Helping architects to design their personal daylight

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Abstract: - This communication is based on a seven years experience of teaching day lighting to graduate architects coming from very different latitudes and climates. We first created didactic software to help them controlling sun paths. Later, we developed it gradually to support the common part of the problem: the geometrical one. With the same knowledge and tool, the students imagined very different projects, which reflected their different sensitivities and ideas about light, especially in its chromatic aspect. Their works confirmed us the evidence that the justified preoccupation about ecology and sustainability must not obviate the fact that good architecture is, first of all, an art. The software, "Heliodon", developed by Benoit Beckers and Luc Masset, offers synthetic and original representations that allow the architect to develop its design freely, but controlling simultaneously space and time aspects. It complements commercial rendering software and is a fundamental component of a personal theory about light ambiances and color. The results are very original projects that blend aesthetic expression, geometrical control and environmental conscience. With this teaching, every architect is expected to discover his personal daylight. In the near future, the contributions of architects and urban designers will also be fundamental in order to extend the studies of solar radiation to large urban areas. The collaboration between geographers, climatologists and physicists will be crucial in order to define the appropriate numerical mockups at different scales.

Key-Words: - Architecture project – daylight - solar radiation – geometry – projections – simulation

1 Introduction

In the last few years, the rendering techniques have known a spectacular progression, and it is now possible to produce very realistic images of an architectural project in a small number of hours, with the correct and detailed illumination of an edifice that does not exist yet.

However, many architects continue using manual methods in the elaboration of their ideas, and only few of them produce final renderings of their projects for a public presentation. The main reason lies in the fundamental difference between design and analysis. Rendering software are too slow to be considered as design tools (interactivity is not yet conceivable) and their computations lack of the necessary limpidity for a secure interpretation.

The sun moves throughout the day and year; a double sequence of renderized pictures, or a sequence of animations can show such a variety of paths. But they deliver so dilute information that these representations are impracticable in the design process, when the forms and orientations are still to be modified. It should be necessary to use a much more synthetic representation of the sun paths and of their effects. The render programs do not offer it because their main goal is photographic realism.

A software dedicated to design must offer computations and representations that should be fast (allowing interactive handling), synthetic (allowing the visualization of all the useful information) and limpid (with unambiguous interpretation).

However, regarding solar radiation, the energetic approach is not enough for architecture. Firstly, architecture is not only concerned by the thermal balance, but by the perception of the energies, as well. In second place, this perception does not depend only on the physical data, but also on their cultural and aesthetical evaluation.

2 Solar radiation

Since the year 2003, we are developing the software "Heliodon" [1] with the intention to realize a proper tool for aided design with natural light [2]. Traditionally, the solar diagram is a stereography of the Sun trajectories drawn on the vault of heaven, (Fig. 1). The stereography is a central projection on the ground from the nadir (opposite point of the zenith). Its geometric properties offer three advantages with respect to the other azimuthal projections: it respects the angles (property of conformity), the circles pertaining to the sphere are projected as circles, and the projections of the elements near the horizon conserve reasonable size.

In this diagram, the projections of the objects of the scene appear as masks or obstructions, but the diagram can also be seen as a calendar that shows the solar trajectories partially hidden by the objects. That means that at some moment of the day or of the year the solar rays do not arrive to the point. This diagram is then informing about the obstructions in the point of the scene called sensor.

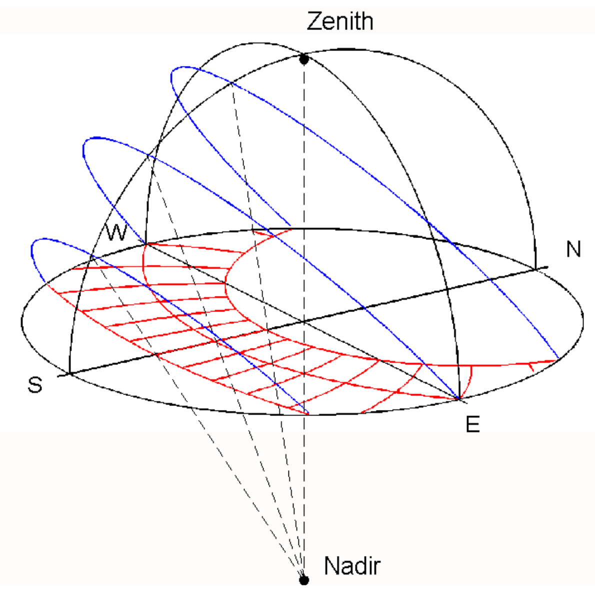

Fig. 1: Sun trajectories shown on the local hemisphere, and in the stereographic projection

In "Heliodon", this drawing is presented with the shadowed top view (Fig. 2) that shows all the space, but in an instantaneous graphic. These graphics are complementary, because the first one is punctual, but shows the whole year, while the second is instantaneous (shadows correspond to a precise instant), but shows the whole space. A third window gives an axonometric view that includes the vertical dimension.

When the sensor is moving in the plane, the solar diagram is changing. When the sun is moving in the stereography (because the hour or the day are changing), the shadows are moving in the plane.

Thanks to this interactive process, the user is moving freely in space and time, i.e. in the five dimensions of the solar problem (three space dimensions, the hours and the days). This is providing global information difficult to get from any other graphics.

This original and simple idea really enhances the tool, allowing the user to control the consequences of his modifications in the geometric model simultaneously in time and space, each representation balancing the limits of the two others. In this first step, we achieve the three requirements for a user-friendly design tool: speed, synthesis and limpidity.

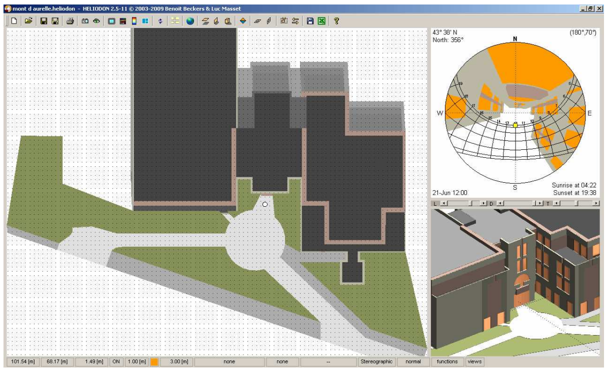

Fig. 2: The three windows of the Heliodon display

Considering the stereography in its spatial aspect, we observe that it does not allow comparing the hidden portion with the visible part of the vault of heaven, since this projection does not respect the proportions between surfaces; so the solution was to implement an *equivalent* projection.

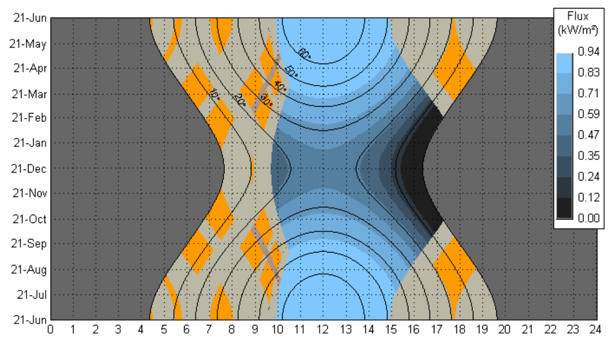

Fig. 3: Isochronal projection with superposed solar flux

Considering the temporal aspect, again it is not possible to compare the hidden part of the sun paths with the visible one, because neither the hours nor the months are equidistant. Consequently, a new projection is necessary, which we called *isochronal* [3], because in this graphics hours (horizontal axis) and months (vertical axis) are equidistant, property which allows integrating the sunlight duration in intervals defined by the user (Fig. 3). This graphics also shows the solar flux (kW/m^2), which depends on the thickness of the atmosphere (air mass quantity) and so, on the latitude, the altitude and the sun height.

In order to achieve a seasonal or yearly balance of the radiations received by each area of the scene, it is crucial to take into account the time intervals corresponding to clouded sky when the sun is fully or partially hidden. Today, despite the numerous studies [2], there is not reliable data about measures (the satellites cannot yet precisely evaluate the lower clouds and the terrestrial measure are too sparse) and the theoretical models also are insufficient.

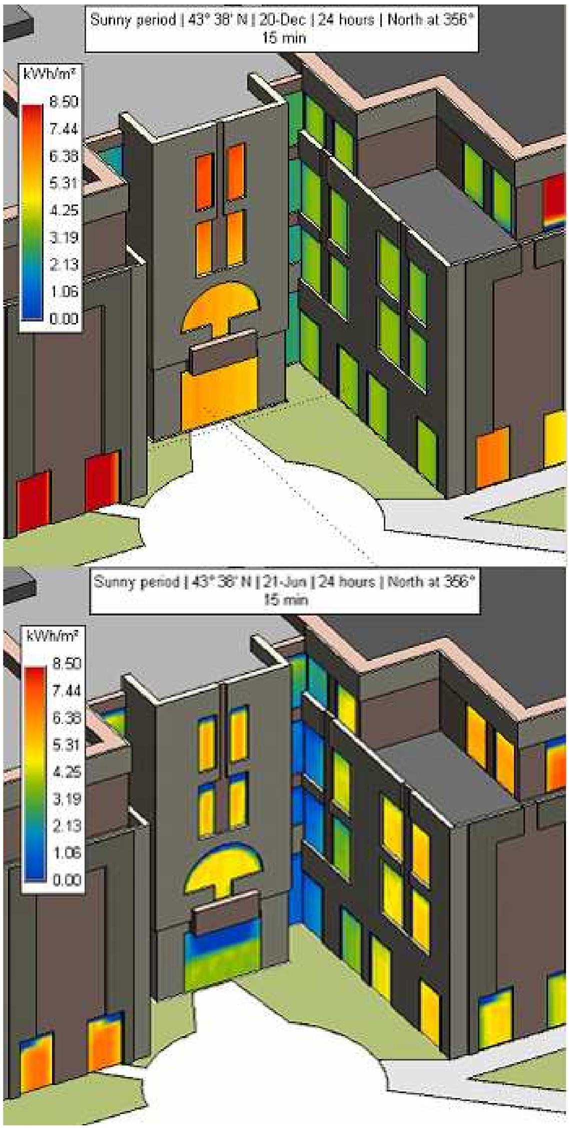

Fig. 4: Solar radiation on the windows during winter and summer solstices

In the context of Heliodon, the objective is to maintain the universality of the program for all the climates and latitudes of its users. The model must then be simple, robust and versatile. It has to accept any type of available atmospheric data. One solution is to use approximation like the Angström one [4] which is giving a linear relation (often conflicting) between the effective number of sunshine hours and the total received radiation. However the relevancy of such calculations is not obvious in the architecture project, because it is generally sufficient to compare the extreme conditions of the two solstices (winter and summer).

At the end of a project, a picture (Fig. 4) shows clearly that the sun access throughout the windows was privileged in winter but avoided in summer (it can be observed that except in few lateral windows, the incoming radiation is greater in winter than in summer). Ideally, this kind of picture is no more than the synthesis of the design process where only the interactive use of the 3D representations and the stereography allow a design including a simultaneous control in space and time of the incidence of each decision on the conditions of insolation.

3 Sky light

In the architecture project, it is important to consider the aperture of each interior space to the sky and the possibility of capturing its diffuse light, always beneficial during overcast days, because it is the unique available natural light and also during sunshine days, because it is heating much less than any artificial light, if the sunbeam doesn't enter directly. In most climatic zones, a good design consists in controlling the direct access of the sun and allowing an important contribution of the sky.

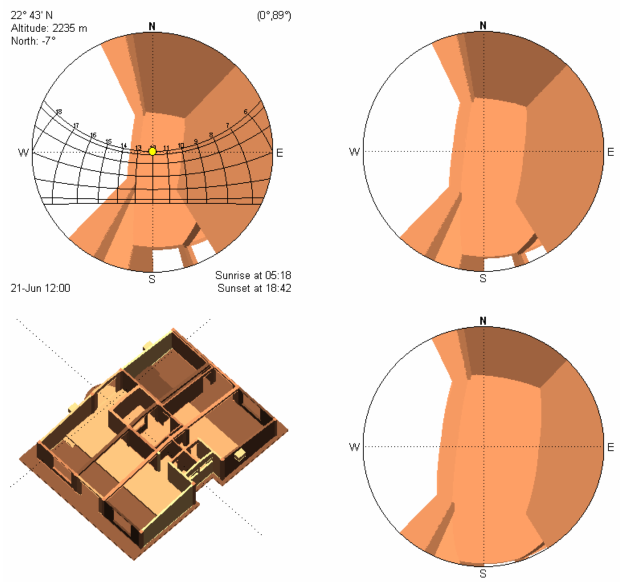

Fig. 5: Stereographic, equivalent (SF= 28.8%) and orthographic (SVF = 25.1%) projections

The Lambert equivalent projection [5] is giving directly the sky factor, which is the percentage of visible sky from any point of the scene (Fig.5). It is a simple solid angle without relation to any surface. The orthographic projection is giving the "sky view factor", SVF (Nusselt analogy [6]); it can be considered as the first step to compute the radiosity. In order to obtain the full balance of the diffuse radiative exchanges, it is necessary to compute not only the sky view factor, but also the view factors of each surface of the scene with respect to the others [7].

The sky view factor depends on the orientation of the surface where it is computed and is the basic ingredient of the radiative heat exchange between the sky and this surface. Assuming an overcast sky with an illuminance of 20 000 luxs and a working plane with a SVF of 1%, this surface will receive 200 luxs by direct sky illumination. In practice, ensuring that all the working planes of an interior have a minimum SVF of 2-3% allows to warranty the possibility of avoiding the artificial light during the day periods.

The average of the sky factor in a volume is giving a reference value that can serve for comparisons, i.e. between two architectural proposals or inside the same room, before and after the construction of another building that modify the neighbour (impact study).

With it, it is possible to design a pavilion offering the same aperture to the sky as the cathedral of Chartres or any modern building used as reference. It is a true design parameter, the simplest one, but very efficient (Fig. 6).

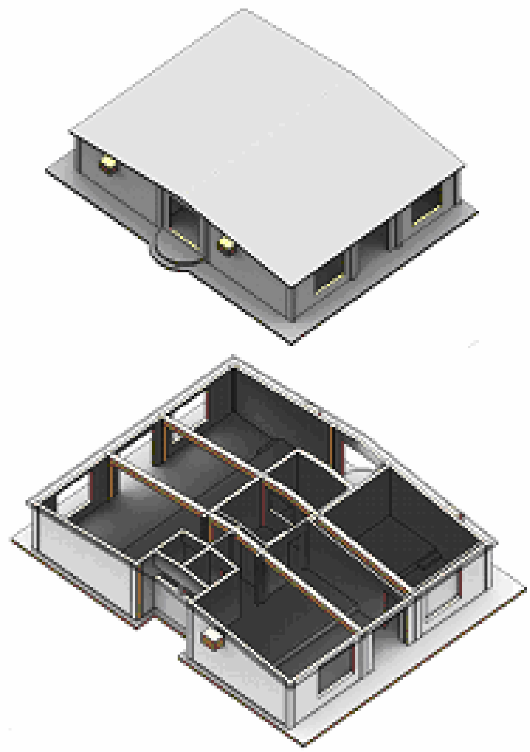

Fig. 6: With all its faces colored by the SVF, this building seems to be a renderized picture using the diffuse light produced by a clouded sky

In comparison, the daylight factor, well known by the architects [8], presents some weakness. Its very simple definition corresponds to the difference of illumination level inside the analyzed room and outside in an open place. This definition is based on the perception and on the observation that the vision is always relative and proceeds by comparisons. So a clear interior is always detected as clear, even if at that instant the obscurity is palpable due to an overcast dark sky. This is because we are more sensitive to the differences than to the absolute values.

The daylight factor results an excellent observation parameter, sufficient to describe globally a given configuration. Moreover it is easy to measure it. However its definition carries series of heavy difficulties preventing its correct simulation and utilization in design. Firstly, its inventors had to define very precise conditions of overcast sky and remove the direct solar radiation for its evaluation. This process is not necessarily questionable regarding to our demand for studying the illumination components separately. But it is fully in contradiction with its pretentiousness of being a global parameter. Secondly, all the proposed formulas (there are a lot of free programs to compute it, because it is part of the norms in many countries like France) are empirical and don't allow error calculation. Moreover, they oblige to specify all the reflection factors of all the surfaces of the scene. In the beginning of a project, it is probable that these factors are unknown. Furthermore it was never proved that some rational procedure based on this parameter has been able to lead rigorously to the selection of paintworks or coatings. This kind of parameter, which needs more information than necessary and not at the right moment, will never be appropriate to follow the project development.

As a first conclusion, we see that parameters limpid and easy to handle (the total quantity of direct solar radiation during the two solstices with clear sky and if necessary the volume average of the sky factor or the space distribution of the sky view factor) offer a valuable information, more secure, coherent and useful for the project than a parameter, supposed global, but providing questionable empirical formulas.

In Fig.7, a sensor located in a very simple building (at bottom right) defines a stereography (on top left) that can be transformed in an equivalent projection (at bottom left) or in an isochronal one (on top right). In the isochronal graphics, a grayscale indicates the variation of solar flux, depending on latitude, elevation and sun height (with a maximum when sun reaches the zenith).

The equivalent and isochronal projections can be evaluated on arbitrary plane sections, yielding, respectively, to sky factors or sunlight maps. At this stage of the application, we have observed that the user is accepting to loose interactivity because he is gaining more synthetic representations. This will give him a better control of his work and the opportunity to present some consequences of his advanced design.

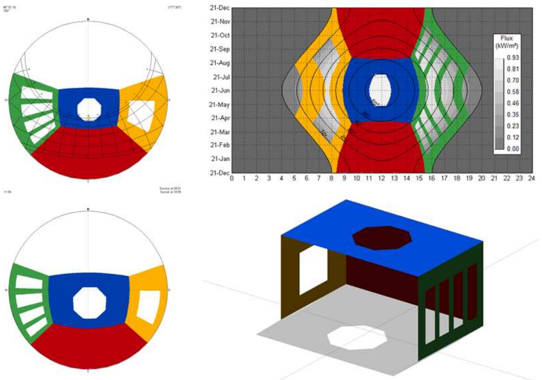

Fig. 7: Stereographic, isochronal and equivalent projection of a simple configuration

In Fig. 8, two horizontal maps are calculated at ground level in the same example as in Fig. 7: sky factor and sun flux. Sun flux is a daily average along the year, and it offers to the designer a global energetic balance of its project. The values are not realistic, because they assume a totally clear sky all along the year. However, such an approximation is already interesting for simple comparisons between different geometric configurations.

We reached this goal using the particular properties of different projections [9].

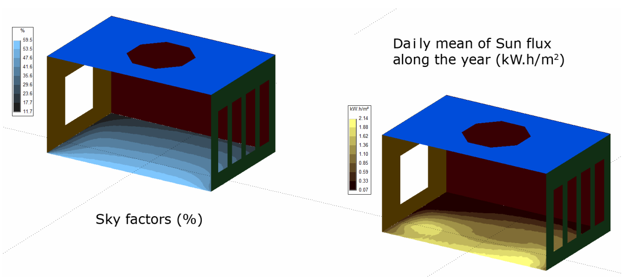

Fig. 8: Sky factors and Sun flux maps

4 Applications

4.1 The colors when Sun enters

The first example is a project by Dalia González [10], at Chilpancingo (Mexico), where the protagonists are colors.

The chromatic proposal (only visible, obviously, in the color version of Fig. 9) is the result of a long and sensitive work realized on a mock-up illuminated by sun and sky light. A particularly beautiful effect is obtained on the reflecting hall ground, where sky meets with the high blue door, forming a blue continue reflection (on the left). Sun-path diagrams allowed the author to control the periods of the day and year when the light appearance shown on the images is really effective (on the right).

This is giving us the opportunity to propose some important comments.

1. The author preferred to use manual techniques (with painting and colored papers) to elaborate the chromatic project. Rendering simulation was considered too slow, and computer colors insecure.

2. However, she used the software "Heliodon" to control daylight along the day and the year. She accepted to study the abstract sun-path diagram, because she needed the synthetic information it offers.

3. She neglected any thermal optimization, because she considered aesthetical perfection much more important.

4. She spent a lot of time in the mock-up, not only to obtain good pictures, but also because she knew that this student project would not be realized. So, the mock-up was the realization, the final result.

Fig. 9: Project of a loft and sun-paths control

This work and these comments are representative of the difficulties and demands of the architect with respect to daylight. The question is: how digital simulation can help without changing the project, as energetic optimization software would conduce? The architects always have to deal with various criteria and any optimization has to be manual, with an interactive process allowing the designer to blend aesthetical and scientific notions.

4.2 Geometry and latitude

In the past centuries, every architect was working for his city, his region or, with a bit of luck, for different places of his country. All his projects were located at the same latitude. He had a practical and intuitive knowledge of sun paths in winter and in summer. He did not need to think a lot about that.

Nowadays, the architects travel and, what is more important, they study projects in reviews, which correspond to very different latitudes. So, they need imperatively to become sensitive to the differences of sun paths due to geographical location. The other components of climate are easy to describe with parameters (altitude, hygrometry) or general notions (maritime or continental location, dominant winds), but latitude is more surprising, because it has significant geometrical consequences on the architectural design.

For example, we can observe in Fig. 10 that London and Rio Gallegos (Argentina) are nearly at the same latitude, as well as Barcelona and Puerto Montt (Chile) or Moscow and Ushuaia. Diversity of climate is easily explained by the oceanic streams (Gulf Stream vs. Humboldt Stream), but it is curious – and not without incidence on architecture – that sun paths are equal in Buenos Aires and Fez. Despite very different climatic conditions, solar protection will impose the same geometric arrangements in these two cities.

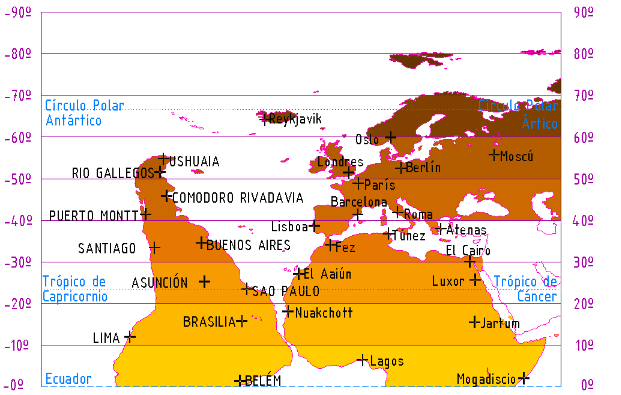

Fig. 10: Latitude comparisons between the Northern and Southern hemispheres [11]

So, it is very important to have the ability to perform the climatic simulations sustaining the project, in any living place, at any latitude. However, the actual knowledge of the atmosphere allows getting the relevant information about the sky characteristics only in the few places where complete measures are available since at least 10 years. Sky models exist to overcome the lack of data or their poor quality due to measurements performed too far from the analyzed site. But their utilization is too difficult if the goal is helping the architect who has to take decisions in the evolution of his project.

However and despite the expected advances in this field, we will show that in numerous situations, the architecture does not need these data if the geometrical parameters (sun paths and sky opening) are fully available and easy to manage. Indeed, the quality of an architectural project depends more on the extreme conditions (sunny solstices, overcast day) than on the averages. The energetic balance for a season or for the year is important for the engineer but has no direct impact on the formal choices of the architect.

Fig. 11: 3D and photomontage

4.3 Daylight control in the project

The next projects are examples of the results obtained after an intensive lecture on daylight (three weeks), which led graduated architects to learn "Heliodon" and commercial rendering software, in order to dominate day lighting in the urban and architectural projects. They had to project a pavilion whose geometry had to be determined by sun paths. The site was "Plaza Cataluña", Barcelona.

Fig. 12: 3D and stereographic projections

The first idea, by Marysol Bahena, Karina Figueroa and Alessa Benatton, is based on the sunset in particular moments of the year, when the quasi-horizontal sun takes along the main street (Fig. 11); correctly oriented, the pavilion seems to escort the sunset. There is no energetic idea, only a powerful but simple visual effect that needs a very easy geometrical consideration. To be shown, and understood by the public, such an effect just needs a good photomontage.

The second idea, by Christina Roussou and Fernando Maia, is based on a more complex configuration (Fig. 12): a minimal energetic control is necessary and is provided by the stereographic projections, where we can verify the radiation received by the different parts of the construction along the day and the year. A meticulous gradation of the transparencies results of this study.

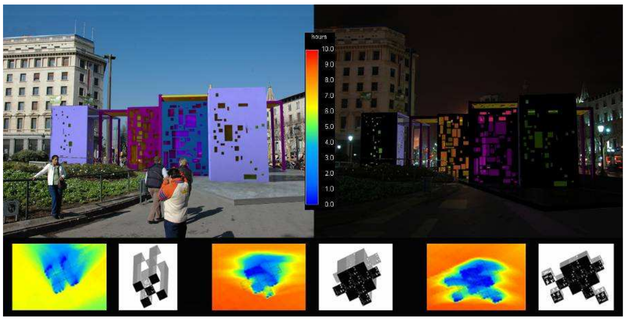

Fig. 13: Sunny period maps (winter solstice, spring /autumn equinoxes, summer solstice)

The third idea, by Marisa Egea and Daniela Fronza, is a modular pavilion whose geometry changed in each season: it is smaller in winter than in spring/autumn and in summer (Fig. 13 at the bottom). The three dispositions are illustrated with maps showing the number of sunny hours, and this number is shorter inside the summer pavilion than inside the winter one: solar protection is thus efficient. On the top of Fig. 13, daylight is compared with artificial light in the night. These two pictures have needed a rendering engine able to compute radiosity (diffuse reflection), and the final photomontages appear very realistic. However, the entire project has been designed with “Heliodon”, and the renders had only an illustrative purpose.

Finally, the project presented by Cecilia Betti, Oscar Martinez and Montse Puig is a walk that is progressively guiding the visitor from the outside light to the obscurity of the central path (Fig. 14). The shape and the spacing between the wooden slats are fully determined by the double intention to get protection against the sun and to filter the sky light. The principal control parameter is the sky factor whose values are progressively transformed to the same as those found in the great gothic cathedrals (3 to 5 %).

This project has been smartly optimized thanks to the qualities of the Heliodon software: speed of simulations and permanent graphical control. This kind of process could be automated, because, here, it is possible to formalize an objective function [12]. As in the previous projects, such an optimization process does not need a full knowledge of the yearly meteorological conditions; it could be perfectly well performed by checking the sun paths only during solstices or equinoxes.

Fig. 14: Render of the final project

From our present experience, such a simplification also holds for architectural projects related to housing or public buildings. It is important to note this point. Indeed the present evolution of official rules (light, but also thermal an acoustic) is fundamentally based on the determination of a global energetic balance. Today, the simulation tools are rather limited and the consequence is the lack of precision in these balances. This situation leads to adopt very strict norms that limit the formal creativity in the project.

The examples presented here show that there exists an alternative logics that can help without restraining the imagination and also that is allowing at each step of the design an effective control of the energetic consequences of every decision about shape and materials.

5 Observation parameters

The same difficulties arise each time the architecture is trying to find a parameter to guide the projects with respect to a given perceptive phenomenon. So, modern acoustic started on the definition of *reverberation*, an easy to observe phenomenon (it corresponds to the delay for extinction of a sound emitted anywhere in a closed enclosure after multiple reflections), easy to measure (from the invention of microphones and loudspeakers) and with obvious consequences on the acoustic quality of any architecture in relation with its utilization (so, an auditorium with excess of reverberation gets tired the hearing and limits the understanding of the speech, while a concert hall without reverberation seems dead and disturbs the musical execution and the audition).

After filling progressively a room with absorbent material, and observing how the reverberation was decreasing, Wallace Clement Sabine deduced a very simple empirical formula linking the volume of the room and the equivalent area of absorbent. This formula is giving good results in some rooms, but is very bad in other spaces (i.e. in rectangular enclosures). Many other formulas were proposed, more and more complex, but never satisfactory. Indeed the reverberation strongly depends on the geometry and the distribution of the absorbents, two parameters which have to be dramatically simplified to obtain a formula. After the elimination of the geometry, it is also impossible to perform any error estimation. Other observation parameters, as justified as the reverberation, have been proposed successively (intelligibility of the speech, clarity of the speech or the music…) and all these parameters focusing on the same phenomenon (in a reverberant enclosure, the speech looses clarity and intelligibility, and *vice versa*) do not present any correlation.

The reverberation is finally a little reliable parameter to guide the architecture project. In this case, it is much better to work with the first reflections which provide a limited but more useful information because they are based on clear criterions, easy simulations and direct link with the geometry [13].

Now it is suitable to compare the daylight factor and the reverberation time: two parameters based on correct observations of important perception phenomena, with global objectives (after Sabine, many concert halls have been designed, mainly in US, whose acoustics was based only on reverberation, with the consequence of heavy focalizations phenomena, due to the presence of vaults, useful only for increasing the volume), and which are leading to empirical formulas whose handling in the architecture project is more than questionable.

It is the reason why some authors [14], although they consider the daylight factor, understand the difficulty of using it and finally propose coefficient similar to the sky factor with the opinion that they are very useful to design buildings in very dense places like Hong Kong.

A similar problem appears at urban scale with the recent concept of "urban heat island", UHI. It concerns a simple but relevant observation: in the center of the big cities, the temperature is generally much higher than outside. To take into account this phenomenon, its possible negative consequences and the appropriate solutions, it seemed convenient to introduce the urban heat island as the difference of night temperature between the city and the countryside.

It seems easy to measure, but some authors are working on the definition of these two items [15] and propose to classify better the different zones between the center and different types of lands. Other [16] propose more general measures like the sky factor and are able to show that, in some way, the sky factor is linked to the difference of temperature.

As a conclusion, the methods used during the last years often suffered of a lack of rigor with respect to the space and time scales. Fortunately, new ideas and criticisms of the past methodologies are now available.

6 Design parameters

According to UNO data, from 2008, half of the world population is living in cities and all the specialists forecast that the rhythm of urbanization will strongly follow (today there are five millions more urban citizens each month) up to reach at least 70% [17]. It is obvious that the main problem of this century will be the city, its lack of appeal in the rich countries, its uncontrolled growing in the poor countries and always its excessive extension that withdraw the humanity of the productive lands. The unavoidable solution, a strong densification of the urban space, will necessarily, amongst other consequences, reduce the quantity of sun and sky available for every inhabitant.

The solar radiation studies performed at urban level are just beginning but they don't give yet relevant results. However, five problems will have to be studied carefully in the next years. In order to avoid the difficulties coming from the observation parameters defined above and to find the relevant design parameters (i.e., helping in their decisions the architects, the cities managers and the political leaders), it will be necessary again to separate the different light components. Indeed, they don't act together and, as a consequence, it should be an illusion to search for a unique global parameter leading to the ultimate solution. Moreover, it is better to refuse the traditional ideas of the urbanism (with the density, compactness … parameters), very elegant, undoubtedly discriminating, but not clearly linked to the physics [18].

The first problem is the passive thermal balance depending mainly on the direct solar radiation. According to the climate and the period, this radiation can be beneficial or not for the receptor. A robust model of the cloudiness is necessary to obtain seasonal balances (perhaps daily averages for each month) that allow to identify and modify the less known zones and to compare the different suggestions of urban planning.

The second problem corresponds to the city as an energy source (in this case thermal and photovoltaic), that incentive to identify the best places to set the panels (well tilted and disposed roofs, less obstructed facades…). With respect to the thermal panels, it is sufficient to study the direct solar radiation; the proximity of the users is an important factor. For the photovoltaic panels, it is necessary to take into account the sky and the reflected lights (and so, the reflective indices of the neighbor surfaces). The proximity of the users is not directly important but it can induce significant savings thanks to the self supplying and the lower dimension of the electric network. The obstruction problem is complicated because a set of cells doesn't react linearly to a partial occultation either spatial or temporal [19].

The third problem concerns the savings of public and private illumination. It should be easy to deduce, for each street, in function of its orientation and width, and also from the height and the color of the facades, when the ground illumination is less than a given level and justify the public lighting. To simulate the consumption inside the buildings, first, it should be necessary to know the percentage of windows on the facades, the use of the buildings (residence, business and offices) and to evaluate the habits of the users. In the public buildings, automatic systems can open or close the louvers in order to avoid the direct sunbeam. The effect of the interior design (dominant colors, partitions…), which does not depend, obviously, on the urban architect, seems to be difficult to evaluate.

The fourth problem is the right for everybody to enjoy a part of the sky. It is a comfort criterion, easy to simulate (the averages of sky factor on the façades allow comparisons based on discriminates between cities, between districts and between streets in the same district [20].

The fifth, much more complicate, problem concerns the interaction between the city and the atmosphere. The actual cities are not only influenced by the atmospheric conditions but they also influence them, they modify the winds, emit pollution (that reduce the incident solar radiation) and, because the built areas represent today nearly 3% of the Earth's surface, they can have a non negligible influence on its albedo.

The subsequent problems, including the yet identified heat islands, occur simultaneously in a *macro* scale (regions, the same size as for climatologists), *meso* (city) and *micro* (architecture), as causes and consequences of many individual decisions. A correct evaluation of each decision (i.e. what is the global balance of a norm that imposes thermal panels in all the new buildings?) needs indeed to work on the three scales.

The modification of scale, even if we consider the same physical phenomenon, generally implies a change of physical model. In the case of solar radiation, the climatologists propose a roughness parameter [21], arguing that a city is not behaving as a smooth area, even at higher scale, as shown with infrared satellite pictures [22]. So they need a simplified model of the city without losing this roughness which represents the third dimension.

At urban scale, the physical model of radiative balance is required, but it is necessary to find an alternative to the too slow solution of the full radiosity equation (probably using techniques like "Level Of Detail", LOD, [23]). At architectural scale, the projection methods (i.e. reduction of the problem to a point, saving the necessary interactivity) are the most productive and only these methods are able to put forward and to handle the convenient design parameters.

The subsequent problems pertain to the multiscale physics whose promising application to urban spaces has not yet commenced. In practice, the principal difficulty resides today in the lack of 3D models tailored for the meso scale of the urbanism.

A useful model should be extremely simplified, but it must contain all the large areas with their orientation and in continuous form, like the surfaces including the windows (according to the application). To model the cities, today, even if many researchers are working to unify the good practices, there are not yet fully reliable models, or optimal methodology helping to extract the best information from the numerical simulations.

7 Conclusions

Presently, young architects use easily a lot of software in their designs. Nevertheless, most programs are oriented to analysis and not to design. Thus, they are mainly used at the final step of the project, when the principal ideas are already defined, and all their possibilities are not apprehended.

With "Heliodon", we pretend to participate directly in the design process. The first consequence is that the other software and tools are enhanced, because they benefit of the greater conscience of the designer with respect to sun paths, local conditions and daylight.

Using "Heliodon" from the beginning of its development, the architect students have constrained the programmers to optimize continuously interactivity and graphic quality. So, this software is a perfect one for architects because it allows them to design freely, controlling both time and space aspects. The presented projects consider aesthetic expression, geometrical control and environmental conscience. Finally, the architect can find here his personal daylight.

The three scale of the light in its interaction with the human buildings, from the architecture to the territory, have been considered. Recently, various questions have appeared (heat islands phenomena, extension and densification of the cities, global heating), leading to original researches made by climatologists, engineers and urban architects.

We have shown that the two extreme points of view – aided design and analysis of large models – are in practice complementary, sharing the same algorithmic requirements (acceleration of the computations, synthetic quality of the graphics). Both require a clean definition of the physical model and the concerned geometry to be able to assist the interpretation of the results.

In the near future, the contributions of architects and urban designers will be fundamental in two aspects, in order to extend the studies of solar radiation to large urban areas.

First, it will be necessary to create 3D models of these areas. They have to be well defined and able to be simplified according to the concerned physical aspects.

Secondly, because the physicists, geographers and climatologists, focused on their own problems, are naturally tending to use the observation parameters.

The contributors at urban scale will have to give arguments to infer that the unique valid parameters are those which are able to give a hand for the decisions and the design, because the city is a mutating geometry, depending on the aspirations of its inhabitant with criteria sometimes unfounded, sometimes coherent.

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References:

[1] B. Beckers & L. Masset, *Heliodon2^TM software and user's guide*, http://heliodon.net/, 2003-2009.

[2] V. Badescu (Ed.), *Modeling Solar Radiation at the Earth Surface – Recent Advances,* Springer-Verlag Berlin Heidelberg, 2008

[3] B. Beckers, L. Masset & P. Beckers, Una proyección sintética para el diseño arquitectónico con la luz del sol , *8º Congreso Iberoamericano de Ingeniería Mecánica* , CIBIM8, Cusco, 2007.

[4] Z. Şen, Solar energy in progress and future research trends, *Progress in Energy and Combustion Science,* 30, 2004, pp. 367–416.

[5] J.H. Lambert, Photometria sive de mensura et gradibus luminis, colorum et umbrae, *Augsburg, C. Detleffsen for the widow of Eberhard Klett.*

[6] W. Nusselt, Graphische bestimmung des winkel-verhaltnisses bei der wärmestrahlung, *Zeitschrift des Vereines Deutscher Ingenieure*, 72(20), pp. 673

[7] K. Domke, Comparison of calculation methods and models in software for computer graphics and radiative heat exchange, *WSEAS Transactions on Heat and Mass Transfer*, pp. 198-208, Issue 4, Volume 3, October 2008

[8] F. Bouvier, Eclairage naturel, *Doc. C 3315, Technique de l'Ingénieur*, 1988.

[9] B. Beckers, L. Masset & P. Beckers, Enrichment of the visual experience by a wider choice of projections, *11th Intern. Conf. on Comp. Supported Cooperative Work in Design*, April 26-28 2007, Melbourne, Australia, ICCSCWD'2007.

[10] D. Gonzalez, "*Los colores cuando entra el sol"*, Master Thesis, Fundación UPC, Barcelona, 2005

[11] D. Rodríquez, "*El juego de las geometrías bajo el sol"*, Master Thesis, Fundación UPC, Barcelona, 2007.

[12] B. Beckers & P. Beckers, Optimization of daylight in architectural and urban projects, *Multidisciplinary Design Optimization and Applications*, ASMDO, September 2-5 2008, Gijón, Spain.

[13] B. Beckers & H. Coch, La acústica diseñada desde su expresión gráfica, *Congreso ibérico de acústica "Tecniacústica"*, Terrassa, octubre de 2005. Revista de acústica, 36 (3-4).

[14] E. Ng, Applying computational simulation results to the development of a design method for daylighting design and regulation in high-density cities, *Eighth Intern. IBPSA Conf.*, Eindhoven, Netherlands, August 11-14, 2003.

[15] I. Stewart, T. Oke, Newly developed "thermal climate zones" for defining and measuring urban heat island magnitude in the canopy layer, *Eighth Symposium on the Urban Environment*, 2009.

[16] J. Unger, Connection between urban heat island and sky view factor approximated by a software tool on a 3D urban database, *Int. J. Environment and Pollution,* Vol. 36, Nos. 1/2/3, 2009.

[17] UN Report, "*State of the World's Cities"* 2008/2009 - Harmonious Cities, UN Habitat, 2008.

[18] L. Adolphe, A simplified model of urban morphology: application to an analysis of he environmental performance of cities, *Environment and Planning B: Planning and Design* 2001, volume 28, pp. 183 – 200.

[19] A. Woyte, J. Nijs & R. Belmans, Partial shadowing of photovoltaic arrays with different system configurations: Literature review and field test results, *Solar Energy* 74(3), 217-233, 2003.

[20] G. Capeluto, A. Yezioro, T. Bleiberg & E. Shaviv, From computer models to simple design tools: Solar rights in the design of urban streets, *Ninth Intern. IBPSA Conf. Montréal*, Canada, August 15-18, 2005.

[21] A. Martilli , Y.-A. Roulet, M. Junier, F. Kirchner, M. Rotach, A. Clappier, On the impact of urban surface exchange parameterizations on air quality simulations: the Athens case, *Atmospheric Environment,* 37, 2003, pp. 4217–4231.

[22] A. W. Azhari, K. Sopian, A. Zaharim & M. Al Ghoul, A New Approach for Predicting Solar Radiation in Tropical Environment Using Satellite Images – Case Study of Malaysia, *WSEAS Transactions on Envir. and Deve.*, pp. 373-378, Issue 4, Volume 4, April 2008.

[23] O. Ripolles, F. Ramos, M. Chover, J. Gumbau & R. Quiros, *A Tool for the Creation and management of level-of-detail models for 3D applications* , *WSEAS Transactions on Computers,* Issue 7, Volume 7, July 2008, pp. 1020-1029.