INTER-NOISE 2007
28-31 AUGUST 2007
ISTANBUL, TURKEY

Acoustics of a very large open-plan Learning Center at the Swiss Institute of technology in Lausanne (EPFL)

Victor Desarnaulds[a]
École Polytechnique Fédérale de Lausanne, EPFL, ENAC-IA-LCC1
CH-1015 Lausanne, Switzerland
Bureau d'ing. G. Monay, 25 av. Vinet, 1004 Lausanne, Switzerland

ABSTRACT

In 2004, the Japanese firm SANAA (Sejima + Nishizawa and Associates) won the architectural competition for the construction of a new Leaning Center at Swiss Federal Institute of Technology, Lausanne, Switzerland. As basic concept, this multipurpose library should stimulate exchange and exploration of ideas for everyone. SANAA proposed a huge single open space (15'000 m2) filled with daylight and natural ventilation. However, simultaneity of activities with various annoyance potential (noise emission) and noise sensitivity (need for quietness/privacy) can be highly conflicting from the acoustic point of view in such a huge landscape.

To address the acoustic problem, detailed room and building acoustic requirements were determined. Thereafter, conflict map were established to optimize the location of various activities such as working areas, multipurpose hall and restaurants in the open-plan. Acoustic simulations using CATT-Acoustic software were performed to determine adequate materials mainly for sloped ceiling and floor so as to guarantee the acoustic quality of these spaces. 3D-simulations were used in particular to optimize the shape of some areas (patios, ceiling of the multipurpose hall) and to predict the noise propagation at long distance (up to 100 m).The paper also compares and discusses noise propagation models for large spaces

1 INTRODUCTION

The rapid evolution of media technologies induced deep changes in information exchange and communication. On this established fact, the Swiss Federal Institute of Technology, Lausanne (EPFL) project to construct a very innovative "Learning Center" in the middle of the campus. In order to achieve the concept of a building enabling exchange and exploration of the ideas of everyone, people have to feel connected in a single large open space. However, it is well known that good acoustic in very large enclosure is often difficult to achieve even in low sensitive areas such as rail or air terminals [1]. The concept of a Learning Center is based on different areas with high acoustic requirements such as silence in library [2], high speech intelligibility in area devoted for teaching or living atmosphere in multipurpose hall. In addition coexistence of activities with various annoyance potential (noise emission) and noise sensitivity (need for quietness or privacy) in the same space can be highly conflicting from the acoustic point of view.

In such challenging building, it is first important to understand the concept of Learning Center and the potential acoustical conflicts associated with this kind of project. It is then necessary to determine the various acoustic requirements such as reverberation time, noise

[a] Email address: desarnaulds@monay.ch

level or sound insulation. Finally, calculation and complex simulation should be done to verify acoustical behaviour and to optimize shapes, materials and position in such unusual enclosure.

2 DESCRIPTION OF THE LEARNING CENTER CONCEPT AND PROJECT

2.1 The Learning Center's mission

As described by EPFL (http://learningcenter.epfl.ch), the new Learning Center "*will be a place to learn, to obtain information, and to live. It will become a place where virtual and physical components combine to provide facilitated access to knowledge. Its concept includes the flexibility and growth potential to evolve and follow, in due course, to pedagogical, social and technical trends of the School. It will integrate areas of relaxation, providing a breath of air within the new context of a significantly built-up campus*". The main objectives are to

- provide to the scientific community the infrastructures and tools required to optimize access to information, thus accelerating the circulation of ideas, opening up knowledge, encouraging exchanges.
- stimulate teaching staff to implement more active educational methods
- offer the physical or virtual resources necessary for student activities, as well as to working areas and various other services.
- create a living, meeting, and cultural space for students, researchers, personnel and the general public.

On the other hand, in view of the huge of investments (about 60 millions Euros) and resulting impacts, the project for the new Learning Center must integrate the concern regarding construction compatible with sustainable development, as well as an energy strategy for the building though its site selection, orientation, volumetry, operation and materiality. The programme (about 15’000 m2 in total) includes library and scientific information areas (6'160 m2), teaching areas (1'150 m2), living areas (1'875 m2), cultural areas (1690 m2) and service areas (3500 m2).

2.2 Architectural project

In order to select the most suitable candidates, EPFL launched a pre-qualification competition at the beginning of 2004: 189 architects applied. In April 2004 the jury selected 12 outstanding candidates from all over the world and asked them to carry out a preliminary study until October: the best of them would be given the mandate to execute the building of this great center of knowledge

In December 2004, Kazuyo Sejima and Ryue Nishizawa, of Sanaa part (Japan) won the competition with a huge (167x122 m) single level building. In their description "*the EPFL Learning Center is a center for exchange and exploration of ideas for everyone. It functions as a catalyst for the breeding of new relationships both within the academic realm and with society. This is a place that will be full of unintended encounters, where you might bump into an old friend, become inspired by another work group, or discover your favourite book. People will feel connected in the large open space but when privacy is desired, enclosed areas are provided for engaged activities. All functions are contained in a large one-room landscape filled with daylight and access to natural ventilation, creating very interior spaces. The spaces within are loosely defined by contours, light wells and patios of various scales to create atmospheres from wide-open public spaces to quiet and private areas.*

The gently undulating structure has been relined in a parallel process-searching for an ideal spatial quality and an efficient structure (600 mm reinforced - concrete- shell structure *spanning approximately 80 m). This concrete is also useful as a thermal mass to help increase user comfort. The gentle undulating shape ensures local wind breathing by low wind resistance; local over and under pressures which activate cross ventilation of the building through the landscape lightwells*."

Figure 1: Photomontage of the Learning Center.

3 ACOUSTICAL REQUIREMENTS

The room acoustics (especially the reverberation time) of the various areas should be designed to provide a sufficient decrease of the noise level as one moves away from noise sources. To ensure the best acoustic comfort referring to the chosen design, it is also necessary to limit (reduce) the background noise level (especially of the technical installations) and optimize the airborne and impact sound insulation of horizontal and vertical partitions (between the 2 floors, parking lot) and with outside.

In 2006, the Swiss standard SIA181 [3] concerning noise control in building was completely revised [4]. It includes guidelines for sound insulation between classrooms and requirements for background noise and reverberation time (T), basically based on German Standard DIN 18041 [5] and on the Guideline of the Swiss Acoustical Society [6]). For classrooms T lies typically between 0.4 - 0.6 s. according to volume 125 m3 - 250 m3.

3.1 Room acoustic

The main specification for the room acoustics is the reverberation time (T) of the area. A room with a long reverberation time sounds noisy and provides poor speech intelligibility. For open space, it is also important to provide a sufficient decrease of the noise level as one moves away from noise sources so as to have a sufficient sound attenuation between the different areas. Requirements for reverberation time:

Open space, multimedia library, research collection : $T<0.5$ s.

Closed offices (in particular for education purpose) : $T<0.7$ s

Multipurpose hall : $0.8<T<1.2$ s

It is then necessary to determine precisely which are the adequate sound absorbing materials (in particular for the ceiling, for the floor and for furniture) to guarantee the acoustic comfort of the spaces especially for sensitive areas like the multipurpose hall, multimedia library and research collection.

The shape of the area should be design to avoid acoustic defects such as flutter echo. Large concave (like circular closed area) or parallel reflecting surfaces should be then avoided or covered by absorbing material.

3.2 Noise levels

The acoustic comfort of a working place is partially determined by the background noise due to technical installations (HVAC), devices (computers, copiers, phones…) and activities of the room, activities from other room (cf. sound insulation of partition) and noise from outside (road). Noise induces annoyance, reduced concentration, tiredness and low speech intelligibility (spaces for education purpose). The sensitivity to background noise depends on the task and activities. Requirements are defined in two classes of acoustic quality. Increased requirements applied for the Learning Center.

Table 1: Maximum noise level requirements from technical installations according to the standard SIA181 [3] (continuous noise during the daytime).

Requirement LAeq \ Activities	**Standard**	**Increased**
Multimedia Library	30	25
Multipurpose hall	35	30
Office/classroom/conference	35	30
Open space*	40	35
Restaurant/reception/bookshop	40	35

* In open spaces, the level could be higher for masking purpose (but maximum 45 dB(A)).

Table 2: Guideline for background noise level (all sources, according to [7])

Activities \ Requirement	**Standard**	**Increased**
Office or production activities	65	55
Intellectual activities that require concentration or creativity	50	40

3.3 Sound insulation

The required sound insulation of partition depends mainly on sound source (annoyance potential) in the adjoining space, background noise, needs for privacy or quietness and geometry and acoustics (reverberation time) of the space. The recommended values for sound insulation are presented in the Table 3 in two classes of acoustic quality.

Table 3: Guidelines for sound insulation of partitions (according to the Swiss standard SIA181 [3]).

Requirement dB	**Airborne Di**		**Impact L'**	
Partition type	Standard	Increased	Standard	Increased
Office/office	35	40	60	55
Office/conference	40	45	60	55
Office/Office with privacy	45	50	60	55
Classroom/classroom	45	50	60	55
Music room/classroom, office	55	60	50	45
Office or conference/corridor	30	35	60	55
Office with privacy/corridor	35	40	60	55
Classroom/corridor	35	40	60	55

All these values are for insulation measured in situ including lateral transmissions through ceiling, floor, walls and openings.

3.4 Layout

According to its function, each area can be acoustically characterized by its annoyance potential (noise emission) and its noise sensitivity (need for quietness or privacy), both defined in 3 classes (low/medium/high) in the Swiss Standard: SIA181 [3]. For example in the multimedia library, we can distinguish two areas:

- Place of silence (individual work): high sensitivity / low noise emission
- Place for small groups: medium noise sensitivity / medium noise emission

The requirement for the layout of the various activities in the building is to avoid important noise conflict between the different areas (for example high noise emission near high sensitivity zone).

Mapping every noise sensibility/emission constitute a simple but powerful tool to reduce noise conflict between the different areas and expensive solution to solve them.

4 ACOUSTICAL SIMULATIONS AND OPTIMISATION

First of all, a great effort was done to analyse the “conflict map” for optimizing the various activities location in the Learning Center. Simple bypass of activities in the open space allowed avoiding acoustic conflicts between them. Finally, noisy activities with low sensitivity (restaurant, bar, exhibition, multipurpose) were concentrated south of the building far from sensitive areas (multimedia, working and teaching areas) situated north of the building.

4.1 Description and goal of the simulations

The cylindrical shape of the inner boxes and the very large area of the open space (15'000 m2) with slopes and limited height (3 m) induce lack of diffusion and then in these areas, statistical calculations based on Sabine theory would not apply.
Therefore 3D simulations were realised with CATT-Acoustic software which utilizes Randomized Tail-corrected Cone-tracing (RTC) that combines features of both specular cone-tracing, standard raytracing and Image Source Model (ISM) [8]. Note that this type of computer model calculation was successfully used in the past for long enclosures [1, 9, 10] or for the Norwich Forum, a very large library with a concept similar to the Learning Center [2].
For the 3D model, Sketchup software was used for the double slopped floor and ceiling whereas other elements (patio, boxes, terraces, etc.) were integrated directly in Catt-Acoustics. Due to the large size and complexity of the space, the software reached rapidly its limit (5000 faces) and needed long calculation time (about 12h for 500’000 rays process). Calculation (reverberation time T30, EDT, speech intelligibility, sound level with different sources, etc.) and auralization were performed to compare different variants in closed boxes (education purpose), multipurpose hall (cultural purpose), and the full open space (working, meeting purpose).

The main goals of the simulations were :

- Study of focalisation effect and optimisation of materials choice in closed boxes.
- Detailed study and optimisation of reflexions pattern from ceiling and walls and reverberation time in multipurpose hall to improve the room acoustics both for music and speech intelligibility.
- Calculation of reverberation time and sound propagation in the open space (study and optimisation of the screening effect of slopes, closed patio and boxes)

4.2 Classrooms in closed boxes

Simulations were first performed for some closed boxes (single or double classrooms of about 200 m2), initially designed with a cylindrical glass walls, a carpet, and plasterboard suspended ceiling. With this configuration, the expected reverberation time would be much too long for teaching purpose (1.7 s at mid frequencies with great discrepancies between various calculation methods according to the lack of diffusion). The simulations allowed optimizing the shape (rectangular with rounded corners) and adding some absorption materials (ceiling perimeter with porous acoustical plaster, wooden absorbing board and curtain behind the back wall) to respect the acoustical requirements in particular concerning the speech intelligibility (cf. Figure 2).

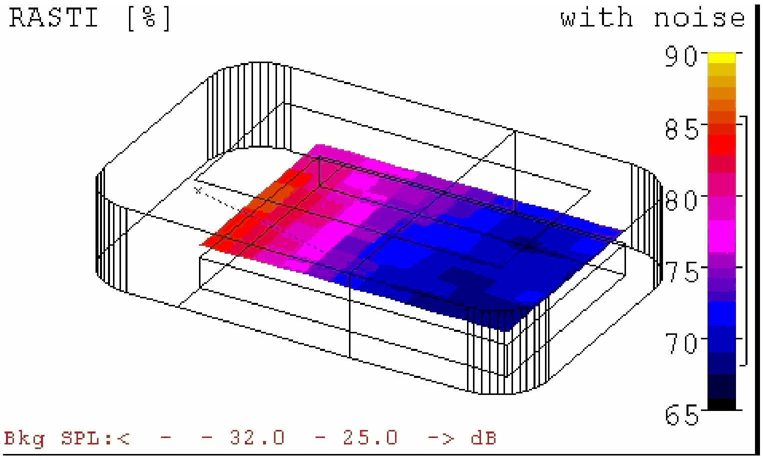

Figure 2: Speech intelligibility calculation in double classroom.

4.3 Multipurpose hall

Detailed simulations were also performed for the multipurpose hall originally designed with carpet floor, glass walls (including rear patio), a porous plaster ceiling and circular stage with parquet floor and mineral wool ceiling (cf. Figure 3).

Figure 3: Photomontage of the multipurpose hall.

With this original configuration, the expected reverberation time would be too short for music performances (0.8 s at mid and high frequencies in the empty hall, which leads however to a good speech intelligibility for raised voice) with a lack of early reflexion. These results including too high clarity (C80 about 6 dB in audience area) can be explained by the highly absorbing stage ceiling and distant façade reflecting walls.

Simulations were performed to optimize the position and the shape (convex in the best variant) of the reflecting plaster ceiling above and near the stage and the vertical reflectors behind the stage (cf. Figure 4). These modification, associated with concrete floor in the front part of the hall, induce much better acoustical conditions for performances (T=1.1 at mid frequency with enough early reflexion). The computer model also demonstrates the need of partial mobile rear walls to have sufficient sound insulation with the fully open area. In fact, without such separation the expected noise level from the nearby restaurant will be over 45 dB(A) at the last row of the audience and amplified music in stage will be heard in the working area of the open plan.

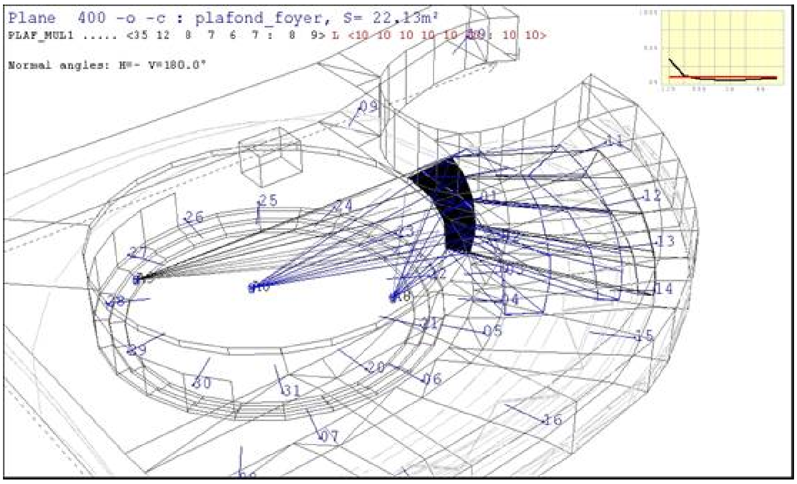

Figure 4: Optimisation of wall and ceiling reflexion of the multipurpose hall.

4.4 Materials and reverberation time in open part

Simulations were finally performed for the full open space (15’000 m2, cf. Figure 5) to optimise the choice of floor and ceiling materials and to study the noise propagation with distance and the coupling between spaces.

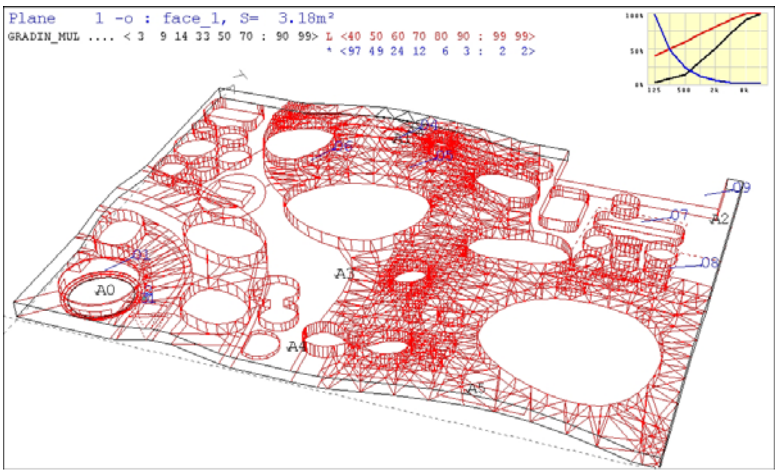

Figure 5: 3D model (top view) of the Learning Center.

The results show that **suspended ceiling** of the Learning Center should provide a large part of the acoustical absorption of the landscape. The absorption coefficient (αs) should be then equal or greater to 0.6 for mid and high frequencies (Noise Reduction Coefficient

>0.65). In architectural point of view, the ceiling has to be waved (to follow the shape of the floor) and look like as a single surface (if possible without any joint).

Various types of material (different kind of porous plaster, stretched ceiling in PVC or cloth, expended metal) and configuration (air gap, presence of mineral wood behind) of this product were investigated to optimize the absorption coefficient.

Taking in account all the constraints involved (architecture, cost, technical, and so on) the best solution adopted is a thin porous plaster ceiling with 30 mm thick mineral wool (60 kg/m3) and a 300 mm air gap (αs = 0.6).

The **floor** should also be acoustically absorbent to reduce the reverberation time, the sound propagation and finally the impact (walking) noise. The concrete, planed in the project, is not adequate in the acoustical point of view, particularly in open space with working places or in areas with high noise sensitivity. After many discussions, about 10% of the floor is covered with carpet (patches concentrated in noise sensitive areas such as multimedia library and open plan offices situated north of the building). But simulation results show that only fair acoustic comfort can be achieved with this solution. They were finally convinced to use, in most area, a carpet, designed in accordance to the various constraints, (concrete is restricted in the restaurant, exhibition and multipurpose area).

With this design (absorbing ceiling and carpet), the simulation results give an early decay time of about T15=0.65 in most of the open space area. The expected value should be however a little lower due to the effect of neglected furnishings that would increase absorption and diffusion.

Screens in an open space contribute to a good acoustical comfort. Associated with an absorbent ceiling, they can considerably reduce the noise between two adjacent working places. In addition, screens contribute to obtain a short reverberation time. In the library area, the great number of bookshelves provide useful absorption (αs=0.8 at mid frequencies when loaded [2]) and significantly contribute to decrease the noise level with increasing distance. Screens with a sufficient height (h>1.6 m) and amount (9 m2/working place) should be however included in the project in open spaces devoted for administrative purpose.

To provide a good acoustical comfort in the whole building it is necessary to have in most areas a carpet, an absorbing ceiling and some screens.

4.5 Shapes and sound attenuation with distance

As already mentioned, sound attenuation between the different areas is of major importance to provide a good acoustical comfort in an open space.

First, sound attenuation with distance have been calculated with analytical models (classic (free + diffuse fields) and with Barron adaptation for large volume (additional attenuation in dB=0.1*d, with d distance to sound source in m, cf. [11]) with various reverberation time, which is the most important parameter. Results (cf. Figure 6) show that at long distance (> 60 m) the sound reduction can reach 26 to 29 dB(A).As example, for a noise level of 65 dB(A) in the area café/exposition the expected level in the multimedia (including the diffraction around the patio 5) is about 30 dB(A) which fulfils the increased requirements.

For a noise level of 70 dB(A) in the area restaurant, the expected level in the multipurpose hall is about 40 dB(A) which is quite loud for noise sensitive activities (conference, acoustic concert, etc). The audience area of the multipurpose hall should then be isolated (at least 15 dB) to have a good acoustic comfort. At short distance, additional noise reduction can be achieved by screens according to their height (about 12 dB for 1.8 and 7 dB for 1.5 m). Doubling the reverberation time induces a 3 dB increase of the noise level.

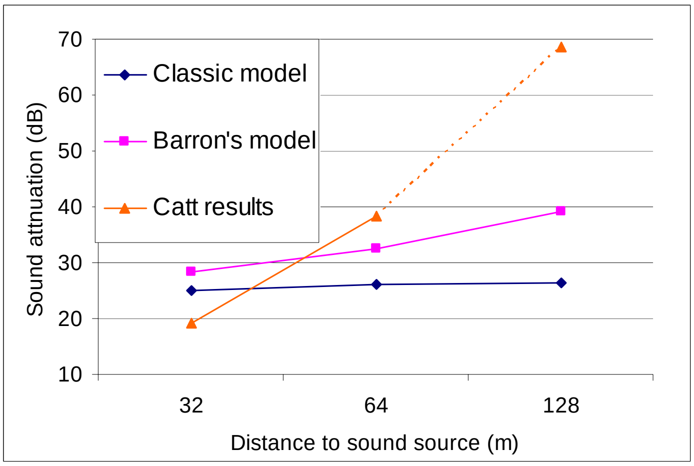

Figure 6: Sound attenuation with distance in the Learning Center.

However these simple analytical models based on Sabine's theory or even adapted by Barron for large hall (for example rail station or concert hall) becomes inaccurate in particular (long) enclosures. In the case of the Learning Center, important factors like limited height (3m), large slopes and presence of box and patios are neglected with these models. Therefore special predicting methods, developed in particular for long enclosure [12, 13], should be preferably used in such complex enclosure. 3D simulation is however the most appropriate method to study the noise propagation in this complex open space.

Sound propagation simulations were then performed with CATT-Acoustic for different sound source positions (multipurpose hall, multimedia, administrative open space, restaurant, cf. Figure 7). Compared to analytical calculations, the results (cf. Figure 6) show a lower attenuation at short distance (probably due to ceiling with limited height and absorption) but larger in mid and long distance from the sound source (d>50 m). The various simulations results give a nearly linear attenuation (0.6*d) with sound source distance (d) at mid and high frequencies.

However, because of limited number of rays arriving at very long distance (d>100 m), attenuation in these area could be overestimated by the model.

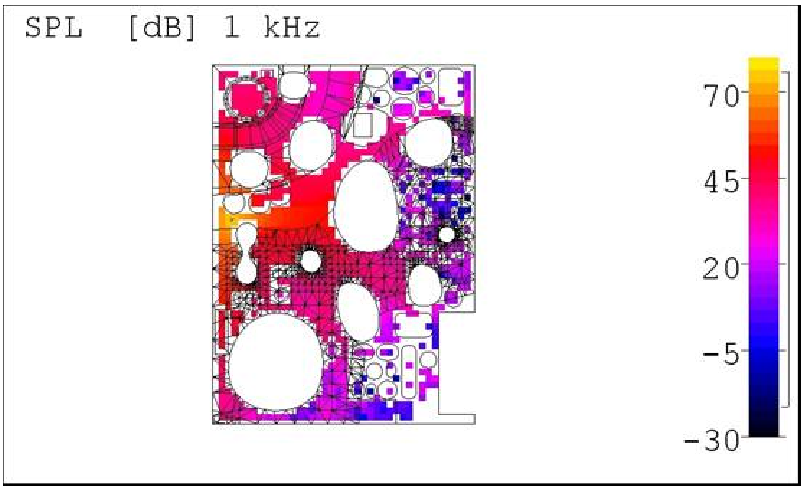

Figure 7: Sound propagation in the LC (sound source in the restaurant on the left).

5 CONCLUSIONS

The concept of a “Learning Center” with various activities concentrated in single large open space is real acoustic challenge. To obtain the best acoustic comfort, the various acoustic requirements such as reverberation time, noise level or sound insulation were determines on the basis of the new Swiss Standard SIA181:2006.

After defining annoyance potential (noise emission) and noise sensitivity (need for quietness or privacy) of the various activities, it is of first importance to analyse the “conflict map” for optimizing the various activities location in the Learning Center. Simple bypass of activities in the open space allowed avoiding acoustic conflicts between them.

In such complex environment (sloped ceiling and floor with screening patios and closed boxes) 3D simulation is a powerful tool to verify acoustical behaviour and to optimize shapes, materials and position in such unusual enclosure. To provide a good acoustical comfort in the whole building, simulation results show that it is necessary to have in most areas a carpet, an absorbing ceiling and some screens.

Classical analytical calculations of sound attenuation based on Sabine’s theory or even adapted by Barron for large hall don’t apply in these complex project.

The results from 3D simulations show a little attenuation at short distance (probably due to ceiling with limited height and absorption) but a large and nearly linear attenuation (0.6*d) with sound source distance (d) in mid and long distance from the sound source (d>50 m). However, because of limited number of rays arriving at very long distance (d>100 m), attenuation in these area could be overestimated by the model.

The acoustic comfort of the final design and the accuracy of the prediction methods should however be confirmed by in situ measurements after completion of the building.

6 REFERENCES

[1] C. Legros, “L’acoustique des grands locaux”, symposium « Acoustique des gares et des grands volumes », SFA, Paris (2002)

[2] A. James, “The Norwich Forum – The acoustics of a library for the 21st century”, Association of Noise Consultants (ANC) - spotlight articles, (2005)

[3] SIA181: Protection against noise in building, Swiss Standard SN 520181 (2006)

[4] F. Emrich, „Neufassung der Schweizer Norm SIA 181 Schallschutz im Hochbau“ DAGA (2005).

[5] DIN 18041, Hörsamkeit von kleinen und mittleren Räumen. (Acoustical quality in small to medium-sized rooms). Beuth Verlag GmbH. (2004)

[6] “Recommendations relating to room acoustics of the classrooms and other buildings intended for educational purposes” Swiss Acoustical Society, www.sga-ssa.ch (2004)

[7] Comment of 3rd Ordinance (1995) relating to the Swiss Law on Work, art. 22 (1964)

[8] B.-I. Dalenbäck, “A New Model for Room Acoustic Prediction and Auralization”, Ph. D. thesis, Report F95-05, Chalmers University, (1995).

[9] X. Zeng et al., “Prediction of the characteristics of complicated sound fields in long enclosures by beam-tracing method”, Building Acoustics, vol. 9(2), pp. 139-150 (2002)

[10] L. Yang and B. M. Shield, “The prediction of speech intelligibility in underground stations of rectangular cross section”, J. Acoust. Soc. Am. 109(1), Jan. (2001).

[11] M. Barron, L.-J. Lee, “Energy relations in concert auditoriums”, J. Acoust. Soc. Am. 84(2), pp. 618-628, Aug. (1988).

[12] J. Kang, “A method for predicting acoustic indices in long enclosures”, Applied Acoustics, Vol 51, No 2, pp. 169-180, (1997)

[13] K. Ming I, P. M. Lam, “Prediction of reverberation time and speech transmission index in long enclosure”, J. Acoust. Soc. Am. 117(6), pp. 3716-3726, June (2001)