar method. The architect must indicate the plan of solar or visual reflection (the " mirror plan").

As you can see on the ***Figures 6, 7, 8, 9***, SVR model is based on a geometrical constructing method of "volume of constraint" ($\mathcal{V}$) which use pyramids unions. Let's have a look at the following details.

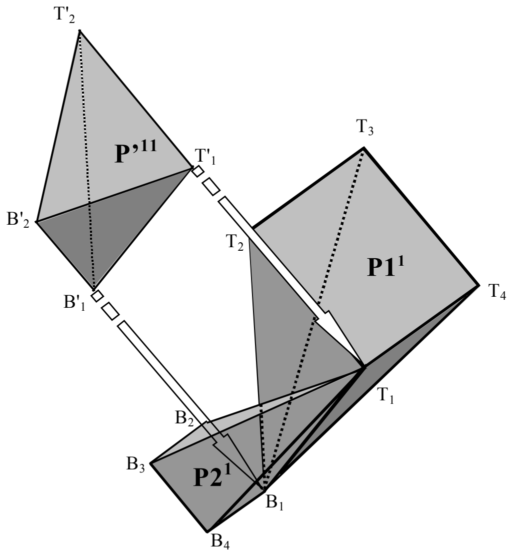
Let x>2　　*1 ≤ i ≤ x*
Let y>2　　*1 ≤ j ≤ y*
Let "Base" be a polygon of x sides [$B_1B_2B_3..._{}B_x$].
Let "Target" be a polygon of y sides [$T_1T_2T_3..._{}T_y$].

Let $P1^i$ be the pyramid whose the base is "Target" and the vertex is the i-th vertex of "Base" (B_i).
Let $P2^j$ be the pyramid whose the base is "Base" and the vertex is the j-th vertex of "Target" (T_j).
Let P'^{ij} be a pyramid joining the i-th edge of "Base" with the j-th edge of "Target".



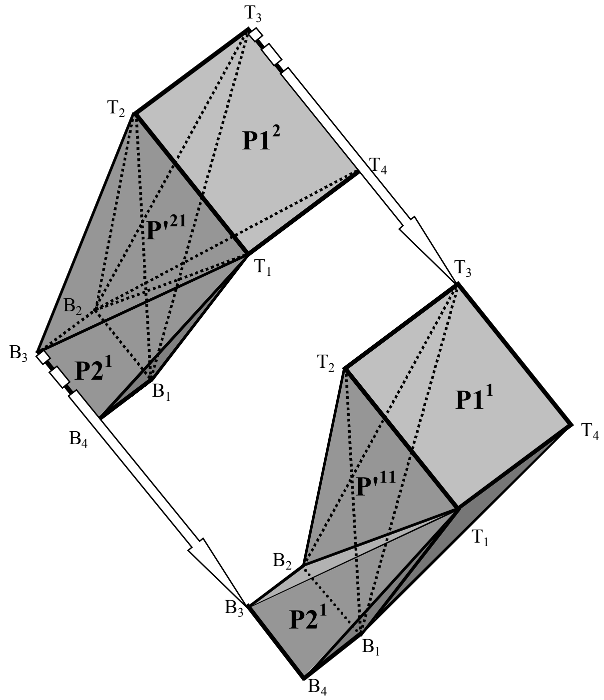
Stage 1 : $P1^1 \cup P2^1$

Figures 6 : *First stage of SVR model constructing a "volume of constraint" ($\mathcal{V}$) (example with quadrilateral "Base of constraint" and "Target of constraint", x = y = 4)*



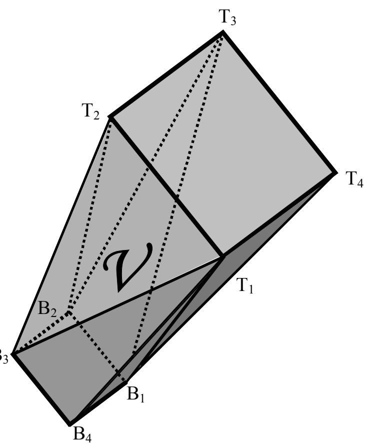
Stage 2 : $P1^1 \cup P2^1 \cup P'^{11}$

Figures 7 : *Second stage of SVR model*
$T'_1 = T_1$, $T'_2 = T_2$, $B'_1 = B_1$, $B'_2 = B_2$



Stage 3 :
$(P1^1 \cup P2^1 \cup P'^{11}) \cup (P1^2 \cup P2^1 \cup P'^{21})$

Figures 8 : *Third stage of SVR model*



Result :

$$\mathcal{V} = \sum_{j=1}^{j=y} \left(\sum_{i=1}^{i=x} (P1^i \cup P2^j \cup P'^{ij}) \right)$$

Figures 9 : *Result of SVR model*
$\mathcal{V}$ is the solid volume of constraint

Now, I would like to draw your attention to the following figure ***(Figure 10)***. It presents a urban block at Nantes – France – not yet achieved ("Boucherie" block). This project of building, presents tow constraints of visibility and sunshining for the neighbourhood.

The goal of this example is to present how SVR model solves a double constraint in a urban environment. The first given constraint is "to be in the sunlight in the middle of the morning during winter". The base of the constraint is a shop window which is near the Boucherie block. The target is a part of the solar vault (a non plane quadrilateral). The second given constraint is "to see the steeple of Saint Nicolas church. The base is a concave polygon. The target is a triangle (the silhouette of the steeple).

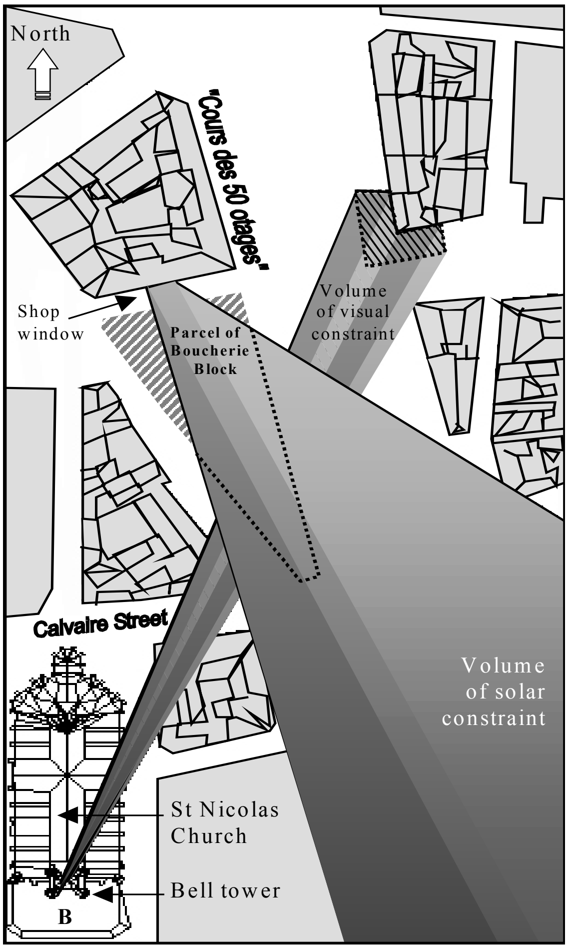


Figure 10 ***:*** *Plan of Nantes – France ("50 otages area"). Tow volumes of constraints.*

The solar and visual constraints are known, but the Boucherie Block obstructs the sunlight and the visibility. To satisfy the solar and visual constraints, the architects and urban planners must subtract both volumes of constraints from the Boucherie Block (***Figure 11***).

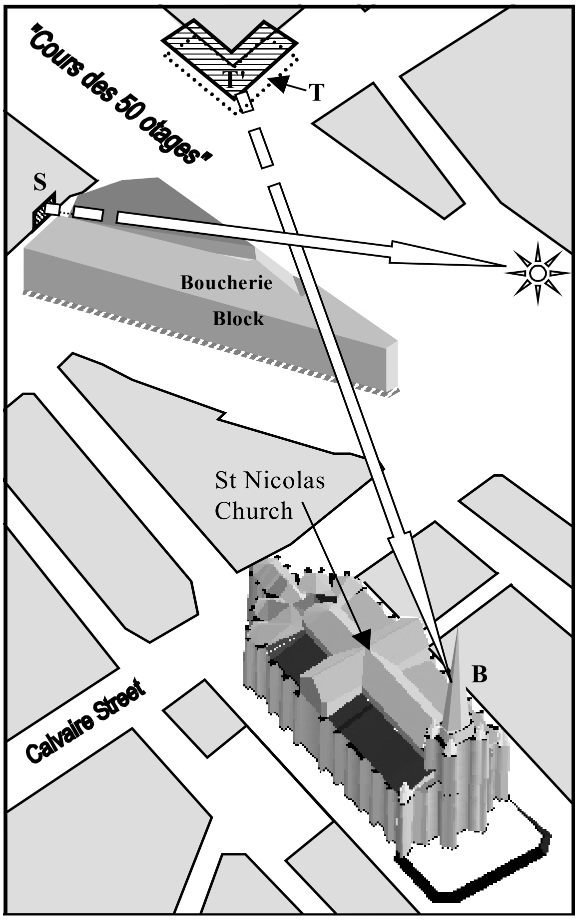


Figure 11 ***:*** *Axonometric view of the exact solution to satisfy both constraints.*
The block is cut out by both volumes of constraints.
T' is the orthogonal projection of T on the horizontal view plan of the terrace (1,2 meters high).
Both bases are T' and S.
Both targets are B and ☼ (part of the solar vault corresponding to the middle of the morning during winter).
The architects or the urban planners must just select the vertices of bases and targets (on the scene and the solar vault model).
SVR model builds the 3D solides $\mathcal{V}$ *(**Figure 12**).*

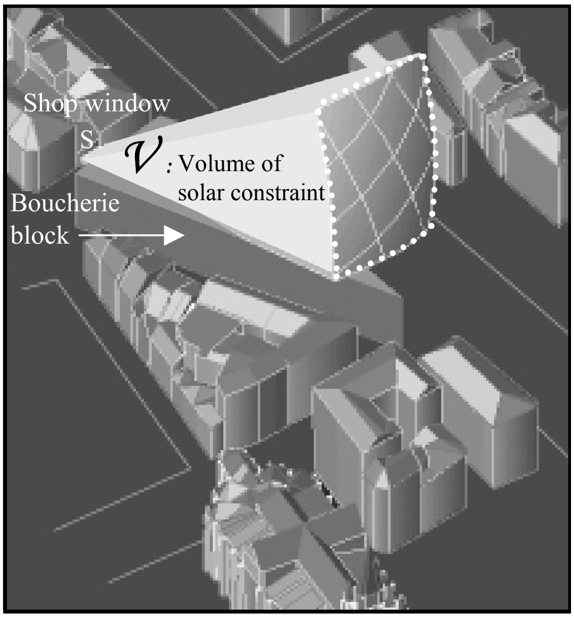


Figure 12 ***: Representation of the 3D solar constraint in the shape of a "volume of constraint" (V).***

As you can see on this example (***Figure 12***), V is 200 meters limited (a parameter) whereas in SVR model the vertices of some constructing pyramids ($P1^i$) are situated at 100 kilometres. This is just a rendering parameter, in order to facilitate the manipulation of the volumetric constraints.

This type of representations enables to explore the solutions of a given problem with a graphic and interactive method. Furthermore SVR interface enables to generate exact visual or solar screens for a given constraint and a given position (selected plan). Thus, these screens represent the exact set of points (of the selected plan) that overshadow the base of the constraint.

Figure 13 shows an example of computer aided design. The new Boucherie block is an architect's proposition. Its volume is included in the volume of ***Figure 11.***

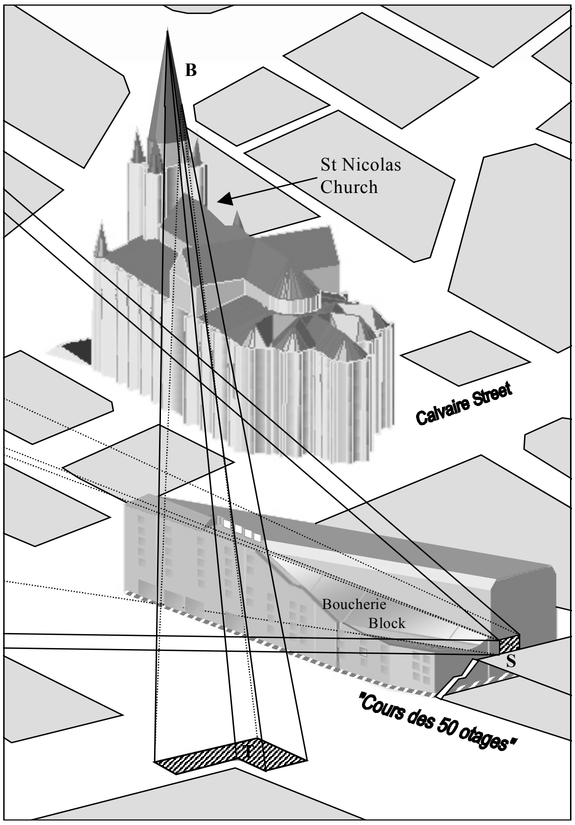


Figure 13 ***: An architect's proposition of the new Boucherie block.***

Figure 14 and ***Figure 15*** are a checking on sunlighting and visibility by ray tracing method.

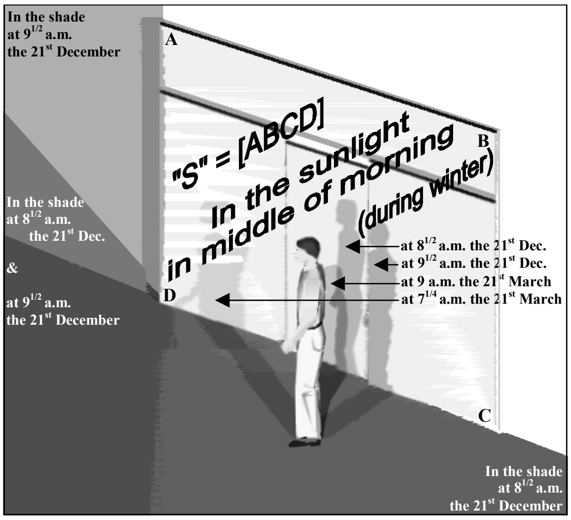


Figure 14 ***: Ray tracing (direct method) to check the sunlighting of the shop window ("S") in middle of morning during winter (solar constraint).***

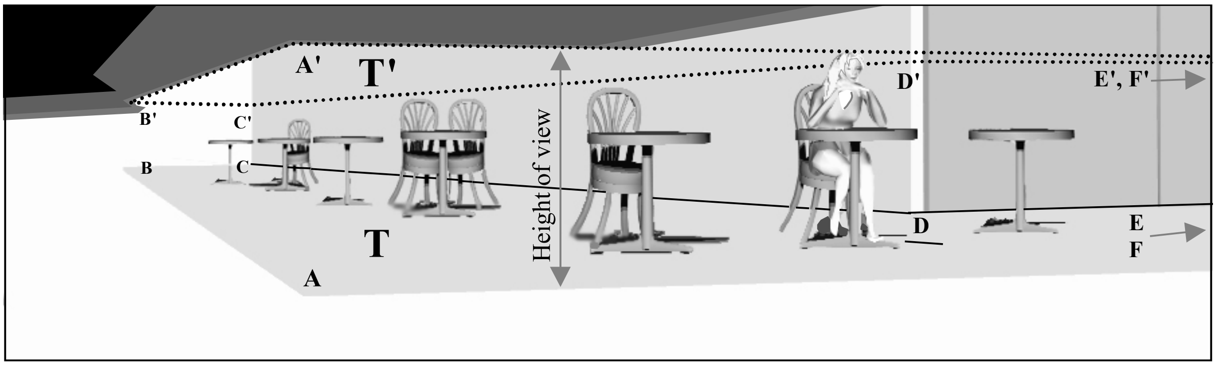


*Figure 15 : Ray tracing (direct method, like **Figure 3**) to check the visibility of the Saint Nicolas church from the terrace (visual constraint). **T' [A'B'C'D'E'F']** is the orthogonal projection of **T** (terrace **[ABCDEF]**) on the horizontal view plan of the terrace (1,2 meters high). The impact of the new Boucherie block volume is the dark zones on **T'** plan. On checking, we find that nobody will be "in the shade of the steeple". Thus, the visual constraint was taken into account.*

4. CONCLUSION

We presented how the constraints of visibility and reflection, or the solar constraints could be represented by 3D solid volumes of constraint.

A new method was found to implement a program in *AutoCAD* (VBA macro – ***Figure 16** and **Figure 17***) to solve architectural and urban problems. The SVR interface is made for the architects, and by an architect [Houpert 01].

The 3D representations enables to generate and to explore the solutions of a given problem (inside and outside constraints) with a graphic and interactive method. Indeed, we think that this reasoning is adapted to the process of drawing at the planning stage. This type of model is handy for the architects, designers or urban planners because it's adapted to the volumetric reasoning.

Figure 16 : SVR user interface

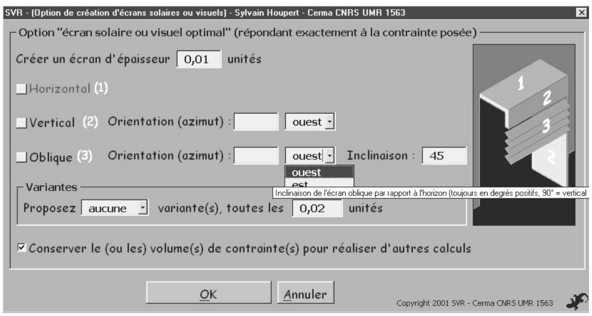


Figure 17 : SVR option "optimal solar or visual screen"

REFERENCES

[Dourgnon 61] Dourgnon J., Chauvel P. et Kokka L., **Déterminations graphiques et mécaniques de l'ensoleillement,** *les cahiers du CSTB, CSTB*, 33 p., 1961.

[Etzion 92] Etzion Y., **An Improved Solar Shading Design tool,** *Building and Environment, Pergamon,* vol. 27, No.3, pp. 297-303, 1992.

[Houpert 01] Houpert, S. : **Un outil de simulation inverse de l'ensoleillement accessible depuis un logiciel de CAO utilisé en architecture,** *CISBât'01*, 2001.

[Nivet 99] Nivet, M. L : **De Visu : un logiciel pour la prise en compte de l'accessibilité visuelle dans le projet architectural, urbain ou paysager,** *Isitem*, 1999.

[Olgyay 63] Olgyay, V. : **Design with climate, bioclimatic approach to architectural regionalism,** Pinceton University, 1963

[Siret 97] Siret, D. : **Propositions pour une approche déclarative des ambiances dans le projet architectural. Application à l'ensoleillement,** *Isitem*, 1997, 323 p.

[Twarowski 62] Twarowski, M. : **Soleil et architecture**, Dunod, 1962, 175 p.