ENVIRONMENTALLY FRIENDLY CITIES, Proceedings of PLEA'98, Lisbon, Portugal, June 1998
Pages 191-194 © 1998 James & James Science Publishers Ltd

Air-flow simulations in a place dedicated to meditation
The Cistercian Cloister

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Abstract

Confronting the high density of town planning, architects and town planners are led to design small outdoor places which are inserted into the city but offer specified properties: serenity, calmness, unusual surrounding... Within the framework of the CERMA laboratory, we are looking for reference architectural examples likely to meet such needs and transposable into a contemporary architectural project.

A research work in progress is dealing with Cistercian abbeys cloisters, archetypes of a space sheltered from outer nuisances which was originally dedicated to meditation and self-communion. Our work consists of checking whether the tranquillity of this place lies on physical datas which are easily controllable by the designer.

In regard to our research, Cistercian cloisters present the following interests:

- it is a typical architectural figure from which several developments can derive: patios, squares,...
- it is present in the whole of European countries and therefore has to suit to very different climatic and topographic compulsions;
- it was designed in a rational way and found upon a pattern which is easy to modelise.

A preliminary work has already been carried out which was focused on daylighting, acoustics, and air flow. The study of daylighting was based upon the modelisation of a sample of Cistercian abbey and its simulation with the software designed by the CERMA : Solène. The study of the soundscape rested on in situ measures made in the cloister of the Cistercian abbey of Noirlac (France) and theoretical estimations. We also undertook a preliminary approach of the cloister capacity for sheltering from the wind by setting up a 2D simulation with the finite element CFD code N3S. Our presentation will show this last point which supplied us quite interesting results and now form the subject of further research work.

INTRODUCTION

The Cistercian cloister, as an element of architecture was designed to be a pure place of meditation and self-communion. We can suppose that its atmosphere was also, more or less empirically, designed to be adapted to this kind of activity. Anyway, the cloisters which have survived to our times bear witness to it. However, how can we find out what is due to physical factors and what is due to the collective subconscious impregnated by the symbolic of the place or to the singularity of our own perception ? We are naturally led to state the following question :

To what extent, the idea that the atmosphere perceived in the Cistercians cloisters is favourable to meditation, is based on physical realities ?

An atmosphere favourable to meditation should allow a detachment from worldly things and favorise a spiritual activity. Therefore, we express the two following suppositions :

- the cloister plays a role as a buffer against the disturbances from the outside world (wind and rain, noise and atmospheric pollution...);
- it favorises spiritual activities, on the one hand through an internal control of the different physical factors (light and acoustic reverberation...) and on the other hand through the symbolics of its architecture.

INTRODUCING AIR-FLOW SIMULATIONS

The main reason which led the European monks to equip their monasteries with cloisters was the desire to be able to circulate between the different buildings protected from the elements. Also, even if the perception of nature can aid meditation, it must be filtered so as not to saturate the senses. The object of this paper is to present the evaluation, by numerical simulation, the capacity of the Cistercian cloister, through its own geometry, but also by its position within the abbey, to play this role as a filter against the wind.

METHOD USED FOR SIMULATING THE AIR-FLOW AROUND THE CLOISTER

Thus, two simulations were undertaken, corresponding to the two possible directions of the wind : north→south and south → north. These simulations were made with the help of the N3S CFD code. The model chosen to compute the turbulence field was the two-equation k-ε model developed at Imperial College, U.K. It is derived directly from the

Navier-Stokes equations and Reynolds decomposition with some additional simplifications, the main ones being, isotropy and the use of Boussinesq assumption.

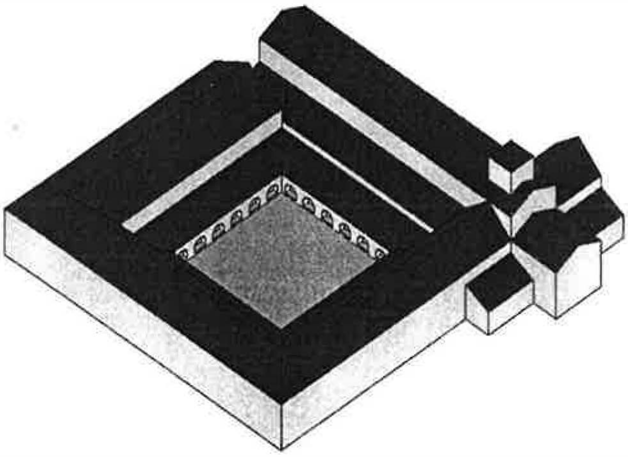

Figure 1. 3D model axonometry

The model used for this simulation was a 2D-model corresponding to a north-to-south section through a 3D model used previously for sunlighting and daylighting simulations. Its main function is to evaluate the capacity of the church, thanks to its own geometry and its positional relationship with the cloister, to protect the galleries from the winds coming from the south and the north.

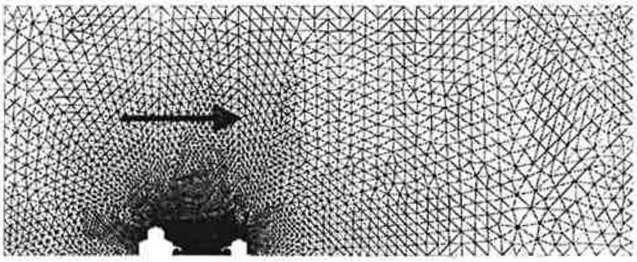

Figure 2. Space discretisation (wind coming from the north)

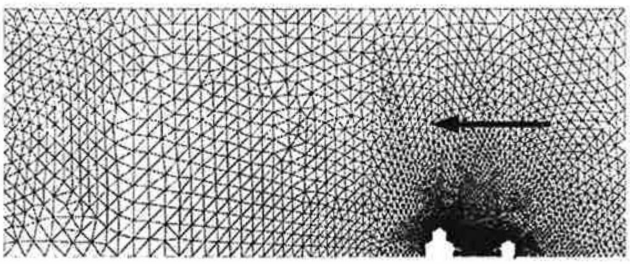

Figure 3. Space discretisation (wind coming from the south)

The abbey, 17.5 m high and 65 m long, was placed in a virtual wind tunnel, 180 m high and 370 m long. It was important, in order to avoid Venturi effect and allow wind to develop, that the tunnel be of sufficient size in relation to the abbey. The flow field was elliptic and the following boundary conditions was imposed on the boundaries of the solution domain :

- symmetry condition on the top of the wind tunnel (velocity vectors parallel to the x axis) ;
- non-slip boundary condition on the ground and the contours of the abbey with the so called « wall-function » ;
- conditions of Dirichlet at the entrance ($u(z)/u_{ref} = (z/10)_\alpha$ with $u_{ref} = 3$ m/sec at $z = 10$m and $\alpha_{\text{cleared site}} = 0.23$) ;
- conditions of Neumann at the exit (no flux, i.e. velocity vectors independent of x).

The space discretisation is made of about 10000 triangles and 20000 nodes. The grid, which is large close to the perimeter of the wind tunnel, is refined around the obstacle where the velocity gradients are higher.

PRESENTATION AND DISCUSSION OF THE RESULTS

Wind coming from the north

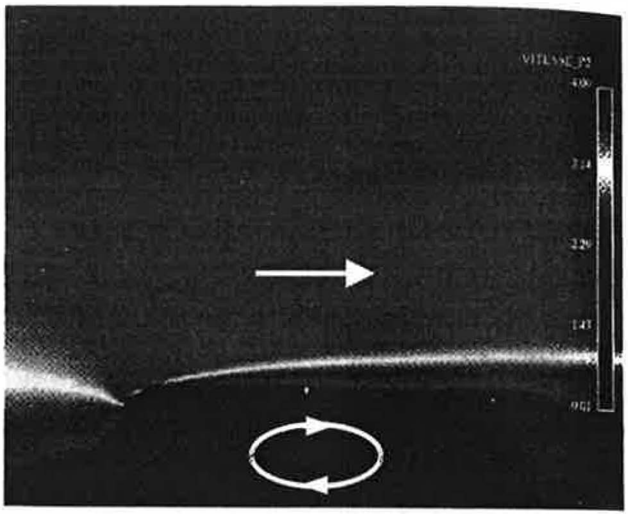

Figure 4. Air-flow around the patio (wind coming from the north)

The church plays a role as a springboard, producing a breakdown of the laminar air-flow above it. The roof being not wide enough to allow a sticking up again, a large vortex sheet is created, separated from the laminar flow by a clearly identifiable shear zone. The patio is therefore into a vortical area where the air velocity does not exceed 1.4 m/sec. The vortical flow follows a clockwise nearly elliptical trajectory.

Close to the southern gallery, the air-flow is sliding down the two same pitches roofs, breaking-down twice ; slightly between the two roofs, but more radically when leaving the roof of the gallery. A secondary eddy is then created, where the air velocity does not exceed 0.10 m/sec. In this area, we can observe an other breaking-down of the air-flow, close to the edge of the basement, creating a thirdly eddy which is penetrates into the gallery. In this last area, the air velocity is about 5 cm/sec.

Close to the northern gallery, the air-flow seems to follow the general motion of the main vortical area and not succeed in penetrating directly into the cloister. Close to the edge separating the arch from the roof, two vortical areas are created. One of them is characterised by an anticlockwise flow which does not penetrate directly into the gallery but after an other breaking-down close to the top of the arch creating a small eddy into the cloister where air velocities is below 5cm/sec.

Wind coming from the south

This time, we can observe a double break-down of the laminar air-flow, on the tops of both buildings. If, in the first case, the geometry of the monastery buildings (in particular, the regular succession of the roof pitches) played a great part in the coherence of the main vortical area air flow, and in its sliding along the obstacles, it now favour

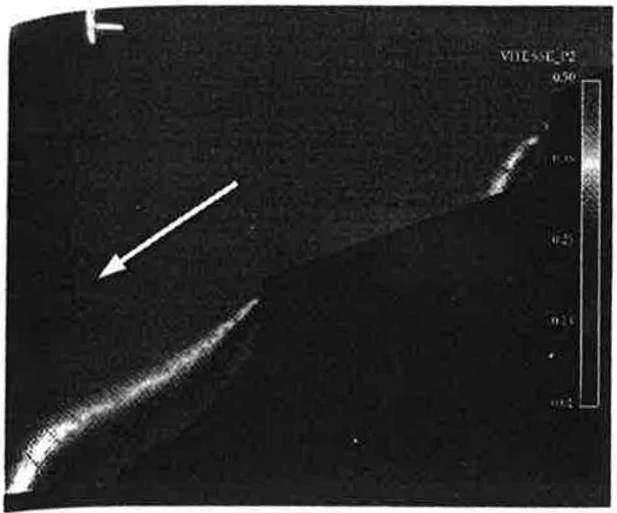

Figure 5. Air-flow close to the southern gallery (wind coming from the north)

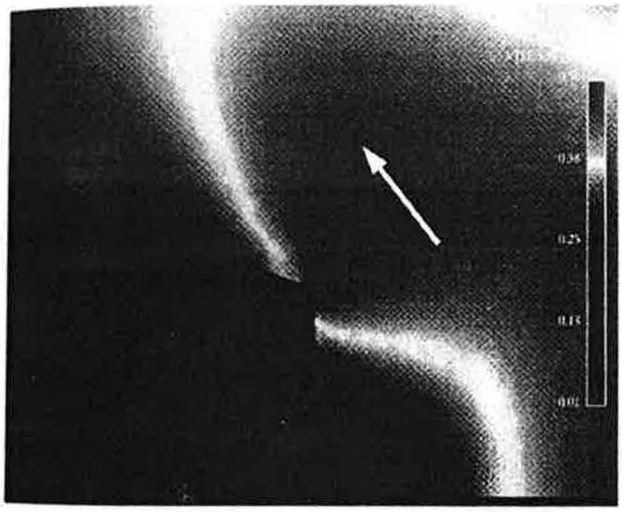

Figure 6. Air-flow close to the northern gallery (wind coming from the north)

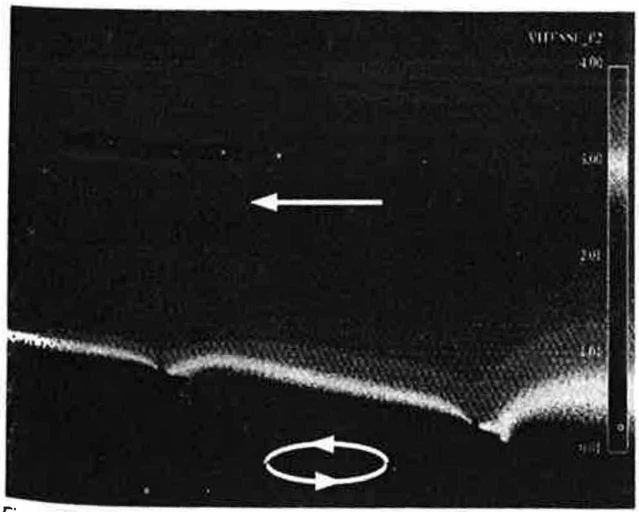

Figure 7. Air-flow around the patio (wind coming from the south)

the setting up of the second break-down on the top of the church and so the way out of an important part of the whole aerodynamic energy.

Figure 8. Air-flow close to the northern gallery (wind coming from the south)

The remaining energy is converted into a vortical area where the mean air-flow follows an anticlockwise trajectory. Inside the patio, the phenomenon are quite the same than in the first case except that, the energy of the laminar air-flow transmitted above the abbey being lower, the mean air velocity inside the patio is quite higher. However the air velocities inside the galleries are nearly the same.

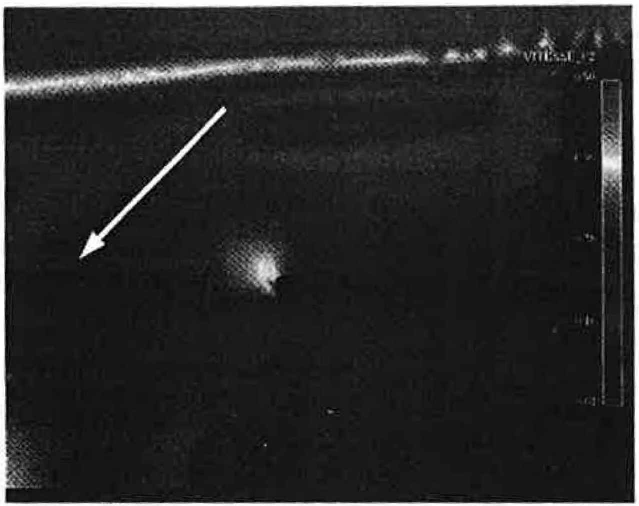

Figure 9. Air-flow close to the southern gallery (wind coming from the south)

Conclusions about the results

So, in both cases, the particular geometry of the monastery buildings, in particular the regular succession of the roof pitches and the presence of sharp edges, seems to permit an important dissipation of aerodynamical energy outside the cloister and makes it play a real role as a shelter from the wind.

However, wind is likely to penetrate into the galleries in a sound form ; we can suppose that, far from being a discomfort, it contributes to the reasonable penetration of nature into the cloister, and therefore can aid meditation.

We can easily guess what would happen if the height of the building in front of the church (the « dinning-hall » building) was increased. Below a maximum height, approximately equal to church one, the general shapes of air-flow should be quite the same as those seen above. Above this maximum height, the protection against wind coming probably be a single break-down situation like in the first case) ; nevertheless, the protection against the wind coming from the north wouldn't be guaranteed anymore because of the breaking off of the slope behind the « dinning-hall » building (no aisle on its side ensuring a middle height between the building and the cloister). However the problem would be solved if « aisles » were added to it.

Validity of the results and work in progress

It is advisable to remain careful, looking at these cheerful results. Indeed, reducing our simulation to a 2D model, we didn't take into account some parameters which are peculiar to the third dimension. For instance, we don't know how would behave the monastery buildings if the wind direction was a bit different from the north-south or south-north directions. It would be also interesting to undertake the same simulations on a east-to-west section ; it is likely that the setting up of a quite coherent vortical air-flow would not happen if the laminar air-flow was too close to the ground. Lastly, we didn't take into account phenomenon linked to temperature effects, especially convection flow. A research work in progress is taking into account all these new parameters.

CONCLUSION

It would be presumptuous to affirm that our research works are sufficient to make of the Cistercian cloister a definitive reference architectural element concerning the control of the atmosphere parameters. however the quite good results we got concerning the air-flow as well as those concerning acoustics and daylighting, induced us to undertake further research works. Moreover, the Cistercian cloister, as a typical architecture figure from which several developments can derive (patios, squares,...) seems to deserve a fresh interest when, confronting the high density of town planning,, architects and town planners are led to design small outdoor places which are inserted into the city but offer specified properties : serenity, calmness, unusual surrounding...

So what about equipping our cities with such places, sheltered from the worldly troubles, where we could for a time rest one's senses and one's mind?

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