AN OVERVIEW OF THE ACOUSTICS OF THE OSLO OPERA HOUSE

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1 BACKGROUND

The Norwegian Opera environment was gathered in one company and with its own stage facilities 50 years ago. Ever since then, there has been a goal to have a building designed specifically for opera and ballet.
Today they have achieved this, and in this building around 600 persons will have their workplace.

There was a political fight about the location of the new building, it is financed by public money and the Parliament had the last word. As in many of the other European cities located close to the seafront, there are large areas formerly used as docks, shipyards and warehouses now being converted to areas for living quarters and active parts of the cities.

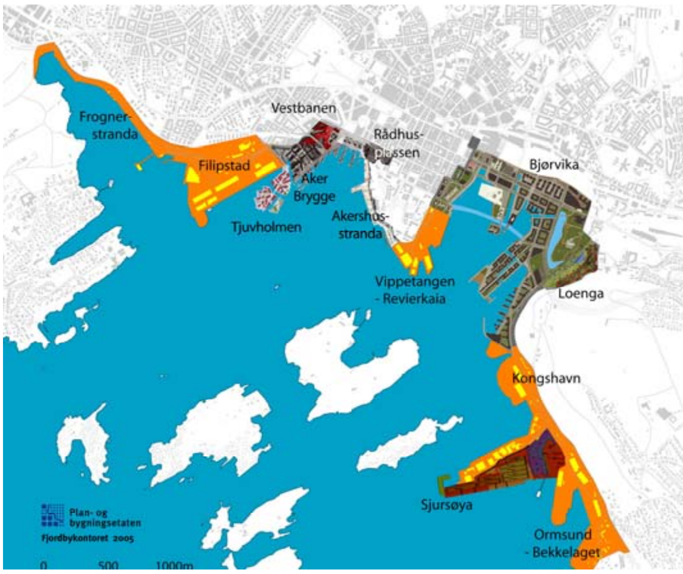


Figure 1, showing the seafront of Oslo City

The picture is taken around year 1960, and shows the shipyard, docks etc. The name of the yard was "Nyland Mek. Verksted", translated *New Land Mechanical Workshop.* All the land where the shipyard was built from around 1850 was originally below sea level. Around year 1600 new technology for producing wood for the European market entered Oslo. Saw mills were built along the river that now ends beside the Opera House. Sawdust from these gradually gathered on the sea floor and created new land. On top this ordinary soil, stone, gravel, brickwork from demolished building was put to make a surface where it was possible to place building, slipways etc.

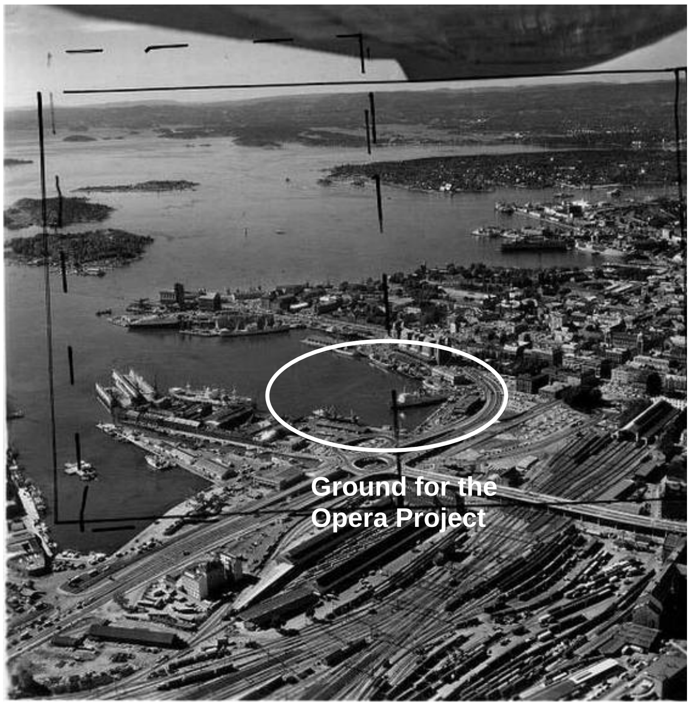


Figure 2, Nyland (the site) from the air in 1960's

Site examinations in the 1990's revealed up to 20m's of sawdust filled with water, and on top of this 2-3m of better quality building ground at the site for the new project.

The building is built partly on this ground, and partly above the sea level. This is done as a normal quay, and the foyer and some other parts of the building sits on top of this. Much of the ground work had to be done in water, and below sea level

Figure 3, the site in 2004, showing part of the basement of the Large Auditorium and the stage to be placed inside the big cylinder.

The Opera is supposed to be a driving force for developing the new part of the city called Bjørvika. Here there are supposed to be raised over 1000 new living residences and above 20 000 places of work. It will also be an important junction for all public transport.

In the lasts months decisions has been taken to move the Munch Arts Museum, the City Library, and parts of the National Museum to Bjørvika. The success of the new Opera building has been a driving force in these processes.

Figure 4, Bjørvika as planned to be in 2020

2 PROJECT DATA

2.1 Den Norske Opera og Ballett

The opera and ballet company is a public company, and has about 75% of the income from the government. The rest is by the box office and sponsors. It is the main stage for opera and ballet in the country, and the repertoire is mainly based on pure operas (not musicals or operettas), and all kinds of ballet.

2.2 The building process

After the location decision in the Parliament, Statsbygg (which is responsible for organizing, planning and completing public building projects) was appointed to take care of running the project up to completed building. After a careful programming process, they arranged an architectural competition which was won by the Norwegian architects Snøhetta in the year 2000. After that tenders for the various engineering disciplines were sent out, including acoustics.

BSA, a joint venture of Arup Acoustics in UK and Brekke & Strand akustikk as in Oslo won this competition. The planning work started fully in the autumn 2000, and the building was opened and handed over to DNOB in April 2008. The first real opera performance was in September 2008.

The Department of Culture, DNOB and Statsbygg has defined *"Excellent acoustics is the main success criteria for the new building".* Compared to other of the large projects we have been involved in, it has been a privilege to work with this, all the way we feeling strong support from the client and users. The architects also seemed to find this an extra inspiration and the close development work has led to solutions and results they enjoy and not achieved without this input.

2.3 Key figures

Areas	
Overall area	38 500 m2
Audience area	11 200 m2
Stage areas	8 300 m2

Important rooms
5 Ballet rehearsal rooms
4 Opera rehearsal rooms
Chorus rehearsal room
Orchestra rehearsal room
3 stages – Main stage, Scene 2, Prøvesal 1
25 studios (music practising rooms)

Seating capacities	
Store sal	1 360
Scene 2	max 440
Prøvesal 1	200

Heights	
Total height flytower	54 m
Depth below sea level	16 m

Economy	
Project cost, today's prices	500 mill €
Yearly running costs	NOK 470 mill
Public money	NOK 346 mill
Own money (sponsors, tickets etc)	NOK 125 mill

Employed
Overall: Ca. 550:
Orchestra ca. 90
Choir: ca. 55
Ballet: ca. 55
Solist, singers: ca. 20
Overall number will increase to 600 in 2010

Number of visitors during the 4 months after opening 300.000

2.4 Brief and building program

Much effort was put in developing a complete brief and program for the building. The user has been strongly involved in over 25 user groups. Statsbygg worked out a complete program with specifications for all rooms in the building, sound isolation, noise and room acoustical requirements was defined. This work has been a very useful and valuable basis for the planning work to be done by the architects and engineering consultants.

3 MUSIC PRACTISING ROOMS/REHEARSAL SPACES

3.1 Small rooms

The small practicing rooms for members of the orchestra and for the singers are built in a traditional way, done in several similar projects in the last 25 years. This is:

- Floating concrete slabs on mineral wool, divided by joints under each wall.
- Lightweight partition walls between rooms and to the corridor
- Freely suspended gypsum board ceiling, mounted only to the partition walls
- Double facades with an inner wall free standing from the outer, included the windows
- Silencers on all ducts, and no raceways or ducts run through the partition wall, all these must be led through the wall to the corridor

Figure 5, Floating floors, fresh concrete covered to reduce warp

Figure 6, Free spanning ceiling, steel carrying system

3.2 Large rooms

There are several large rooms for rehearsals, all built as box-in-box rooms. The largest, Scene 2, has a location close to the Orchestra Rehearsal Room, and a need for a high degree of sound isolation. Our goal has here been to achieve a sound isolation above R'_w=80 dB, to take care of the need to use these two rooms independently. All these rooms are made with heavy slabs, some of them with a load carrying inner system based on steel columns and beam trusses etc.

Figure 7, Steel in orchestra rehearsal room

Figure 8 Steel in inner box in Scene 2

3.2.1 Floors

All these rooms are built with heavy concrete slabs.

- **Scene 2** and **Orchestra rehearsal room** has a slab of 250-300mm concrete on 150mm Rockwool, these slabs carry the load from tall walls and the inner gypsum board ceiling. A separate steal system with columns and beam trusses in the ceiling is built to take carry of stability and to carry the loads down the concrete slab

- **Opera rehearsal rooms** are built with traditional floating slabs, 100mm concrete slab on top of 50mm mineral wool.

Figure 9, Pads used in ballet floors

- **All ballet practising rooms** has a point supported concrete slab, 100mm Sylomer pads carries the 150mm thick concrete slab. There are also requirements for reduced span widths for the hollow core concrete slab that carries the floating slab and floor, due to risk of vibrations from persons dancing at the floors.
- The dance floor on top of the slab is built with a layer of foam, a board of plywood, different sets of cross laid timber and a massive wooden floor on top.

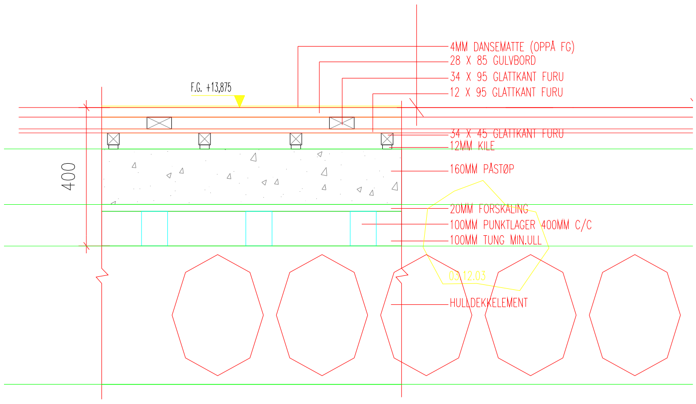


Figure 10, Section through ballet floor and slab etc

3.2.2 Walls

Most of these rooms are made with lightweight partition walls as material in the inner boxes. Only the most requiring room (when it comes to noise and sound isolation), the Orchestra rehearsal room has a heavy inner wall, 200mm Leca with plaster inside.
Due to large height of many of these walls, special care had to be taken to ensure stability.

3.2.3 Ceilings

Ceilings are either free spanning as shown on the pictures 7 and 8, or carried by steel beams hung by vibration isolators. 50% of the ceilings shall be able to carry the load from a light grid, where light sources, curtains and parts of scenery also may be fixed.

Figure 11, Suspension of beams

Figure 12 Detail of isolator

4 ORCHESTRA REHEARSAL ROOM

ROOM ACOUSTICS

This room will be used for practicing; the orchestra has this room as their main space in the building. When doing common rehearsals with the choir, this will take place here. Recordings for producing CD's etc will also be done here.

Variable acoustics is important to be able to adjust the room for the various needs.

To obtain the reverberation conditions combined with the need to keep the sound levels down, there is need for large volume. The room itself has a floor area of around 450 m2, and a height of 13m. The volume will be about 5.800m^3. At many of the orchestra rehearsals there are around 80- 90 musicians involved, which gives a volume pr person around 65 m^3.

Figure 13, Orchestra Rehearsal Room, interior

From the musician's point of view, there is a wish to experience the same acoustical conditions in the rehearsal as in the orchestra pit in Store Sal. This is not possible, but the design is based on some ideas;

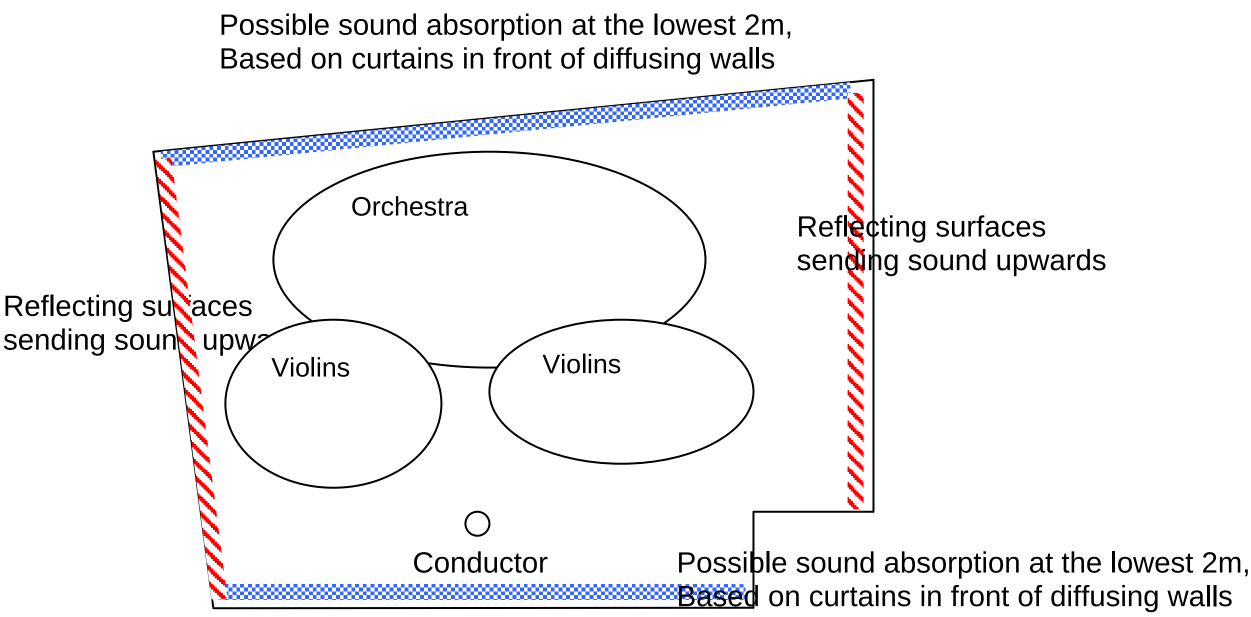


Figure 14, Orchestra Rehearsal Room, Principles - acoustic surfaces

- In the pit, all the sound that travels across to the side walls is diffused, and not returning back The side walls (red) are made upwards reflective

- The sound that hits the rear wall in the pit will often be reduced by absorptive panels, or it may be reflected / scattered. The wall is made of a scattering shape, based on two sets of horizontally placed triangular shapes.

- The same is done with the front wall
- The upper parts of all walls are based on a module system, like large book shelf covered with a panel based on battens in different sizes (to avoid coloring of sound). In the shelves, there is different kind of acoustical treatment, thick layers of mineral wool covered by perforated steel sheets, acting as a broad band absorber (yellow on the figure below). Other shelves are filled with reflective panels angled out of the vertical, and together with the neighboring elements creating a diffusing surface (Blue and green). The battened surface also acts as a diffusing element and creates nice reflections.

Figure 15, Orchestra Rehearsal Room, Walls.

- The ceiling is made by slightly sloped reflective surfaces (13m above floor). To enhance the possibility for mutual listening in the orchestra, there is a set of reflective dishes acting as reflectors (and light sources). These may be set at different heights, normally they are used around 9 m above floor level.

Figure 16, Orchestra Rehearsal Room, Prototype acoustic reflector/lamp.

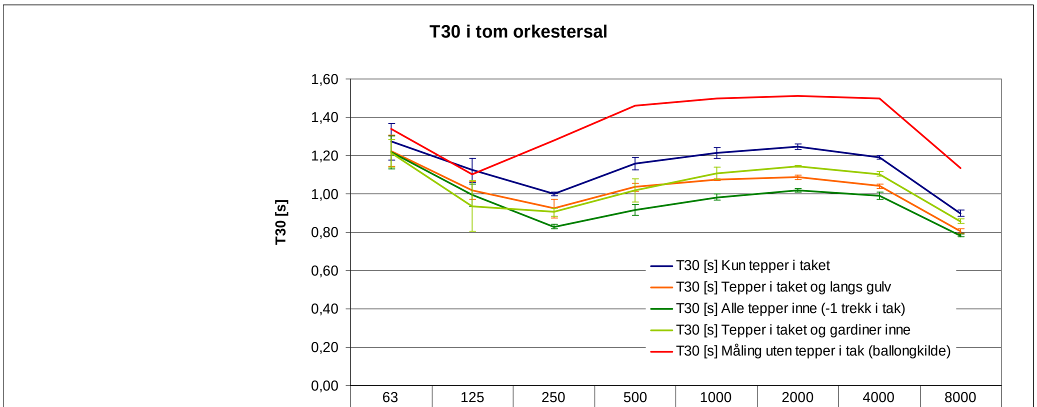
4.1 Variable acoustics

To make the function well to all different kinds of uses, the brief called for a wide variation in reverberance in the room. These are the systems used:

- Banners crossing the upper part of the room. 5 sets of motorized curtains on tracks, heavy folded wool fabric
- Roller curtains, motorized (purple on drawing below), hidden behind the battens on the walls
- Heavy wool curtains (brown on the drawing below), folded at the lower part. Manually operated
- Curtains in front of the windows, motorized
- Movable acoustic reflectors in the ceiling

Figure 17, Orchestra Rehearsal Room, Variable acoustics

Results,



	63	125	250	500	1000	2000	4000	8000
T30 [s] Kun tepper i taket	1,27	1,12	1,00	1,16	1,21	1,25	1,19	0,90
T30 [s] Tepper i taket og langs gulv	1,22	1,02	0,92	1,04	1,07	1,09	1,04	0,81
T30 [s] Alle tepper inne (-1 trekk i tak)	1,22	0,99	0,83	0,92	0,98	1,02	0,99	0,78
T30 [s] Tepper i taket og gardiner inne	1,21	0,94	0,91	1,02	1,11	1,14	1,10	0,86
T30 [s] Måling uten tepper i tak (ballongkilde)	1,34	1,10	1,28	1,46	1,50	1,51	1,50	1,13

Figure 18, Orchestra Rehearsal Room, Reverberance times
(The results may be influenced by a building scaffold in the room during the measurements)

NOISE FROM PERFORATED FACADE PANELS

Parts of the facades are covered by aluminum panels. (Mostly Back of House). In all public buildings, 2% of the budget shall be spent on art work. The architects involved the artists very early, some of them were involved in the design of the facades. They started with an idea of copying old Norwegian weaving patterns, as a pattern of holes in the panels.
Based on experience from air passing by perforated panels, we warned the client of a potential risk for tonal sound coming from these panels at certain wind speeds. This could cause problems for panels fixed in front of musical practicing rooms.
A test in a sound lab was then carried out, mounting various kinds of panels in front of a laminar air stream with different speeds.

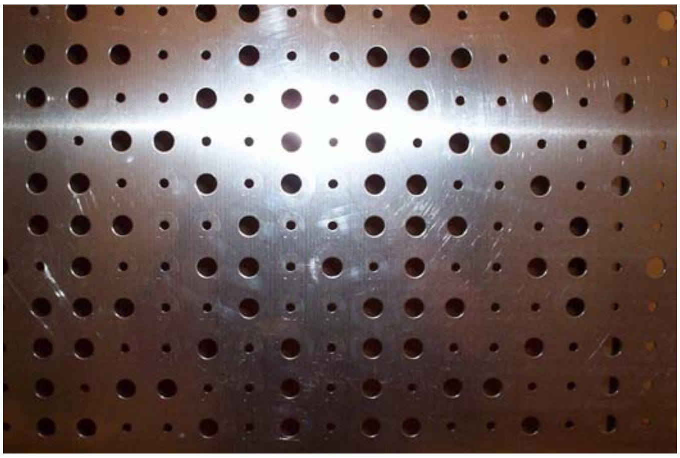


Figure 19 Test panel, aluminum facade

Typical sound levels measured for the panels was up to 53 dB (pure tone) for a wind speed at 11,5 m/s.

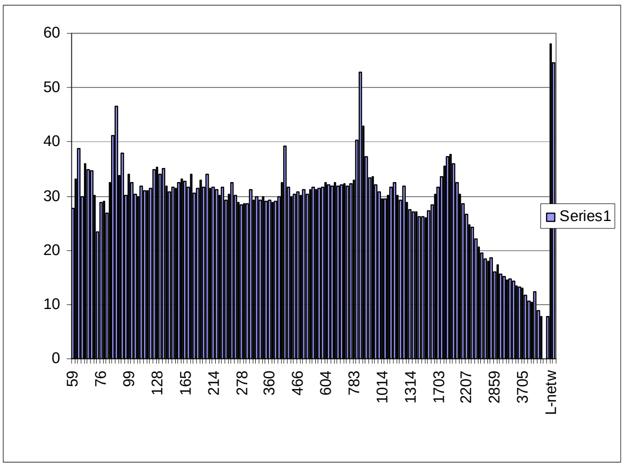


Figure 20 Test result, sound pressure levels with pure tones

Perhaps all this scared the client; he claimed the design to be done without holes. Today you can see the panels made by another technique; the holes are replaced by imprinted circles with variable diameter.

Figure 21 Part of the aluminum facade

5 CONSTRUCTION OF THE ROOF

One of the main ideas behind Snøhetta's winning concept in the competition was to give back to the city some of the land the building occupied. Part of the roofs should open public spaces and designed in a way that invited to be used.
Below these roofs there are large auditoriums and rehearsal spaces, and to take care of noise from people on top of the roof, there are sound isolation built in the construction. The picture shows the build up of the different layers on top of the concrete slab. First there is a membrane for water, then a layer of mineral wool for sound isolation, then some layers of XPS for thermal isolation, the mortar to place the marble blocks in, and the marble itself.

Figure 22 Build up of marble roof

On top of the Large Auditorium we were afraid of this area being used for skateboards etc, and measurements from a similar situation were carried out. Based on this, there is here an extra contrete slab on point supports to give the required isolation, and on top of that the same treatment as shown in Fig22.

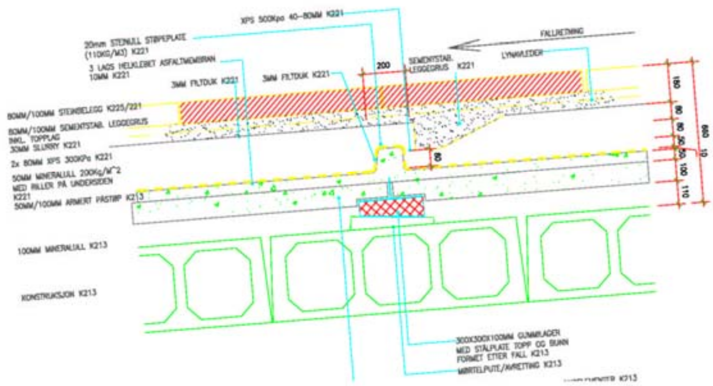


Figure 22 Build up of marble roof

6 FOYER

Many of the well known Opera building have foyers with mirrors, large chandeliers, rich decoration based on ornamentation etc. Floors may be marble or stone. These rooms are often rather reverberant, and to many the acoustics feels bad when the main use is to give room for the audience in the breaks.

In this project there has been a strong wish from the client to make the foyer quiet and with rather short reverberance time. The volume is large, and we aimed at 1.4 seconds, and this was achieved. There are no doors to the public toilettes, and noise from here was considered. Due to high degree of absorption this works well.

All the ceiling is made of micro perforated stretch foil (Barrisol) in front of a 40mm mineral wool ceiling hung from the concrete slab.
The large wooden wall is made by oak battens in front of a wall isolated with 50-100mm mineral wool covered by a black textile.

7 EXPERIENCES

So far the project has been a large success. The users a very pleased with their new working environments and the building has been given very much attention.

This also brings more focus to DNO and their activities. As in other similar projects all tickets for all performances are sold for next year.

The acoustics in the two main auditoria has been very well received. It has been tested for opera concerts, and a limited range of operas. The critics in the main national media channels talks about the big difference from the old house, and "at last we have got an auditorium in Oslo with excellent acoustics". Even though the reverberation time in the Store Sal is a bit above the lowest limit defined in the brief, nobody has asked to do something to that.

On stage noise from theatre lighting creates a big problem. Modern motorized light sources with strong lamps (1200W discharge lamps) create noise levels at about 50-55 dBA at 1m. When using 40 of these in the light rig at stage noise levels may be above 55 dBA at floor. All the lamps that will be used in a performance must be turned on before start of the performance and be kept running at full power, due to high noise levels in the start up process.

Color scrollers also create noise problems. In the beginning there were about 200 of them in the auditorium, and all running their fans at high speed. After working with this, now only part of these are run during the normal performances, and a redesign of the set up of the control system will give the possibility to adjust fan speed at each scroller individually (full speed is only needed when using dark colors, red, blue etc).
Noise from dimmers (a new technology based on sine wave dimmers) was higher than expected, noise levels up to 85 dBA in the dimmer rooms is experienced, and the same is measured in the motor control rooms for flying equipment in the tower. These noise sources are controllable, but a high degree of sound isolation and noise sealing around cables, pipes and ducts is needed.

So far all sound isolating constructions and treatments has worked well. Minor problems are discovered, like a joint in slab not working, and lack of some silencers that reduces sound isolation between highly isolated rooms. Both of them are easy to improve.

Personally the work as acoustic consultant in a project like this, 8 years in close contact with architects and other acousticians has been a big pleasure, and I am grateful for this. A lot has been learned by this, both acoustically and also all the other considerations that must be taken has been very useful be brought into.