Enrichment of the visual experience by a wider choice of projections

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Abstract

Collaborative work is very important in engineering and architecture because of the many disciplines involved in the design process. For this reason, it is necessary to deliver to all the actors of the system not only relevant data, but also information corresponding to their specific skills. Because in architecture the visual experience is mainly based on projections, we want to show that a wider choice of them is the best way to improve the data exchanges. We choose the simple geometric problem of solar illumination. Because it is essential to take it into account from the first steps of the design to the final project, the partners have to communicate with several kinds of projections that are not always the most standard ones. In this process all the collaborators are expected to contribute to the fluency of the exchanges with the consequence that, in order to magnify some aspects of the design, they are induced to define new representations.

Keywords: Architecture, Collaborative Design, Natural illumination.

1. Introduction

In the design process, data exchange between the many participants is a crucial problem [1]. Many publications are dedicated to this subject and today, it is a central leitmotiv in the industry. Data describing the virtual mockup benefits of the storage capacity and processing power of the present computers.

There is however a fundamental problem rarely investigated. It concerns the synthesis and justification reports of the project. They are unavoidable if we want to provide an efficient knowledge transfer between designers.

Computer graphics developments and specifically 3D graphics have given in the 70's and in the 80's a significant improvement of communication because they allowed concentrating on few images the main characteristics of the object's behavior.

With the multiplication of numerical simulations and the increasing number of tests, we are now saturated by the amount of results and it is difficult to sort out many high quality images the ones that are giving meaningful information.

Using graphic animations or interactive drawing gives a positive contribution but is far from solving this problem.

Many people are trying to develop systems able to find the required information inside a high quantity of data in order to highlight meaningful results for the analyst (data mining techniques [2]).

In this paper, we present an alternative method that helps us to find the most synthetic representation able to show the critical or most significant aspects of the design. This kind of representation must help the designer to take the right decisions and to effectively transfer to others the justifications of his choices.

2. Choice of an application

In order to illustrate the methodology, we select a pure geometric problem where all the initial and contextual conditions are well known. This problem concerns the direct natural illumination of buildings.

We will explain how to design simulation software that helps, firstly, to take the good design decisions and, moreover, to write the final report where the previous decisions must be explained and justified.

In the first part of the previous century, the architects tried to solve this problem in two different ways.

In the first one, they proposed to build a mockup of the building and to provide it with some lighting device able to reproduce the sun trajectory and illumination. The four intrinsic dimensions of the problem are reproduced on the one hand by the three dimensions of the mockup and on the other hand by the time modification of the relative positions of the lamp and the mockup. This device allows visualizing what happens in the building. It was called *heliodon* [3]. Data results are pictures or movies produced with a camera.

A second initiative consisted in drawing on a tracing paper a plane projection of the Sun paths on the canopy of heaven in a given location (given latitude). This transparent sheet is moved on the drawing plane of the building, so it allows deducing easily the basic characteristics of the illumination. In Spain, this method was introduced by the republican architects of the

GATPAC in the beginning of the 30's. They were using an orthographic projection [4].

This method is more abstract than the previous one but is more synthetic and helps better to display the building characteristics. The plane is supporting the space definition eventually reduced to a 2D description and the tracing paper is providing the time dependent definition.

The objective of this work is to combine both approaches in a CAD tool called "Heliodon" [5].

3. The Sun path diagram

The Sun trajectory is defined on the celestial vault. It is composed of parallels situated between the two Tropics, Cancer Tropic for summer solstice and Capricorn Tropic for the winter solstice of the North hemisphere. Each day is represented by a parallel in between. The parallels are graduated in hours dividing the Earth sphere into meridians drawn each fifteen degrees. This is a simplified representation based on the hypothesis of an Earth's circular orbit.

Locally, we only see half of the celestial sphere limited by the plane of local horizon and whose highest point is called the zenith. Let us notice that the Sun is assumed to stay at infinite, in fact it is at a distance of approximately 150 millions Km. Consequently, only directions are important.

The size of the projection sphere doesn't matter; the whole space can be projected except the center of the sphere.

In the local reference system, the directions or headings are defined with respect to the geographic North, indicated also by the compass if we take into account the magnetic deviation. The solar diagram has to show azimuths, hours and Sun heights at the different moments of the year.

Because the 3D representation is not very useful, it is better to use a plane projection of the hemisphere. Many are the possibilities, but the natural choice corresponds to the so-called azimuthal projections. The representation is always built on a circle whose center represents the projection of the zenith. All these projections are deforming the hemisphere but all are transforming the circles passing through the zenith into radii of the circle representing the hemisphere.

There are five standard methods [6] given in table 1 where we show the ratio between the length of the arc connecting a point to the zenith on the projection and on the sphere, it is called radial deformation. In the last column, we give the ratio between the representation of the area of a spherical portion surrounding the zenith and its true area (surface deformation). The angular distance to the zenith is noted θ, complement of the height.

According to table and figure 1, we eliminate the gnomonic projection, unable to represent the full hemisphere; however this projection will be used later.

Table 1: Radius & surface deformations

Method	Radial def.	Surface def.
orthogonal	$\sin(\theta) / \theta$	$(1 + \cos(\theta)) / 2$
equivalent	$2 \sin(\theta/2) / \theta$	1
Postel	1	$(\theta / (2\sin(\theta/2)))^2$
stereographic	$2 \tan(\theta/2) / \theta$	$1 / \cos^2(\theta/2)$
gnomonic	$\tan(\theta) / \theta$	$(\cos(\theta/2)/\cos(\theta))^2$

The orthogonal projection is not used because it compresses excessively the items close to the external circle. The three remaining projections behave very well for representing the hemisphere.

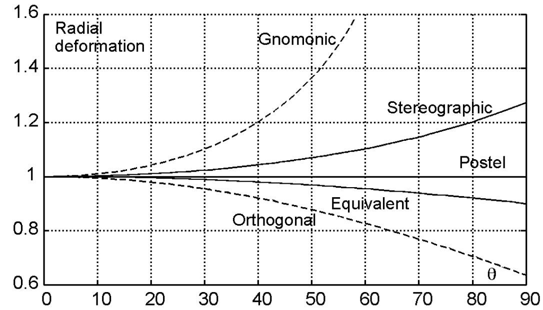

Figure 1. Radial deformation

Let us now analyze the properties of the stereographic projection. Because the stereographic projection is also an inversion, it exhibits two remarkable properties. It is conform, that means that the angle between two lines intersecting on the sphere is reproduced exactly on the image. Indeed, the intersections between meridians and parallels are orthogonal both on the Earth sphere and on the projection.

The second property ensures that the image of a circle drawn on the sphere is also a circle. When people were drawing the stereographic projection by hands it was a significant advantage.

Moreover, as seen in figure 1, this projection is preserving reasonable radial deformation while it magnifies the zone close to the horizon line, increasing so the readability of the diagram.

A last advantage is the easiness to implement the algorithm, thanks to the fact that this projection is also a central projection of the sphere with a viewpoint situated on the same sphere and the projective plane perpendicular to the diameter containing it. The computation of this projection can take advantage of the many methods and algorithms developed in the frame of the perspective geometry. In this application, the viewpoint corresponds to the antipode of the analyzed point. The only point of the sphere that cannot be projected is the center of projection.

Now, we can build this graphic for a specific location and choose a particular time, day and hour to obtain the Sun position.

Like in the early method presented in § 2, this diagram can be superposed to the horizontal projection of a building in order to know when a face is potentially illuminated (figure 2).

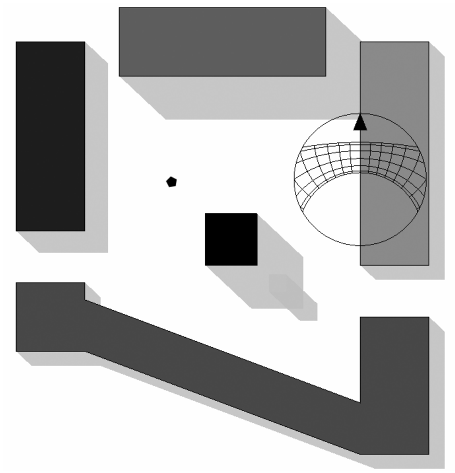

Figure 2. Plane projection with Sun path diagram and shadows

4. Introduction of masks

The sun diagram becomes more useful if we superpose the masks of the buildings surrounding the analyzed point. Now, we can see in each direction the height of the visible part of the sky.

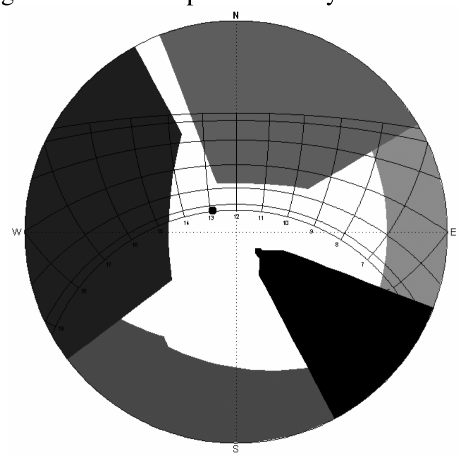

Figure 3. Stereographic projection with masks

This operation is easily performed by projecting all the objects, first on the local hemisphere and in a second step by computing the stereographic projection of these projected masks (figure 3).

By adding the masks, the sun diagram becomes very sensitive with respect to the position of the viewpoint. This position is a new element pertaining to the scene and allowing the evaluation of its properties.

This position is shown on the plane projection, the classical working document of the architect (black small circle of figure 2).

5. The plane projection

The orthographic projections and more precisely the plane projection constitute the base working documents of the architect. They display the geometric description of the model.

Here we see an item, the view point that manages the interaction between the two graphics. The first, in 2D, contains geometric information; it is well know by the designers. The second, the solar diagram is 1D, but also time dependent: it allows, from the point of view position, to observe the consequence of the decisions on the illumination.

A second interaction has to be provided, but it is working in the opposite direction. We need to define the orientation of the building. It is achieved by introducing a compass. A modification of orientation has a direct effect on the orientation of the solar diagram.

6. The 3D visualization

To have a complete graphic interface, it is convenient to introduce a 3D view of the scene. This one conforms to the standard of architecture, it is often an axonometry. As in the usual tools of CAD systems, several options allow to emphasize or hide some elements.

7. Interactions between the three graphics

We have yet introduced two links between the point wise time dependent graphic and the plane view (2D by definition); they are the viewpoint position and the building orientation.

If required, an additional interaction can be introduced in the 2D and 3D graphics, from the Sun position defined in the time dependent graphic (see the small black circle in figure 3). Firstly, it is possible to compute the illumination of the buildings and secondly, the shadows on a horizontal plane of reference (figure 2). To preserve high interactivity, we limit the computation to horizontal planes. Let us notice here, that we just introduce a new projection: the oblique axonometry.

8. Input data

Mostly, the specialist in illumination is working from a project performed by other actors of the design. Some links have to be set up in order to communicate with the standard tools of CAD, principally to import the geometry.

At this moment, the most difficult point is the necessary simplification of data whose objective was quite different (structural analysis, bill of materials, esthetics, flows...). It is then mandatory to reduce the volume and to keep only the part concerned by the illumination.

On the contrary, if the illumination specialist is the first one, he needs a geometric modeler well suited for his job and allowing him to modify the resulting model after processed by others. The exchange format must absolutely be structured in layers in order to distinguish the different partners and to ensure the coherence of the whole.

Another essential function in architecture is to localize the building in its local geographic area. This one is introduced in a standard image format, from a map or a picture providing the background of the model.

9. The report

The last task of the design and simulation process is devoted to the final report that must be concise, synthetic and able to emphasize the arguments leading to the final decision.

This report must be illustrated with schemes, drawing or pictures corresponding to the visual experience of the reader. They must be conceived not to understand or check the utilized software but to contribute to the comprehension of who has to take them into account for his own work.

Unfortunately, all the interactive functions included in the program to facilitate the job of the designer disappear in the printed report. Specifically, the interactivity was providing a bridge between the traditional point of view (plane views, axonometries), three-dimensional but instantaneous and the stereography, time dependent but point wise. We have then to overcome this difficulty by using new representations devoted now to the reader's mind and based on a shared visual experience and on each singular situation that ask him to pay attention according to the peculiar case study.

9.1. A gnomonic projection

As an example, let us come back to the solar diagram including the masks. This graphics contains a lot of information, but it is abstract and often misunderstood. It is then interesting to try to complete it, maybe with the same information, but now, in a more concrete presentation pertaining to the visual experience.

We propose to give, from a given point of view, the image of the sun trajectories through a plane opening like a window. It is here a classical linear perspective where the user is able to detect a usual landscape.

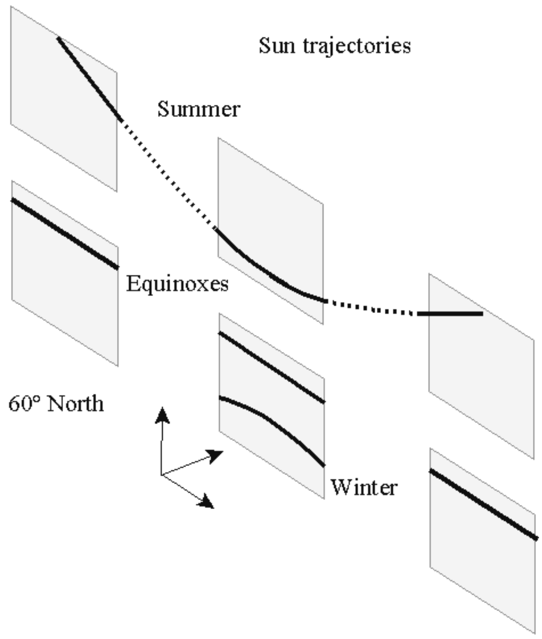

Figure 4. Gnomonic projection of Sun paths

The advantage is to perceive where and when the sun is appearing or disappearing in a precise point of the window. The figure 4 shows several Sun paths in six possible windows as seen from the origin of coordinates.

9.2. Cylindrical projection

Initially, the building is designed in relation to the immediate environment, but sometimes it is important to consider the skyline (the separation between sky and earth's topography, which would correspond, in the case of a flat horizontal ground, to the horizon line). In mountains, the landscape can hide an important part of the sky. It can be added to the buildings masks in the solar diagram.

To understand better the impact of the topography, it is convenient here to use a cylindrical projection. After development, we can control the height of the skyline, in the same way we would observe a panoramic landscape on desks providing explanations in tourist sites.

It seems that the most suitable projection is the one that reproduces exactly the angular heights. In cartography, it is called « plate carrée ». The heights can be deduced from a topographic map or measured at selected points with a theodolite.

10. Sunshine time

Another important property, qualitatively present on the solar diagram, is the period of sunshine in the analyzed point. But the time cannot be deduced from this graphic except if the time scale is introduced with a mesh of lines in function of days and hours.

10.1. Computation in a point

To perceive the durations of sunshine it is interesting to draw on a linear scale the day period and with a second coordinate the year period. In this diagram, the sun paths are horizontal straight lines which vertical position is changing every day.

On this graphic (figure 5), we can observe in a given location or given latitude the lengths of days and nights according to the date. In figure 5, from left to right and from top to bottom we observe the situation in Equator, Tropics, arctic polar circle and North Pole. Everywhere, the total duration of sunshine is equal to six months. By superposing the masks, we deduce the sunny periods.

However, taking into account the different impact of the first or the last hours of daylight in comparison with the midday light, it is convenient to divide the daylight zone into different regions indicating the height of the Sun. Giving to these zones adapted coefficient, we can evaluate more precisely the influence of the direct sun illumination.

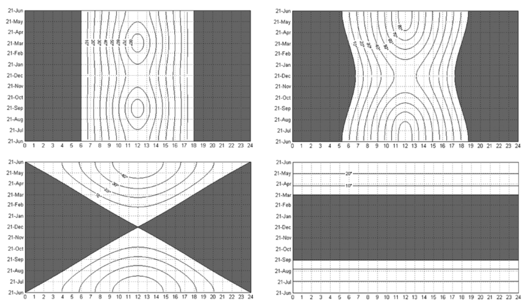

Figure 5. Daylight diagrams

10.2. Sunny period's maps

After computing the sunny periods at one point, there is no difficulty to dispose points on a mesh and to repeat the computation on each node of the mesh. The contour map is built by interpolation.

The mesh can be defined everywhere, either on existing surfaces either in new ones. As in the point wise computation, we can weight the influence of the sunrays according to their angle with the normal to the illuminated surface.

11. Sky factor

At a point, the illumination is depending not only of the direct illumination but also of the diffuse one produced by the sky.

If this one is uniform, it depends only of the solid angle corresponding to the sky.

As before, this solid angle is seen qualitatively on the solar diagram. But in order to evaluate exactly the solid angle we need an equivalent projection. Considering again the table 1, we can build the graphic that shows that this projection is the only one able to visualize the solid angles without any deformation (figure 6).

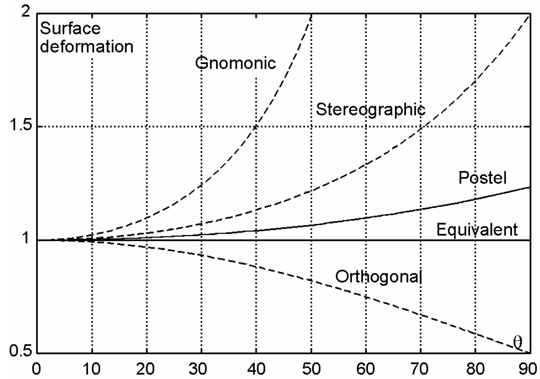

Figure 6. Surface deformations

The quadrature of the part of the disk not covered by the masks gives us the required information. We can immediately check that the result is independent of the latitude and of the orientation of the building. In figure 7, right side, we have an exact image of the solid angle. Let see here the difference with the stereographic projection, on left side.

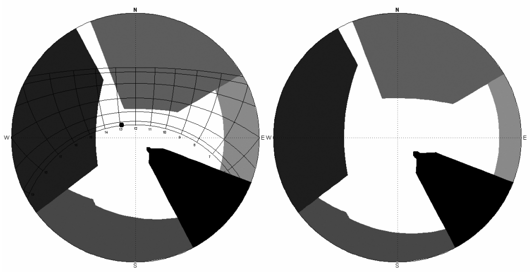

Figure 7. Sky factor in stereographic and equivalent projection

Finally, the sky factor doesn't depend on the surface containing the observation point or on its orientation.

This sky factor just defined above is very similar to the view factor computed in a preprocessing step of radiosity calculations. But the second one is defined in relation to a surface. To obtain it, we perform first a spherical projection on a hemisphere attached to the concerned surface. In a second step, we have to compute the orthogonal projection of the hemisphere on the surface. Applied to the horizontal plane, the view factor of the sky is simply obtained by computing the orthogonal projection of the hemisphere on the horizontal plane. This method is known as the Nusselt analogy [8], cited in [7].

After calculating the sky factor at a point, we can, as before, evaluate it on the nodes of a mesh. We obtain now a graphics that reproduces the quantity of sky viewed from each point of the surface.

This visualization (figure 8) corresponds to our visual experience (in a cloudy day) because the points that are seeing larger part of the sky are also more illuminated.

12. Conclusions

In this application, we observe two aspects of communication and information exchange. On the one hand, we must take care of using all the graphical aids relevant in the design step. This step must be very interactive and the user must be able to test solutions and to impose eventually important modifications that allow him exploring new configurations [9]. In most situations, if it has no impact on the judgment, high precision is not necessary.

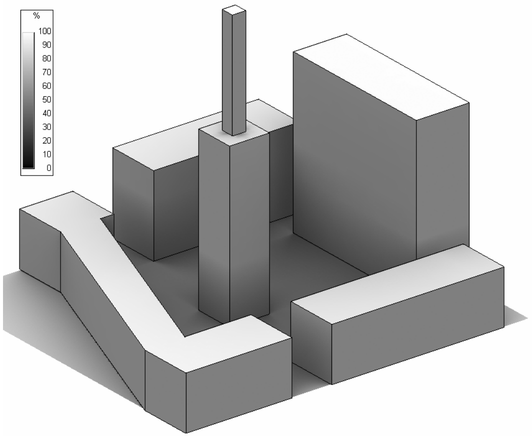

Figure 8. Sky factor for the whole scene

On the other hand, when the job is finished, it is essential to be able to transfer the results and to justify the previous design choices.

The final report must be written for readers who are not necessarily specialists of the analyzed aspect. For this reason, it is important to take care they can understand the reasons of the decisions. The graphics they will receive must stay inside their usual environment so that they can immediately detect the information we try to transmit to them.

Very often, the report contains very nice but not very useful and sometimes more or less incomprehensible illustrations or graphics whose unique justification is to demonstrate that the computation has been successfully performed.

In this example, we hope that we demonstrated that using all the resources of the different projection methods, it is possible in each situation and for every analyzed detail, to produce a comprehensive document for colleagues who know the general rules but not all the details of the used methods.

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We thank all the students of the Master's degree who used and tested the first versions of the heliodon software. They helped the authors in improving the graphical user interface and in finding for each situation the most relevant graphical representation.

References

[1] F. Enembreck, I. Thouvenin, M-H.Abel, J-P. Barthès, "An Ontology-Based Multi-Agent Environment to Improve Collaborative Design", 6th International Conference on the Design of Cooperative Systems - COOP'4, 2004, Hyères. Coop'2004 conference supplement. Scenario based design of cooperative systems, 2004. v. 0. p. 81-89.

[2] A. Baccini & Ph.Besse, *Data mining I, Exploration Statistique,* Publication du Laboratoire de Statistique et Probabilités— UMR CNRS C5583, Université Paul Sabatier, Toulouse, France, Version septembre 2005, mises à jour : www.lsp.ups-tlse.fr/Besse

[3] A. F. Dufton and H.E. Beckett, "The heliodon: an instrument for demonstrating the apparent motion of the sun", *J. Sci. Instrum.* **9** 251-256, 1932.

[4] J. Aponte, L. Bravo, J. Casals, G. Conte Pomi and J.R. Fernandez, "Sombras en plantas y alzados", *dossiers dibuix 1 n°5*, Escola d'Arquitectura del Vallès, España, 1998.

[5] B. Beckers and L. Masset, "Heliodon.2", software and user guide, 2006.

[6] P. Beckers, *Communication graphique*, Editions de l'Université de Liège, 2003.

[7] C. Puech & F. Sillion. *Radiosity and Global Illumination*, Morgan Kaufmann Publishers, Inc., 1994.

[8] W. Nusselt, Graphische Bestimmung des Winkelverhaltnisses bei der Wärmestrahlung, *Zeitschrift des Vereines Deutscher Ingenieure*, 72(20), pp. 673, 1928.

[9] B. Beckers, L. Masset & P. Beckers, "Descriptive Geometry Mutating to Design Tool", *Proceeding of ICCES05 Conference,* Chennai, India, December 2005.