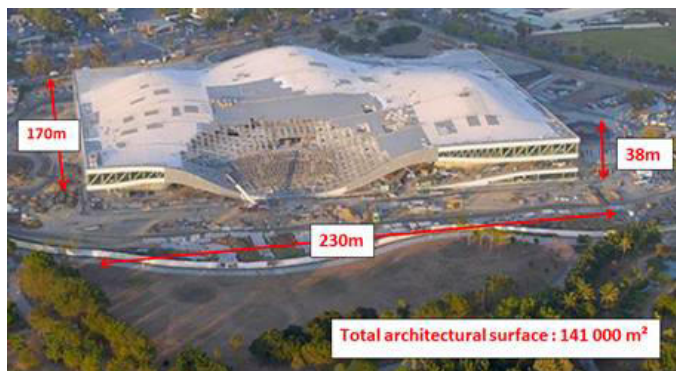


ACOUSTICS OF THE WEIWUYING PERFORMING ARTS CENTER, TAIWAN

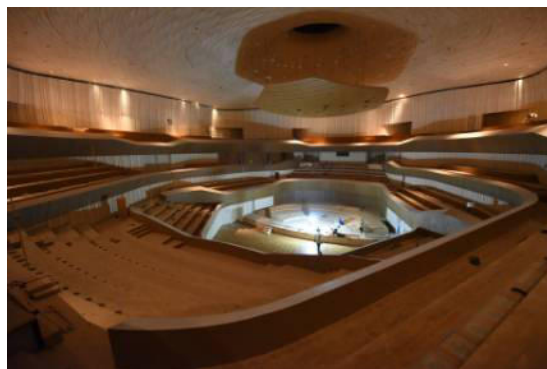
Albert Xu Xu-Acoustique, Paris, France
Mario Philippe Xu-Acoustique, Paris, France

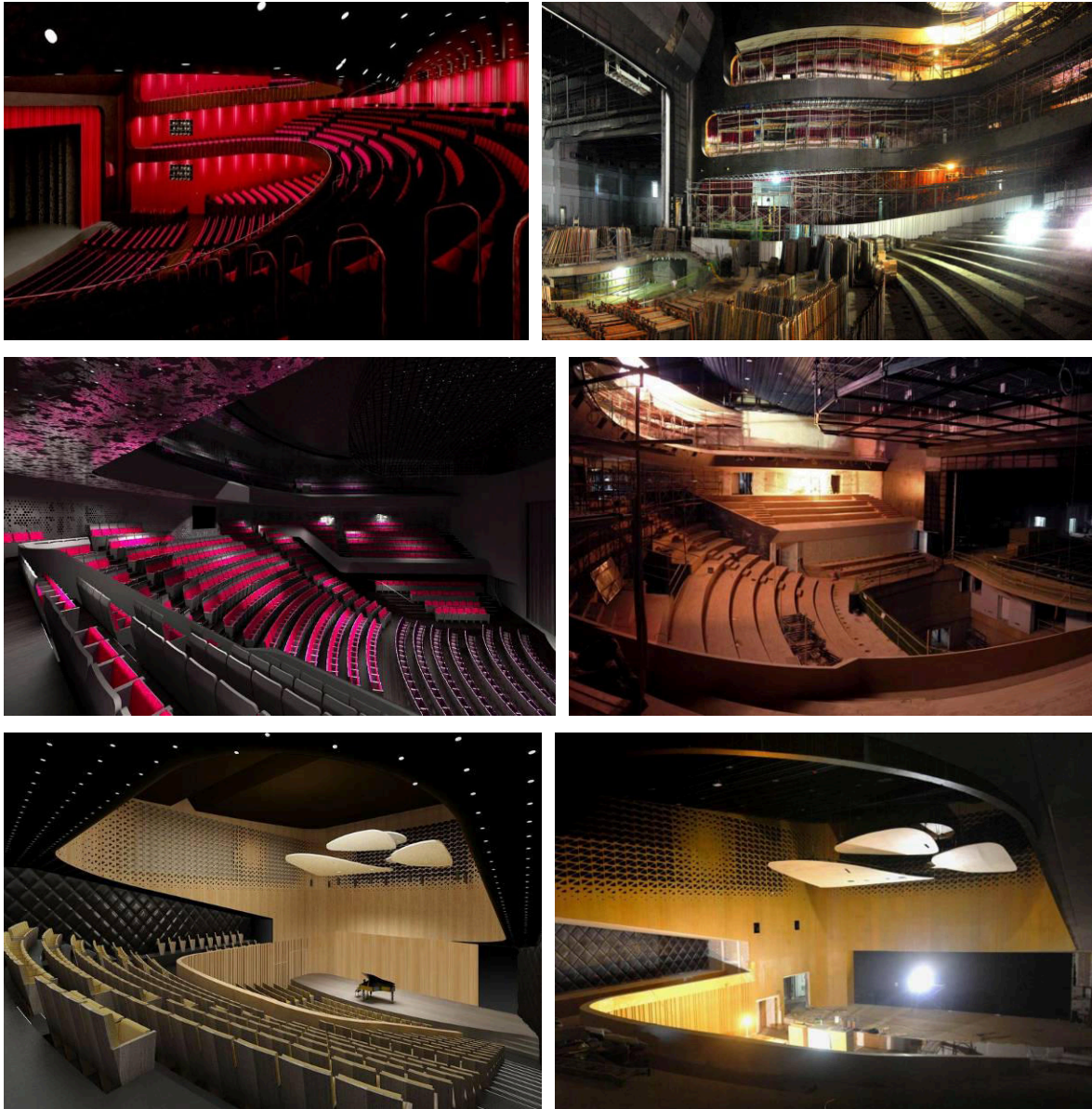
1 INTRODUCTION

The National “Wei-Wu-Ying” Performing Arts Center is one of the biggest cultural center in Asia. It is located in an ancient military camp of Kaohsiung, Taiwan. This performing arts center is composed of a Concert Hall of 2000 seats, a Lyric Theatre of 2250 seats, a Playhouse of 1250 seats, an asymmetric Recital Hall of 470 seats and a large orchestra rehearsal hall.



This center is equal to the National Chiang Kai-Shek Cultural Center (1978) in Taipei; it is a cultural politic counterweight between North and South in Taiwan. The design work was started in 2007 after the closing of an international competition, which has been won by the architect MECANOO (The Netherlands). The predicted inauguration time was 2015, but due to the complexity of the whole facilities, the opening time is delayed to the end of 2016. The following pictures show the four main halls during the design phases (left side), and the actual situation on the construction site (right side).





2 ACOUSTIC DESIGN OF THE CONCERT HALL

The Symphony Hall is destined for symphony concerts including the concert organ repertoire. The volume is 24000 m^3 , or 12 m^3 per seat. A large canopy of 200 m^2 is suspended above the stage, and its height can be adjusted between 9 m (recital), 14 m (symphony) and 17 m (organ and romantic symphony). The predicted occupied Reverberation Time is 2.0 s (500 Hz).

2.1 Influence of the Different Geometric Shapes of the Hall

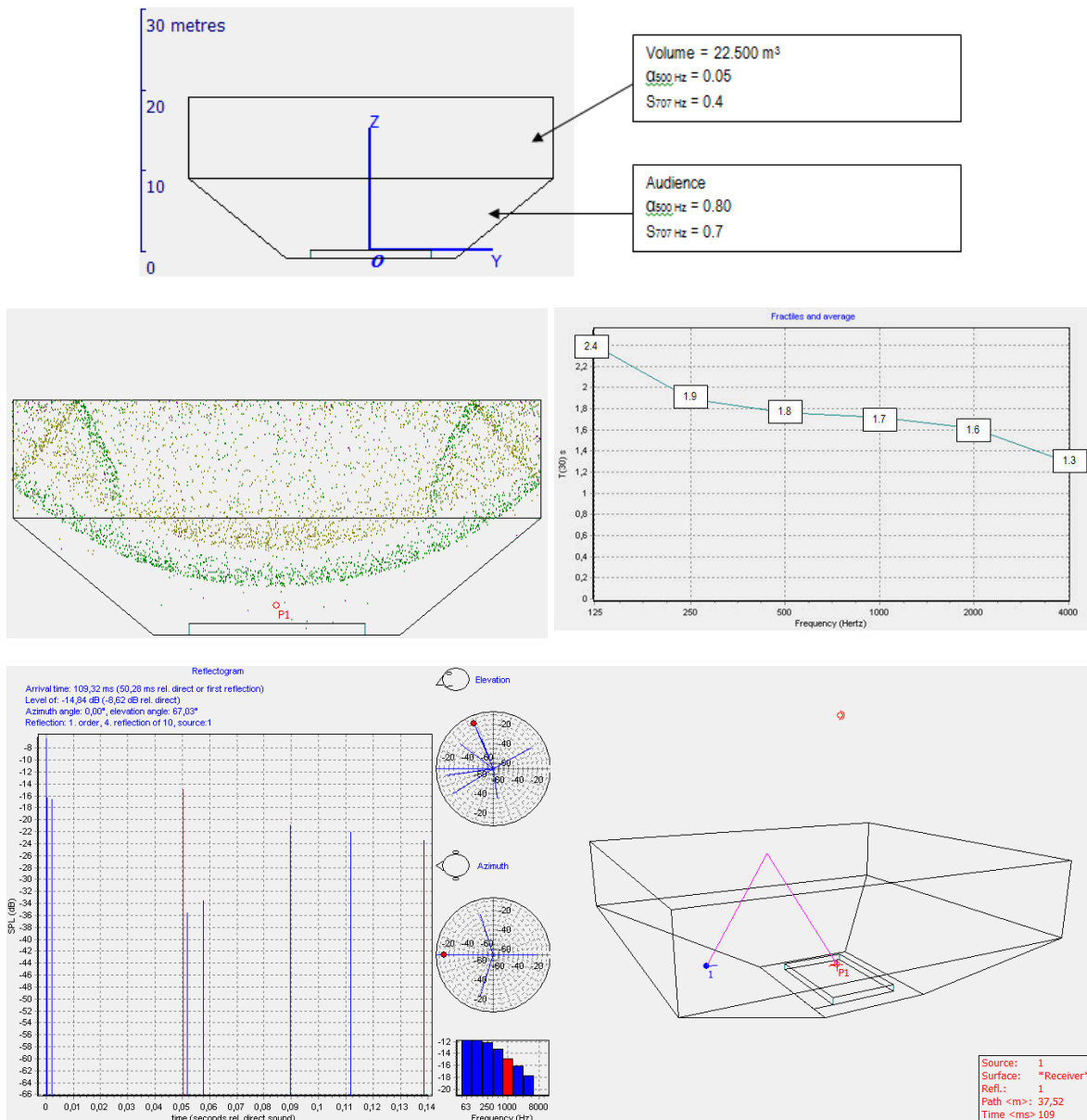
During the study phases, there were two questions that need to be clarified:

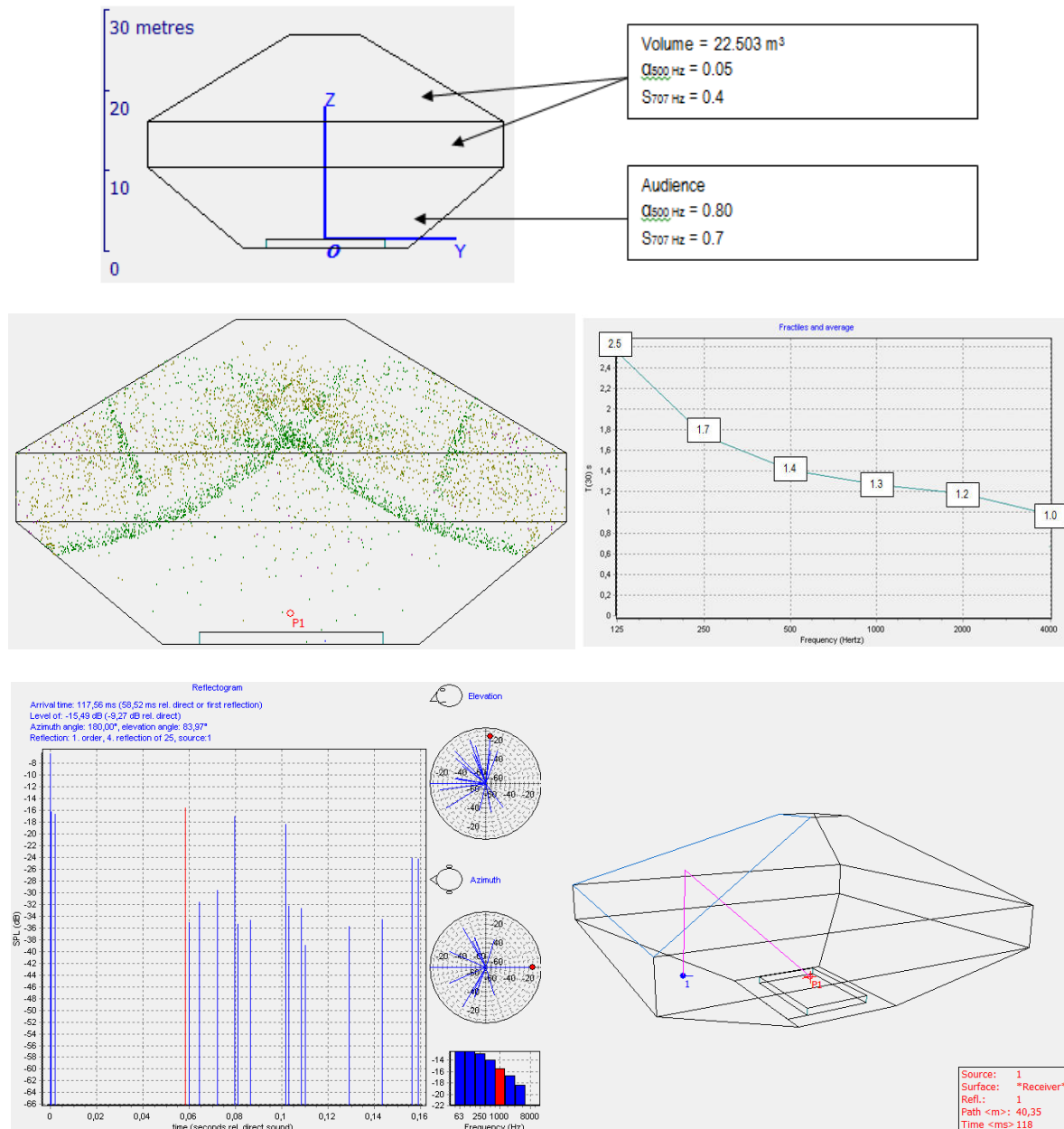
How does the **shape of the ceiling** may influence the occupied RT value?

Does the **variation of the canopy height** will influence the Clarity of perception on music?

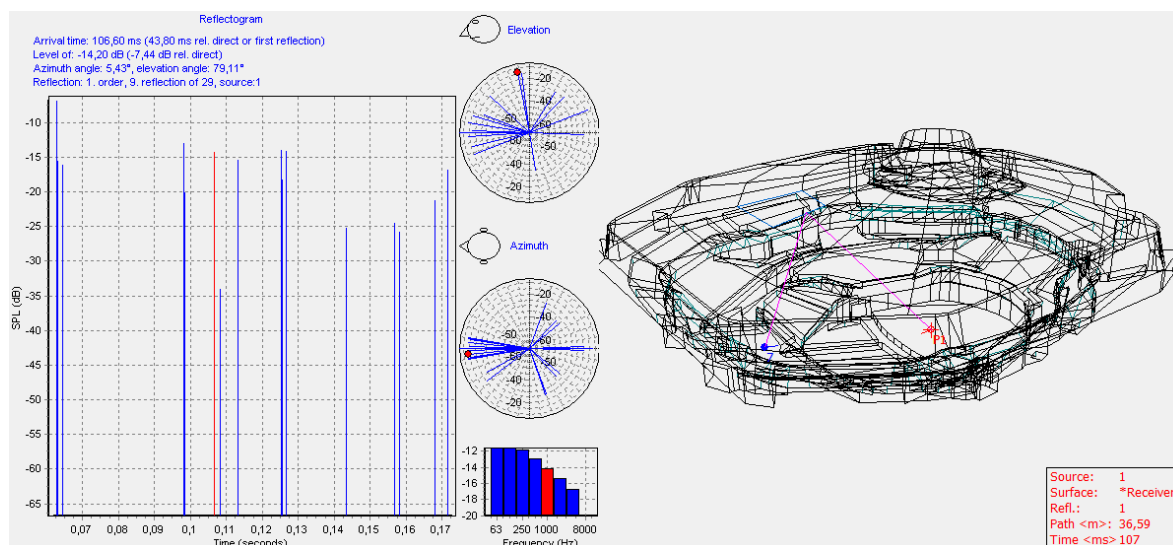
2.1.1 Influence of the Ceiling Shape on RT

Due to the shape of the original ceiling as a “Tent” (or Volcanic ceiling), the most first reflections from the ceiling will touch the audience, so the strong sound absorption of the audience (0.8 according to Beranek’s data [1]) may provoke a shorter RT than in a hall with a flat ceiling (same volume with “hard cap”). In order to investigate this phenomenon, a comparison using a simplified 3D model (ODEON software) has been done between two different shapes of ceiling (flat and tent shape). Results are shown following.



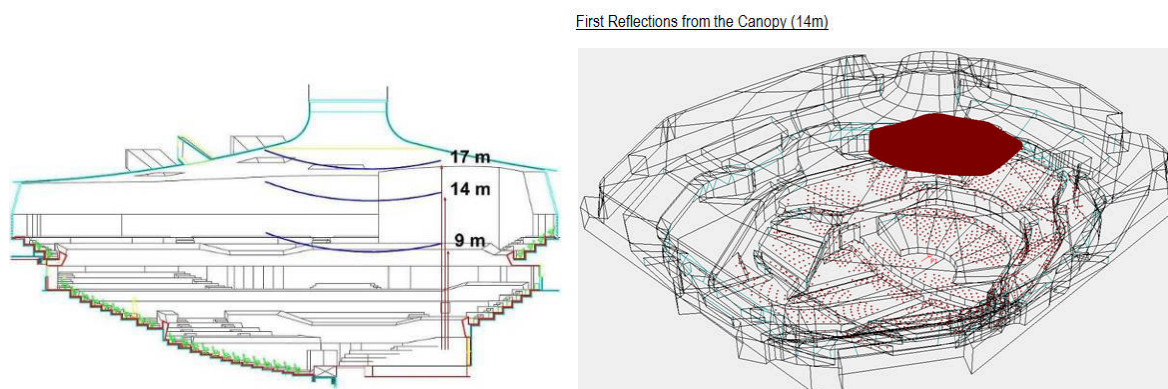


The tent shape ceiling can provide more early reflections than the flat one, so it leads to a higher C_{80} (2.1 dB vs. 1.4 dB for the flat hall, in the centre of the stalls). But the RT value (500 Hz) for the flat ceiling is as long as 1.8 s (EDT 1.7 s), and the RT for the tent shape ceiling is dropped to 1.4 s (EDT 1.5 s) which is too short for a symphony hall. Consequently, the volume of the later hall seems necessary to increase (for example, from 12 to 15 m³ per seat, or 30000 m³ for a capacity of 2000 seats) in order to compensate the strong absorption of the audience [2]. However, the oversized volume may provoke a weaker sound intensity for a middle size orchestra when play in this large hall. Therefore, it is necessary to adjust the shape of the ceiling towards “flatter” volcanic shape plus a suspended canopy as defined on the final design, and keep a reasonable volume such as 12 m³ per seat. Based on this analysis, the final design of the ceiling concert hall is as shown following.



2.1.2 Influence of the Canopy Height on C_{80}

The variation of the canopy height (between 9 m and 14 m above the stage level) may change around 1.0 dB the C_{80} within the zone covered by the first reflections of the canopy. It is quasi no evident influence for the audience beyond this zone. Inversely, when the canopy height is dropped to 9 m, the seats on the higher and rear part of the hall will loss the direct sound (they can see the back of canopy), so you cannot sell the tickets here for the events of Recital concerts.

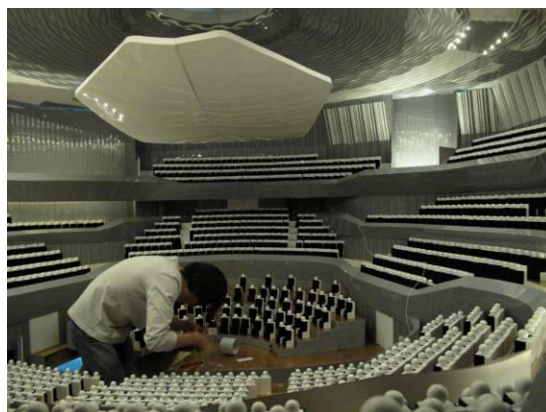
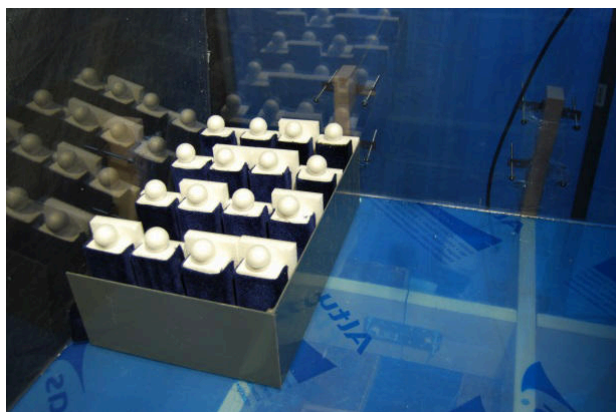


When you look at the average values from the “Mapping” of the acoustic simulation, the influence of the canopy height is less evident, for it is a matter of color scale. But, when you look at a single reception point - within the coverage zone of the canopy - at a certain distance from the source, then you can see that the variation of C_{80} becomes evident. Lower heights of canopy only improve the Clarity within the first reflections zone:

Canopy height	RT (500Hz)	EDT (500Hz)	C_{80} at certain distance
9 m above stage	2.04 s	1.83 s	2.0 dB (at 10m from the source)
14 m above stage	2.02 s	1.87 s	0.9 dB (at 10m from the source)

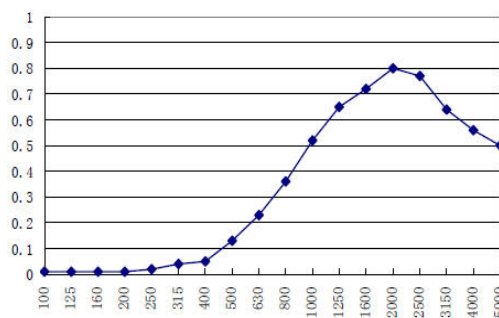
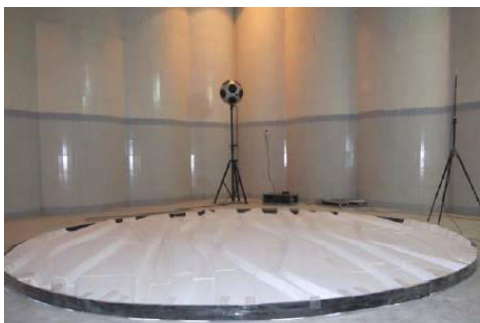
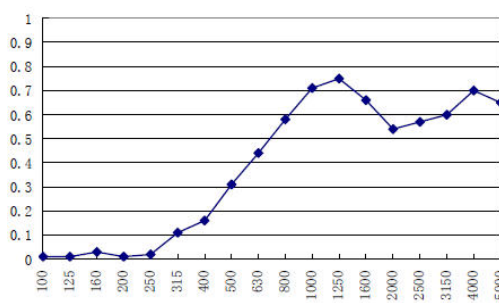
2.2 Acoustic Scale Model

A $1/10^{\text{th}}$ acoustic scale model has been made in order to predict the acoustics of the concert hall, and investigate more precisely the risks of echoes and others defaults. The relative humidity of the ambient air in the local of the model was controlled in order not to exceed 2% RH. A 2.0 s RT has been achieved, and the other criteria are much like the one simulated with the acoustic software. Another paper describes with more details the procedure of the acoustic tests in the scale model [3].



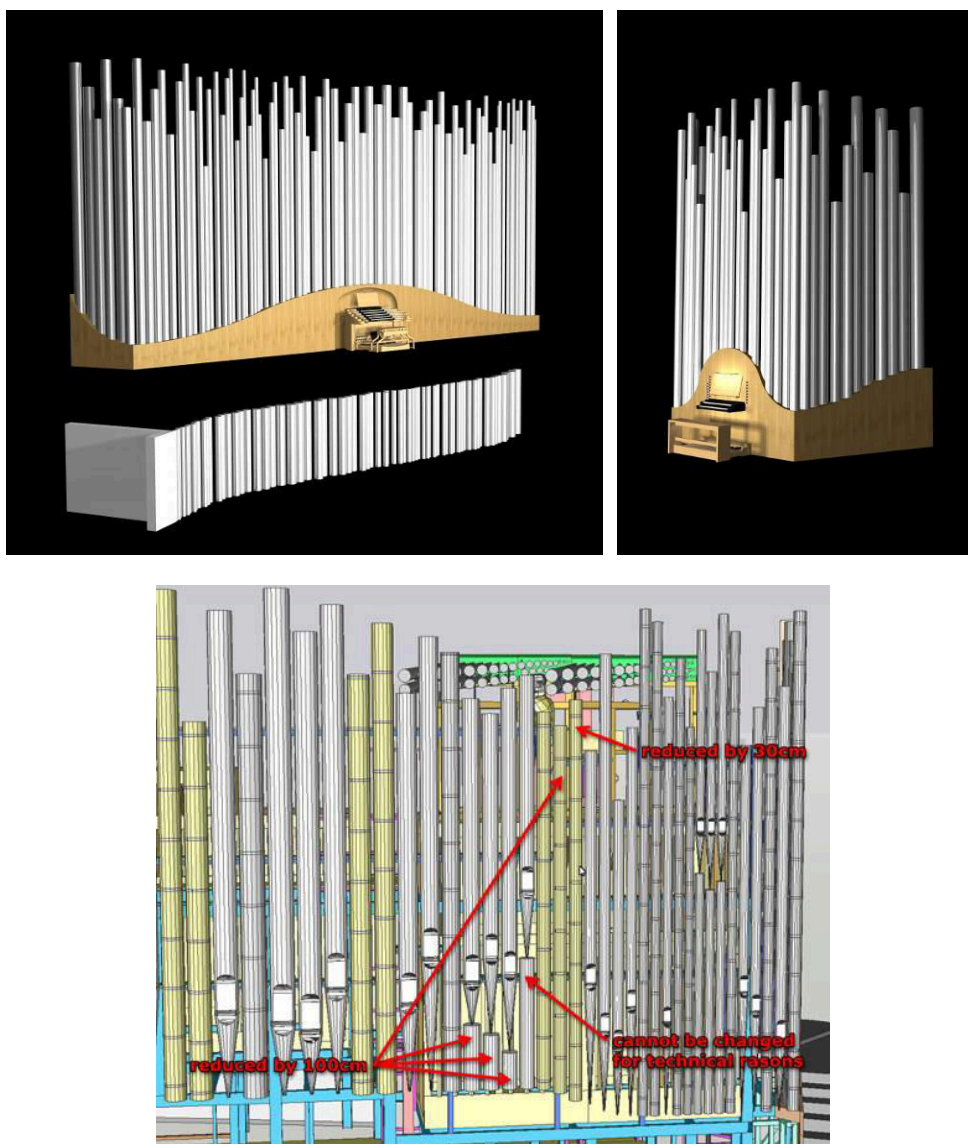
2.3 Test of the Scattering Coefficient

Most of the ceiling and walls of the concert hall have a finish of GRG panels ($> 60 \text{ kg/m}^2$), with a MLS relief shape (with a depth of 5 to 8 cm), so the sound scattering effects of these elements had to be tested according to the ISO 17497-1:2004, in a special reverb chamber. Two different shapes and depths of relief have been tested: a classic, straight MLS relief shape ($d=8 \text{ cm}$), and a more artistic shape, designed by architect Mecanoo, such as in the picture below ($d=5 \text{ cm}$). We can see on the results that the scattering characters of the two shapes are similar, but the peak value is a bit higher in the case of a smaller depth. Absorption coefficients of the samples have been tested too in order to check the very weak absorption at lower frequencies - which has been achieved. The results are shown below.

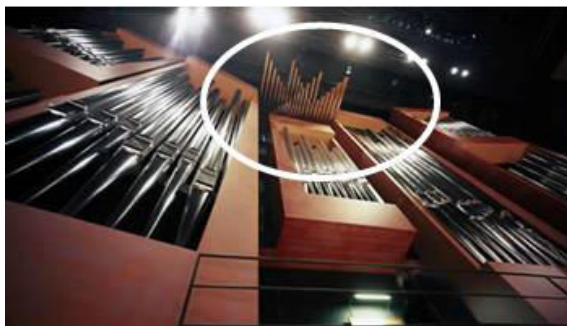


2.4 Acoustic Considerations for the Pipe Organs

The two pipe organs (Klais, Bonn Germany) in the concert hall are located on both sides behind the orchestra platform: the big one is Symphony style (figure below, left) and the smaller one is Baroque style (figure below, right). The total number of the pipes (speaking and non speaking pipes) is 8888, which is a lucky number in the Taiwanese traditions! Within these pipes, a part of them are pure decorative elements which form an image of “Bamboo forest”, but certain of those pipes were positioned in front of the Chamade, involving that the high frequency components of the Chamade would be attenuated and its brilliance becomes dark. So we worked with the organ builder in order to re-design the masking pipes and make the organ sounds better.

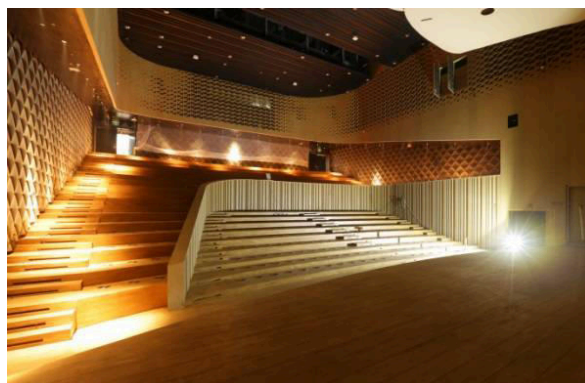


Another issue is the orientation (vertical tilted angle) of the horns of the Chamade. Learnt from the experience of the Chamade installed on the top of the organ of the **Luxembourg Philharmonic Hall**, when the orientation is horizontal, the high frequency sound is “flying” above the audience, especially the VIP on Stall level can’t hear the high frequency components. Therefore, a demand of modification of the angle of the Chamade towards the audience let the public able to percept the complete organ sound as shown on the figure following (right).



2.5 Site Measurements of Absorption Coefficients of Audience and Seats

During the acoustic simulation, one big question is the correct absorption coefficient of audience. Even the design team always asks the manufacturer to test the absorption coefficient of empty and occupied seats in reverb chamber (according to ISO or KK method), but nobody use these parameters in the calculation and simulation. The most applied coefficient is suggested by Dr. Beranek and tested in the real auditoria, even though it had been varied at different years (especially the α at 125Hz changed from 0,39 to 0,62 [4, 1]). In order to obtain and accumulate the data measured in the real halls, a series of RT measurement had been started from August 2015 (in Concert hall and Recital hall). The ideal condition of these measurements is to test in empty hall just before the installation of the seats, and when most internal finishing materials are completed. The comparison between the different RT values tested in “empty” hall and “occupied” hall, then the “useful” absorption coefficient of audience (seats) could be estimated.

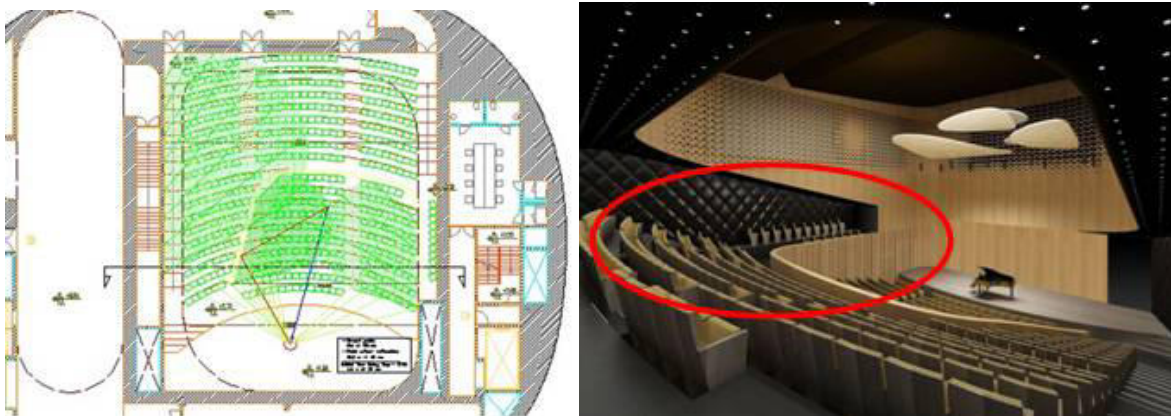


3 ACOUSTIC DESIGN OF THE ASYMMETRIC RECITAL HALL

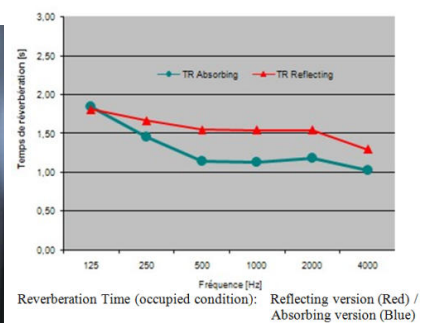
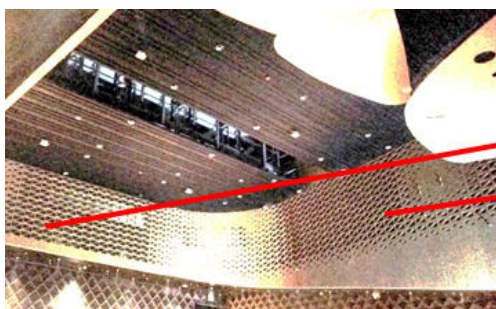
The 500 seats recital hall is an asymmetrical space. The original reason of this design is to allow more audience to see the movements of the hands of the pianist. The observation on the distribution of audience during the International Piano Festival in La Roque-d'Anthéron (France) shows a natural preference on the choice of the seats: during the first part of the piano recital, the audience was evenly distributed (symmetrically); but after the pause, many audience moves to the side (even with no seats, seated on the steps) where they can watch the action of the pianist's hands. By then, the $\sim 1/4$ of the total seats at the other side became empty, because the audience can only see the masked pianist (as shown on the figures below).



From the acoustic point of view, a symmetrical layout of seats in a Recital Hall is not an obligation. The best seats for a piano recital are located at the left side (towards the stage) and at the higher gallery, due to the above reason plus the directivity of the instruments. So, the final design is a compromise between the acoustic perception and aesthetics.

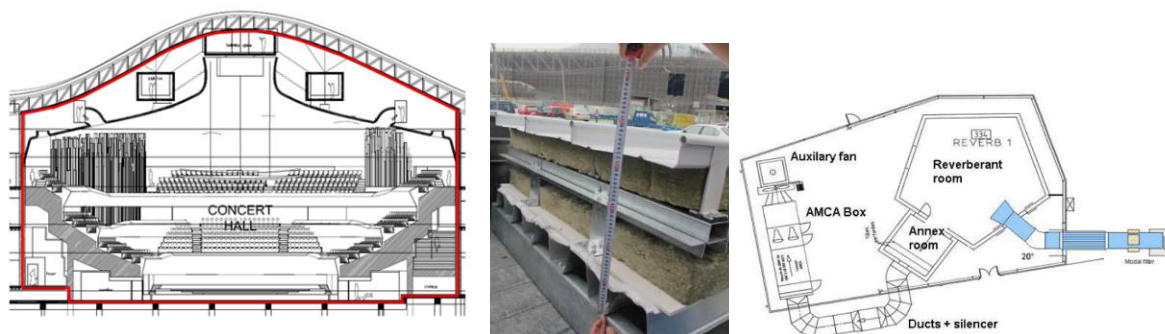


In this recital hall, the performing program is quite complete. It includes Chamber music, Recital, Jazz, etc. Therefore, the required RT is variable, and a variation of absorption is necessary. It is achieved with the changing of the surface of the velour curtains installed behind a sound transparent upper wall (perforation more than 60%). The calculated RT variation can vary from 1.2 to 1.5 s (500Hz).



4 ACOUSTIC SITUATION OF OTHER SPACES AND NOISE CONTROL IN THE BUILDING

The finishing work in Lyric Theatre, Playhouse and Orchestra Rehearsal Hall are not done yet, so the description and the site measurements will be presented in another document. The insulation of air borne and impact noise have been verified with laboratory tests. The following figures show the double isolation layer (metallic roof + RC roof); a sample of the external metallic roof; and a silencer tested in the CETIAT laboratory in France. The complete site control and tests will be done in the coming months.



The authors would like to present sincere thanks to the architects (MECANOO of Netherland and ARCHASIA of Taiwan) and to the collaborating engineering firms (Theateradvies of Netherland, Supertech, Yuntai and CK group of Taiwan). A special thanks to K. Cheng and C. Szu-Hao for their good assistance with the acoustics measurements.

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4. L. L. Beranek, "Audience and chair absorption in large halls", J. Acoust. Soc. Am., January 1969.