A FURTHER STEP IN ENVIRONMENT AND BIOCLIMATIC ANALYSIS: THE SOFTWARE TOOL SOLENE

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ABSTRACT

It is obvious that a building permanently exchanges with its nearby environment (mainly light, heat, sound, visual accessibility); these interactions are numerous and complex enough to require serious means of investigation, more especially as the requests of the new regulations and those of the users become increasingly demanding. This is why one of the aim of our laboratory is to develop software tools that can give help to the architect and the urban planer in their decision making process.

After a concise summary of the main principles behind the tool we present here, we will describe case studies that highlight the possibilities of the sofware in various situations and scales, including urban questions, indoor analysis, the level of performance of a control device, etc. The examples are choosen among recent studies that we achieved for architects, engineering departments or else the office of the urban development of our city.

Finally we will conclude with educational considerations by how the open structure of this tool can be very interesting from a teaching point of view by "forcing" the user to understand of each one of the stages. Further prospects will be mentioned, including specific developments about urban microclimate and its control.

KEYWORDS

Simulation toolkits, bioclimatic analysis, energy diagnotics.

INTRODUCTION

The growing need in urbanisation and at the same time a better energy savings consciousness led urban planners and architects to pay more and more attention to the relationship between the buildings and their nearby environment. But the lack of comprehensive tools able to give reliable responses to the multiple constraints (which are sometimes in contradiction) makes difficult the taking into account of the various parameters; and even the intentions are real, functioning problems are too often noted, creating discomfort for the users and extra-costs (for example problems with overheating, glare, poor natural light, etc., result in addition of uncontrolled protection devices, costly air-conditioning systems, increase of electric light consumption, etc.)

This is why among the various topics of research of the Cerma laboratory, important efforts are devoted to the development of suitable tools, mainly based on numerical simulation. Our key software tool, called SOLENE, makes it possible the urban planner and the architect to carry out investigations concerning the microclimatic and solar fittings of buildings and more generally urban forms. If urban issues require macro-scale studies, smaller scales can be considered too, like the impact of solar protections or other devices such as porous screens.

So the first objective of this tool is to help the designer in the early stages of the designing process by providing informations to support his choices ; this is a "classical" use of simulation on design. But in our laboratory, the tool is also used for the constitution of a theoretical knowledge by carrying out the analysis of some well-known "architectural references" or typologies, or making the comparison between the writings of famous architects or scientists and the transposition of their key ideas in the real world (Le Corbusier, Aalto, Rey, Godin, etc.)…

SUMMARY

Some previous papers (Miguet & Groleau, 2001, 2002) already gave a detailed description of the physical models and the various simulation procedures that are used in SOLENE. In the present paper we will only summarize the main principles.

Its particular structure consists of a hundred of small piece of software that achieve a specific operation; these can be chained or combined, automatically or according to the user's needs ; thus it becomes quite easy to develop its own functions for a specific problem.

The visualization functions use a 3D graphics API that proposes various ways of representation which outline the different behaviours observed in space and time, all of them with coloured maps over the faceted surfaces of the 3D model, as shown further in the examples. These functions can display various requests and calculations from the database that any simulation build - for example the user can display the values over a given threshold only, the difference between two simulations results on the same geometry, etc.

The geometrical model

The geometrical model can be imported from any CAD software through the ACIS file format (.sat). In theory the model is not restricted in form or complexity, provided it is consistent enough. A new interface with Google Sketchup® that was developped in our laboratory allows also geometric import / export, and makes it possible to display the results over the Google Earth 3D maps, thus showing the studied spaces in their "real" environment.

The model has to be meshed to perform most of the simulations, except for cast shadows; but even the whole model is taken into account in the process, the simulation itself can be performed on selected surfaces of the meshed model only. This is interesting both for reducing the heavy calculation and for vizualisation purposes (Figure 1).

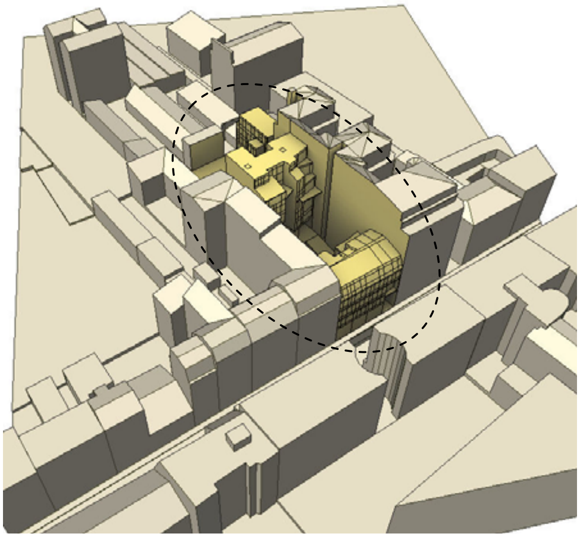


Figure 1 Simulation can be performed on surfaces selected by the user only; the levels of details for the object and the environment are different

Sun and sky models

Sun is modelled as a point source ; its angular position is given by the celestial geometry and its energy is calculated from a statistical radiance model.

The model of the sky vault is a hemisphere of infinite radius, with the scene to be simulated located at its center. This hemisphere can be seen as a source of diffuse energy with a non-uniform distribution (Figure 2).

For simulation purposes it is meshed with a geodesic triangulation, and the luminance values that are mapped on the hemisphere come from the well-known "all weather" Perez model (Perez and *al.*, 1993). So SOLENE can deal with every kind of statistical distribution, from dark overcast to bright clear sky, including or not the sun.

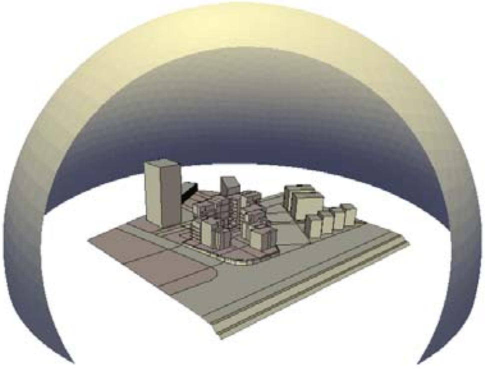


Figure 2 The urban scene under an overcast sky (its small radius is for visualization purpose only)

Gathering the energy

Radiance or luminance values are collected on every patch of the studied scene; irradiance is calculated directly, but the illuminance of the environment is obtained from an integration over the luminance distribution over the whole hemisphere. From irradiance values we get illuminances through the light efficacy model proposed by Perez again.

Radiosity

The previous process has brought energy to the surfaces facing sun or/and sky only. But many surfaces of the environment (mostly inside surfaces such as a ceiling, or the back wall in a deep room) are not directly exposed. They receive energy from the nearby surfaces (lateral walls, ground) that reflect a proportion of the collected energy according to their reflection factor. This is now a classical radiative transfer problem which is solved in SOLENE with a radiosity algorithm. The solution is calculated by the "progressive refinement" method due to Cohen (Cohen & Wallace, 1993).

It must be noted that the computation of the solution needs form factors, that is to say the geometric relationships between the patches of the meshed scene. They express the intensity of the energetic exchanges between surfaces. In computer graphics these are usually computed "on the fly", while in SOLENE they are calculated first and stored on disk.

This method presents some drawbacks but offers adventages : more time consuming because of large space needed and multiple disk accesses, but a very fast computation of the radiosity solutions, which is very usefull in case of an every-hour simulation or a reflection factor modification. In any case a change in the geometry requires a complete new calculation.

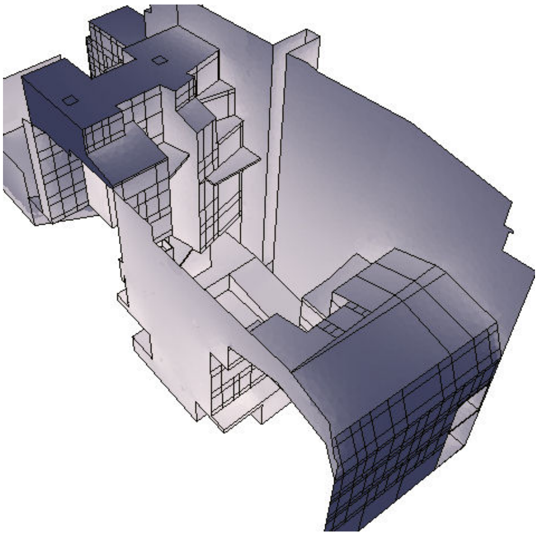


Figure 3 Display of the form factors: in light color, the zones of which it is interesting to increase the reflection factor to obtain more light in this small urban courtyard

Furthermore, the method allows to display the form factor sum for every patch of the scene (Figure 3); it points out the zones of main exchanges of energy, and so gives useful information for the choice of materials, textures or colors (*i. e.* the zones for which the reflection factor might be increased to get the light deeper in a room).

Visibility

The previous functions need visibility algorithms; but unlike usual CAD sytems, the hidden surface removal is solved with a geometric projection system followed by a clipping algorithm. This enables us to keep the information about the hidden / non hidden parts and allows to display them when needed (see in the applications below).

The user interface (GUI)

Most of the functions are accessible via a graphic interface which is divided in three main areas (Figure 4), while other ones need a command line :

- The display window where the user can zoom, move and rotate the model ; he can also select a face and get various informations about it.

- The left window lists all the geometries; only the highlighted ones are displayed. When a geometry is selected, it is possible to carry out various types of simulations and modify its display (color, lines, etc.).

- The menu bar makes it possible to define the characteristics of the project (latitude, material properties, sun and sky conditions, etc.), operate various operations with the geometries, and launch the simulation processes on the selected geometry.

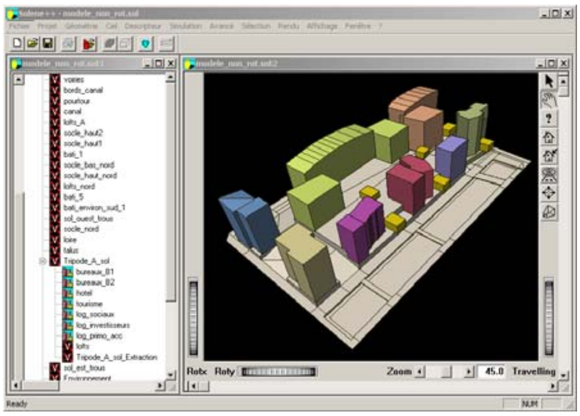


Figure 4 The SOLENE interface; all the geometries in the left window, visualization in the right one

APPLICATION TO MULTICRITERIA ANALYSIS

The analysis of a urban space or a building in terms of comfort and energy savings needs a multicriteria approach. Several parameters related to the physical environment must be studied simultaneously.

But if the way in which the constructions interact with their environment depends on these physical parameters, the effects on the users and the power consumption can vary in an important way according to whether the studied areas are rather residential, with a commercial vocation, for business activity, or these various functions mixed all together. So we will pay particular attention to the connection between these indicators and the purpose of the constructions; they must not be considered in their absolute values.

For building and urban analysis, we developed specific indicators that focus on the morphology (density, compactness, heat losses and gains), the exposure to sunlight radiation (duration of sunshine and energy), the potentiality in natural light (daylight access and occultation), questions of visibility (areas seen from a particular point), etc. Comparison between various proposals can be carried out, with highlighting the impact of such or such modification.

URBAN SCALE STUDIES

Microclimatic analysis of a urban space requires various types of investigation; they may concern physical parameters (sunshine, daylight, energy gains and losses, aerodynamic flux, etc.) that greatly affect the user comfort, but also more subjective aspects as the visibility of more or less interesting parts of the nearby environment.

In the following we describe (partially only) various studies that we have carried out on behalf of the urban community of Nantes during the two last years. All simulations except aerodynamic are performed with SOLENE; the aerodynamic approach is achieved with a commercial CFD code.

Fist of all cast shadows, that has become very common in most of architectural and CAD softwares; but with them the removal of a wall or a roof for getting a better look inside completely alter the simulation results !

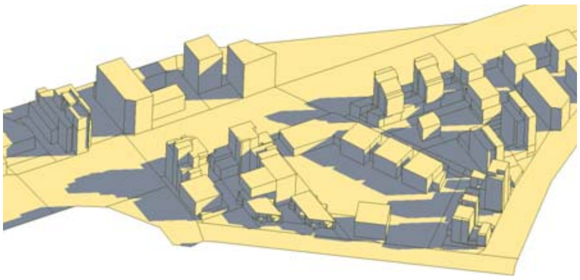


Figure 5 Cast shadows June 9th

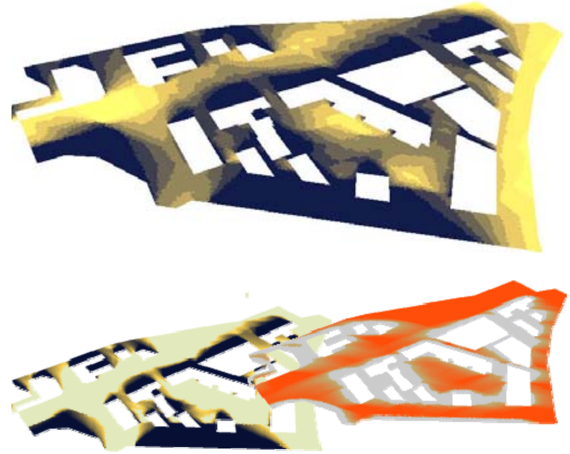
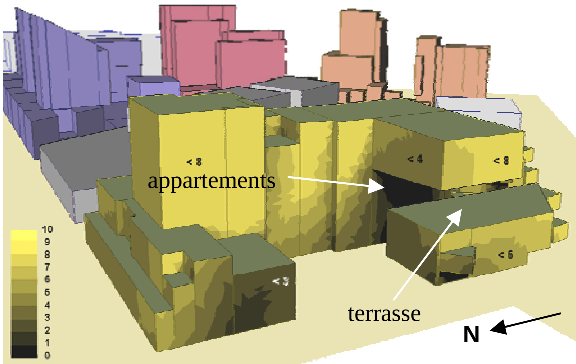


Figure 5 Sunny lengths of the public spaces only (top); display of sunny length threshold: less than 2 hours of sun in December and more than 8 hours in June (down)

A more interesting approach is to get spatial information (how long a given point of the model is sunny for a particular day ?). For example it points out the facades with very little sun even in June (Figure 6), little daylighting (not presented here), and a morphology that favour a pinch effect, as shown on the aerodynamic simulation; so the facades below the cantilever and the "terrasse" does not seem to present good qualities of comfort (they are dark and windy). Further to our results, this has been modified by the architects.



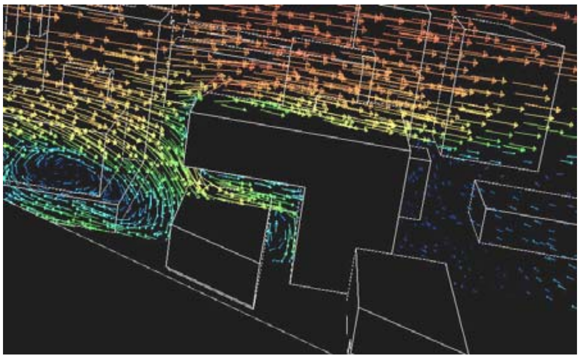


Figure 6 Sunny lengths on the façade of one of the buildings (top); aerodynamic simulation for a south-west wind (down)

In most of european countries and particularly in France, we attemp to get the most possible sun inside the rooms in winter. But in summer, we try to protect the south-facing façade (which is relatively easy with an overhang or a balcony due to the sun height) and the west-facing façade (more difficult because of the low angular height of the sun).

So for energy considerations (limitation of the power consumption in winter and the air conditioning in summer), it is important to quantify the energy received by the facades in order to evaluate the heat profits or the risks of overheating, especially in offices that are great producers of heat. The simulations give informations about the surfaces to which to pay attention, and so may help the architect in the choice of either a window protection system, or an enveloppe material, or else the tree species for a vegetalised terrasse, etc. (Figure 7).

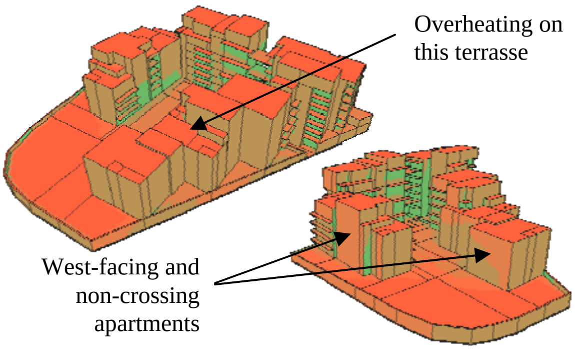


Figure 7 Solar energy (W/m^2) received in summer in a new residential and commercial operation. The west-facing flats are non-crossing, and risk over-heating by insufficient ventilation in summer

Daylighting

SOLENE can perform daylighting studies with any sky type. But if the light level is important to be estimated in interior spaces, it depends completely on the outside available light, and so on the configuration of the outdoor spaces. For example the walls in a concave angle as shown on Figure 8 can "see" no more than 25% of the surface of the sky vault, and so a window in this part will be of poor efficiency. This must be related to the function of the rooms behind (Figure 9).

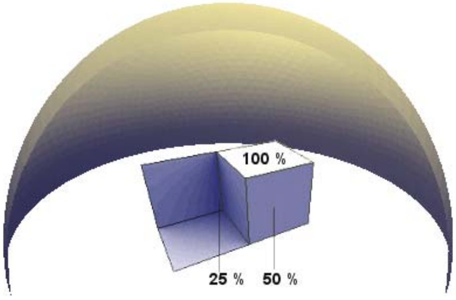


Figure 8 Theoretical availability of the natural light

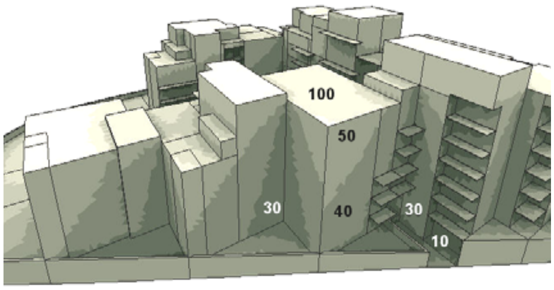


Figure 9 Application to an urban configuration. The values correspond to a percentage of visible sky, in other words to a uniform luminance distribution

On the next example, we point out the impact of the surrounding buildings only, and especially a high tower. The architect was worried about the loss of natural light due to this building, especially for the lower storeys. The display shows the difference between two simulations: one with and one without the masks (the tower and the other small buildings); it reveals that the loss is significant (Figure 10). On top of a new distribution for the apartments decided by the architect, the advice was the use of a lighter colour for the renovation of this tower that was dark blue before, expecting a significant amount of diffuse reflected light (not displayed here).

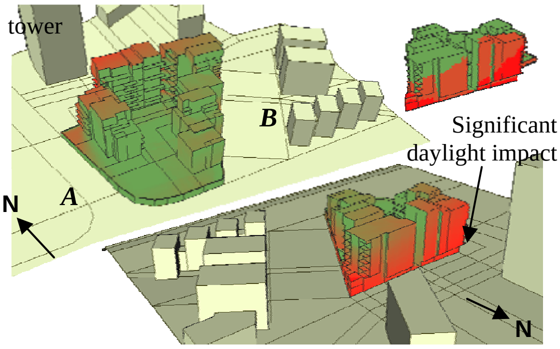


Figure 10 The more red the more important is the reduction of daylight due to the surrounding buildings; it is obvious that the tower causes an important loss in natural light for these north-facing and non-crossing apartments (~ 20%)

At the urban planing stage, this kind of study (impact of the surrounding masks) help to define the opposite buildings size and the space between them. In this particular case a previous study with templates had specified the size of *A* and *B* blocks to minimize their relative impact. The studies can be carried out for cast shadows, light from the sky vault or energy.

Visual accessibility

This aspect deals with the notion of "visual comfort", or on the opposite with "visual pollution". Besides the impacts listed before, any new construction has a visual impact too. It can be "measured" by answering to the following questions: which are the surfaces visible from a given point (a balcony in the example shown on Figure 11), or from which streets of an old urban center the pedestrian will catch sight of a specific monument, or will see even a small part of an ugly tower (Figure 12) ?

In particular theses questions are of great interest for the department that takes care of the conservation of the architectural heritage in the old european urban centers. Another application should be for example the visual impact of a field of wind generators in the countryside, etc.

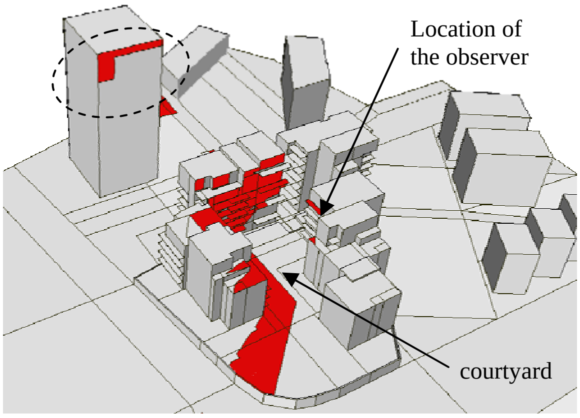


Figure 11 From his balcony, the observer sees only a very small part of the nearby tower; the inner courtyard is visually protected from the tower

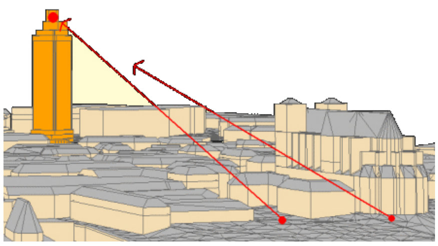


Figure 12 From a 3D model of the old centre of the city of Nantes, in white colour the streets where from the top of the tower is visible

BUILDING SCALE STUDIES

On a first step the case of a single building is not very far from the previous urban studies since its external enveloppe is subjected to outside conditions that depend on the building environment. May be in this case the level of detail can be more accurate for the studied building than for the environment, which is used as a mask (see Figure 1 again).

Among the many possible simulations, cast shadows and the illuminance values or the daylight factor on a workplane are the most commonly asked - they are traditionally computed on a horizontal workplane, possibly vertical for specific needs (Figure 13).

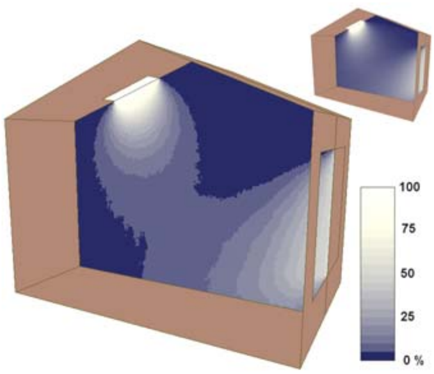


Figure 13 Daylight factor on a vertical cutting plane; windows have 100% transparency

Figure 14 shows the last results of a complex analysis in medical laboratoires, with multi-reflexions in the patio and the indoor spaces (radiosity processing); several different configurations have been tested.

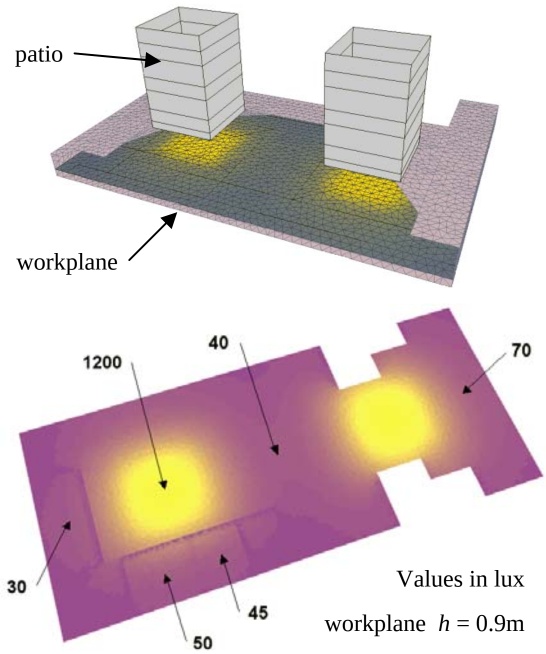


Figure 14 Illuminance values on a work plane (down); light comes from two patios through horizontal translucent glass (top)

DEVICE SCALE STUDIES

As long as the architect knows that a solar protection is essential, he has to make a choice among many shading devices: types and forms (awning, blind, wire mesh), orientation (horizontal, vertical), fixed or mobile, its material (wood, metal, glass), only passive or with PV modules, etc. Whatever his choice may be, its consistency and its efficiency must be verified, or different solutions may be tested.

The analysis of these devices is somewhere more tricky to carry out. The problem is mainly due to a great difference between scales: generally the scale of shading devices is the centimeter, or even the millimeter in the case of the small links of the metallic porous screens. On the other hand the analysis of their impact is made at the size of the room, so with a huge difference in scales.

This aspect make us consider and model a small piece of the device, sometimes a single mesh only, sometimes a few dozens of them, depending on their shape and combination (Figure 15).

In the following we give as an example of some results about the analysis of a welded wire mesh used for solar protection on three sides of an engineer school block. We had to determine which orientation was the best to give to the meshes.

Percentage of occultation of a meshed filter

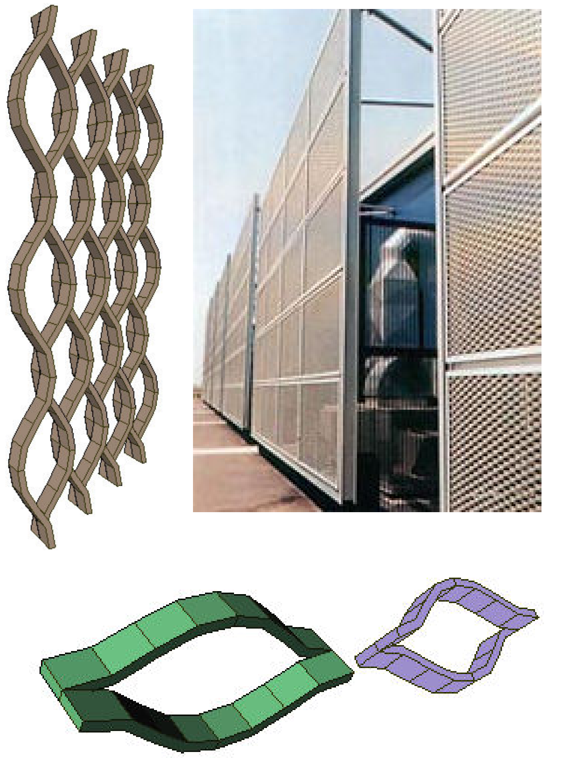


Figure 15 An example of an expanded metal screen (top right) and 3D models of the meshes in various orientations (left and down)

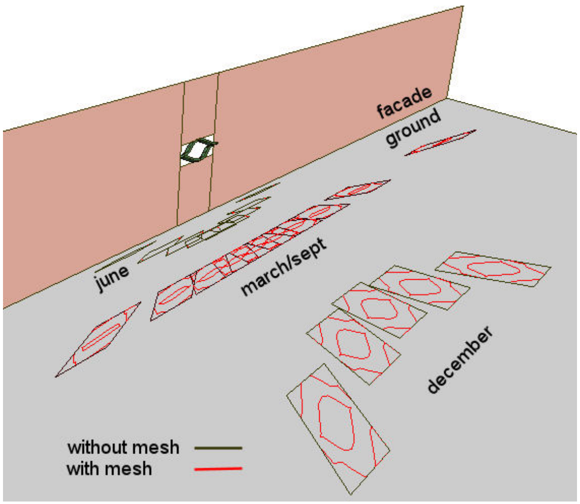


Figure 16 Sunshine studies for a south-facing façade; inside view; simulation performed every hour at equinoxes and solstices (45° lat.)

The percentage of occultation of the meshed screen is obtained by a calculation ratio in SOLENE : the area of the projected rectangular opening on the floor without the mesh / the same with mesh in an infinite room (Figure 16). Then an interface with an Excel® speadsheet gives the transmission factor of the device (Figure 17). Note this is a geometric approach and so diffraction problems are ignored.

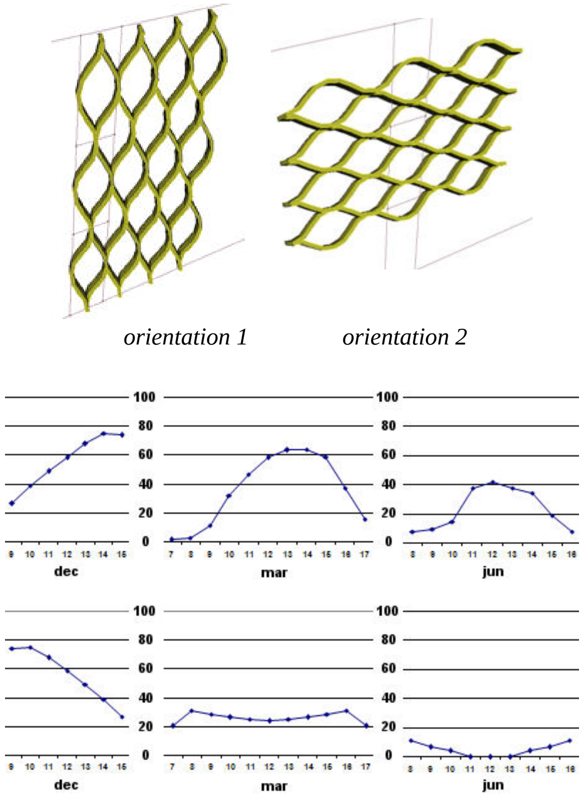


Figure 17 Comparison of the transmission factor of an infinite meshed filter for two different orientations of the meshes; the case of a south-facing façade at equinoxes and solstices

The results are quite obvious : for a given façade, the same device can show very different performances according to its orientation ; the final choice will be made after looking at the uses of the spaces these filters are designed to protect.

The purpose of the previous study was to test the efficiency of a given device for sunshine purposes. But of course such a filter may reduce drastically the natural light inside the spaces they are designed to protect. So it is important to quantify the loss of natural light in case of bad weather conditions, *i.e.* under an overcast sky. It can be achieved in Solene with two simulations and then calculation between the two databases : the difference between the light levels on the surfaces of the tested room without / with the device gives the loss of natural light due to the filter as shown on Figure 18 below.

It points out that such a filter significantly reduces the natural light mainly near the picture window, but much less as one goes deeper in the room. This can be interesting for a south-facing façade of a class-room : it is protected from sunshine in summer while the natural light must enter the room easily in winter.

These results combined with the previous ones bring deciding factors for the choice of the type and the orientation of the device.

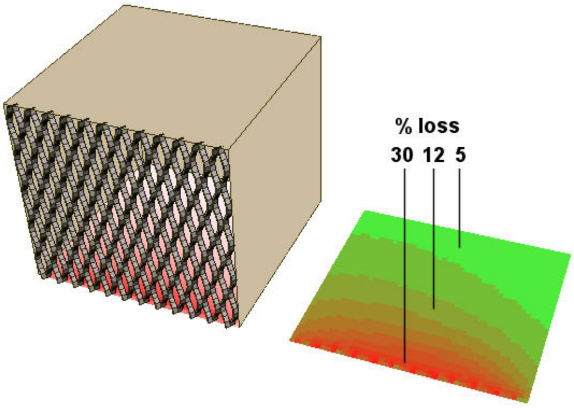


Figure 18 The reducing of natural light in a cubic room due to the meshed filter

CONCLUSION

The goal of this paper was to highlight how the recourse to a simulation tool such as SOLENE can help the architect or the urban planner in their decision process. The simulations give them important and reliable information about the close connections between the buildings and their environment.

On the other hand it's important to keep in mind that this tool will give of course no ready-made solution; the decision-maker has to compromise with many constraints. These are more or less difficult to manage, and the objective and practical elements given by the simulations results will be reliable deciding factor for the final choice.

Finally, the possible uses of our tool are not limited to the applications that have been described here. Its open structure makes easy the development of new functions (as said in the introduction it is not a "black box" or "closed" software but a set of independant fonctions that can be linked together). It's precisely what we are doing at he moment, programming new functions for studying urban microclimatology with more parameters and better accuracy. This structure is also attractive from an educational point of view. It makes the user to understand the mechanism of the interactions between the various parameters; this is the reason why in a specific master at the school of architecture of Nantes, we use SOLENE with the students to help them to adjust their project.

The tool allows also the constitution of a theoretical knowledge with the analysis of some well-known "architectural references", and particularly the confrontation between the theoretical writings of the architects and the objective results of the scientific analysis of some of their projects (this work is carried out mainly on the occasion of PhD thesis).

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