INTERNATIONAL SYMPOSIUM on MUSICAL and ROOM ACOUSTICS
ISMRA 2016
September 11-13, 2016
La Plata, Buenos Aires, Argentina

Simulation and Auralization of Concert Halls / Opera Houses: Paper ISMRA2016-40

The choice of architectural materials and its influence in the acoustical performance of an opera house

Roberta Smiderle[(a)], Alexandre Maiorino[(b)], Rafaella Estevão da Rocha[(c)]

[(a)] School of Civil Engineering, Architecture and Urban Design, Unicamp – University of Campinas, Brazil, ro.smiderle@gmail.com

[(b)] School of Civil Engineering, Architecture and Urban Design, Unicamp – University of Campinas, Brazil, alexmaiorino@hotmail.com

[(c)] School of Civil Engineering, Architecture and Urban Design, Unicamp – University of Campinas, Brazil, rafaellaestevao@yahoo.com.br

Abstract

Several cultural buildings have the start of its project conception ruled by other issues than those concerning its future use of space. Architects have to follow laws, finances, culture, society and other aspects before get in to the architectural features. In addition, most of the projects developed in Brazil, follow the aesthetical parameters rather than the necessities of the project. For an Opera House, it is mandatory that the project strictly follows the acoustical demands in order to achieve the adequate behavior for its use. In this research, the aim was to analyze the acoustical aspects influenced by the choice of specific acoustical materials and their positioning inside the building. Quantitative analysis was done through computational simulation in an Opera House still in project stage. The virtual simulation considered four situations: (I) Acoustical materials specified on the original project; (II) Changing the materials inside the stage house; (III) Changing the materials in the audience area; (IV) Acoustical materials changing in all the theatre. Analyzed parameters were Reverberation Time, Early Decay Time, Clarity, Definition and Sound Strength, and compared to the literature. The results demonstrated that although the analyzed theater is considered as a project for an Opera House, it does not pursue the ideal criteria according to the directives found in the literature. The theatre does not have an appropriate acoustical performance, nor the stage or the orchestra pit follow proper architectural parameters. Changing in the material along the experiment improved the acoustical performance of the project.

Keywords: acoustical performance, opera theatre, computer simulation

INTERNATIONAL SYMPOSIUM on MUSICAL and ROOM ACOUSTICS
ISMRA 2016
September 11-13, 2016
La Plata, Buenos Aires, Argentina

The choice of architectural materials and its influence in the acoustical performance of an opera house

1 Introduction

Architectural conception's rules for cultural buildings depends on several factors not only those regarding program and necessities. In the moment when the architect starts his production, laws, finances, environmental and geographical conditions, restrict his choices. Architectural concept is this guidance for creative conception of architectural projects [1].

The formal architectural concept based on the final shape is usually more attractive than considering the necessities of the building. The speech of the shape as the architectural concept takes place since 18th century, when the École Beaux-Arts decided to split Architecture and Polytechnics [2], until nowadays, when expressivity guides the architectural perception of the space as a poetry not only as the building itself [3].

The shape importance being stronger than the necessities aspects fates the project to misinterpretations of its needs. Different projects have different needs regarding their complexity. Some projects are extremely complex and peculiars to build only as a formal expression.

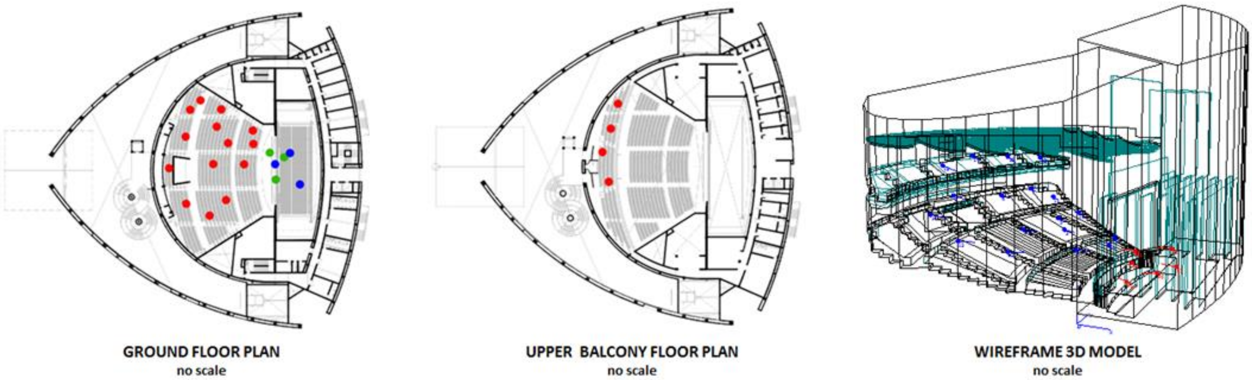
For an Opera Theatre, the important issues to consider are acoustical behavior and spatial needs to host all staff related to an opera production. It is mandatory that the architectural concept must follow such aspects in order to achieve the real purposes for its use.

Creative process for acoustical buildings requires specific knowledge to attend an elementary cycle of development. First, it is important the comprehension of room acoustics' theory. With this knowledge, specific decisions in project aiming join all particularities conduce the preliminary studies concerning quantitative and qualitative behavior for the acoustical project. Nowadays virtual tools are in charge of specific verifications. The next steps come regarding the response of these simulations. It can evaluate the shape, materials and its blend.

When such steps are not followed, there is a huge risk that the building will fail its primary intention. From a previous study [4], it was possible to analyze the problems of the Campinas opera house in Brazil, from quantitative and qualitative aspects. Now, this study aims analyze acoustical interactions resulted by from choices of acoustical materials used in its project. The Semperoper in Dresden will be a comparison venue, hence literature shows that this opera house achieves great values for the acoustic parameters analyzed and it is similar in volume and number of seat with the object of study [5]. Understanding the necessities for an opera house, the relation among infrastructure developed in the project and the chosen materials, the obtained results show how this interaction can happen and how alterations on choice of materials and its positioning can influence the acoustical performance of the building.

2 Methodology

In order to understand the influence of the materials in the performance of an opera house, it was chosen the same object of study as the authors' previous paper published at ENCAC 2015 [4]. The Campinas Opera House is still a project, which public bidding was suspended due to problems at the prospected total cost of the construction. A new public bidding so far is still pending, so the theatre was not constructed. However, the executive architectural and acoustic projects were available for download at the City hall's webpage for anyone interested in the public bidding. From this project it was possible to create a computer model to perform an acoustic simulation. Simulation was done with Odeon room acoustic software version 13. The opera house is a fan shaped theatre with a volume of approximately 11,500 m^3 and 1,230 seats. In order to perform the simulations, 6 sound sources, being 3 sound sources at stage and 3 sound sources at the orchestra pit, were placed along with 18 reception points. Parameters analyzed were reverberation time (RT), early decay time (EDT), clarity of speech (C_{50}), clarity of music (C_{80}) and sound strength (G). All parameters except sound strength (G) were analyzed over frequency in octave bands and averaged in mid frequencies (500 Hz and 1000 Hz). Sound Strength (G) was calculated as an average of 500 Hz and 1000 Hz octave bands. Results for speech clarity index (C_{50}) was calculated only for sound sources in the stage, which would represent the opera singers. Results for music clarity index (C_{80}) were calculated only for sound sources at the orchestra pit, thus taking into account the orchestra. Sound sources and receiver points can be seen at Figure 1.

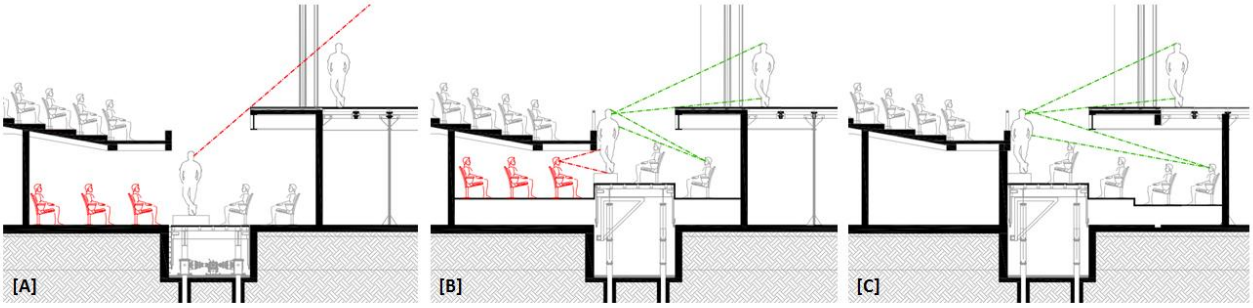


Source: the authors.

Figure 1: Receiver points (red), sound sources at stage (blue) and sound sources at the orchestra pit (green).

2.1 The orchestra pit

In our previous research [4], the orchestra pit was analyzed from a qualitative point of view and it was found to be small, only with 75 m^2. This time, in order to model the theatre with the orchestra pit, it was again realized that the original project predicted a highly unusual feature, which was not fully discussed in the previous paper: more than half of the designed orchestra pit was actually under the audience stalls. That project approach came as a surprise, and although an effort was made to try to understand this unique point of view, the orchestra pit under the stalls is simply impractical. First, this is not an open pit, but a partially covered pit. Therefore, some considerations must be taken. Usually, the pit elevator must not be set all way down, because the conductor must see the orchestra and the singers on stage (Figure 2A). That is probably the situation proposed in the original project, but in this situation the conductor does not have a visual contact with the singers on stage. Hence, it is very common to raise the conductor up to a visual point to the stage and to set stage risers in different heights decreasing the height of the orchestra as they go to the back of the pit. This is done so all musicians can have a clear vision of the conductor's head and arms (Figure 2B). In this situation, it would make it impossible for musicians seating behind the conductor to see his signs. Figure 2C illustrates a proposition by the authors to fix the orchestra pit.



Source: the authors.

Figure 2: (a) original orchestra pit; (b) original orchestra pit adapted; (c) proposed orchestra pit.

A wall must be placed according to the shape of the pit elevator behind the conductor. The back wall of the pit should be moved 2 m towards the stage, diminishing the area where the stage is fully suspended. That way, the new pit would have an area of almost 100 m^2, suitable for an orchestra of around 60 to 70 musicians, much more appropriated for a large number of operas. For that reason, all simulations were done, assuming that the orchestra pit is according to the new proposition (Figure 2C).

2.2 Simulations

Previous research [4] found that this opera house does not have a good acoustic performance for opera when simulated acoustic parameters are compared to literature recommendation. The main reason is that there are too many surfaces with highly absorbent materials. Therefore, simulations were done gradually substituting absorbent materials in specific areas of the theatre by reflective or diffuse ones. In order to understand the influence of such materials at the acoustic performance of the theatre, 5 simulations were performed which will be called SETs 1 to 5. SET 1 is the simulation of the theatre with the materials assigned at the original acoustic project, which was also simulated at [4]. Every following simulation will return the original materials of SET 1 and only the specified area will be replaced with a new material. Hence, SET 2 changes the material at the orchestra pit, SET 3 changes materials at the stage house and SET 4 changes materials at the audience area. SET 5 replaces the original materials from SET 1 by materials from all other sets. It also changes the audience seat by a more absorbent one, with an absorption coefficient of the empty chair closer to an occupied situation.

2.3 Materials assigned

Table 1 shows a summary of all materials used. It was also placed on stage, house props pertinent to an opera house such as main velvet curtains, stage curtains, wood scenarios, cyclorama and proscenium arch vertical and horizontal regulators in order to simulate a real situation. The colors represented in the material description at Table 1 are set to facilitate the visualization of which material has been replaced by another one. Materials with no color were not replaced in any of the Sets.

Table 1: Assigned materials for simulations.

SET 1	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Perforated drywall - entrance and balcony ceiling	0.67	0.92	0.75	0.84	0.62	0.73
Stage floor	0.19	0.14	0.09	0.06	0.06	0.05
Double glass windows - Technical booth	0.1	0.07	0.05	0.03	0.02	0.02
Curtains at stage	0.03	0.12	0.15	0.27	0.37	0.42
Main Curtain	0.3	0.45	0.65	0.56	0.59	0.71
Proscenium arch regulators	0.13	0.06	0.09	0.23	0.48	0.72
Cyclorama	0.03	0.04	0.11	0.17	0.24	0.35
Canopy - hard wood	0.1	0.01	0.01	0.03	0.06	0.08
Canopy - back panel - mineral wool	0.16	0.52	0.82	0.92	0.96	0.96
Stage House - Fibracitex 25 mm	0.05	0.25	0.5	1	0.73	0.8
Perforated Panel - Lateral wall and orchestra pit	0.28	0.96	1,00	0.94	0.77	0.65
Wood Panel - Lateral wall	0.2	0.09	0.07	0.1	0.15	0.21
Wall behind canopy - Fibracitex 35 mm	0.08	0.14	0.29	0.93	0.6	0.75
Perforated Panel - back wall	0.26	1	1	1	0.87	0.79
Medium upholstered seats	0.19	0.37	0.41	0.45	0.42	0.42
SET 2						
QRD on orchestra pit walls	0.22	0.26	0.32	0.23	0.19	0.20
SET 3						
Stage House - brick wall (except ceilling)	0.01	0.01	0.01	0.02	0.02	0.02
SET 4						
Wood Panel - Lateral wall	0.2	0.09	0.07	0.1	0.15	0.21
QRD on back walls	0.22	0.26	0.32	0.23	0.19	0.20
Wall behind canopy (except ceiling)	0.01	0.01	0.01	0.02	0.02	0.02
SET 5						
High upholstered seats	0.31	0.64	0.73	0.70	0.58	0.60

On the simulation of SET 2, the perforated panels at the orchestra pit were replaced by QRD panels, which propitiate diffusion. Literature points a preference of musicians to play near surfaces that propitiate diffusion [6].

For SET 3, a brick wall replaced all vertical walls of the stage house, which were covered by a panel made of vegetable fibers and cement.

SET 4 was actually performed in different simulations, but due to space issues it will be presented the simulation where three materials were replaced. Regular non-perforated wood panel replaced the lateral perforated panels. The part of the vertical walls behind the canopy ceiling, which initially were coated with Fibracitex 35 mm, is now brick walls. And the curved back of the theatre, which originally had wood perforated panels, now were covered with wood QRD diffusers.

On SET 5, the last one, all materials from SETs 1 to 4 replaced the original materials. Seats were also changed to a heavy upholstered one in order to better simulate the situation where seats are occupied.

3 Results and Discussion

The average results between the octave bands of 500 Hz and 1000 Hz for all simulated Sets can be seen at Table 2.

Table 2: Averaged results of acoustic parameters.

	EDT(s)	TR(s)	G(dB)	C80(dB)*	C50(dB)**
SET 1	1.2	1.1	-1.7	2.5	4.1
SET 2	1.3	1.1	-0.7	-0.1	3.9
SET 3	1.4	1.5	-1.4	2.3	3
SET 4	2	1.8	0	-0.1	0.3
SET 5	1.7	1.5	-0.7	-0.2	2.2

*Log average at orchestra pit only

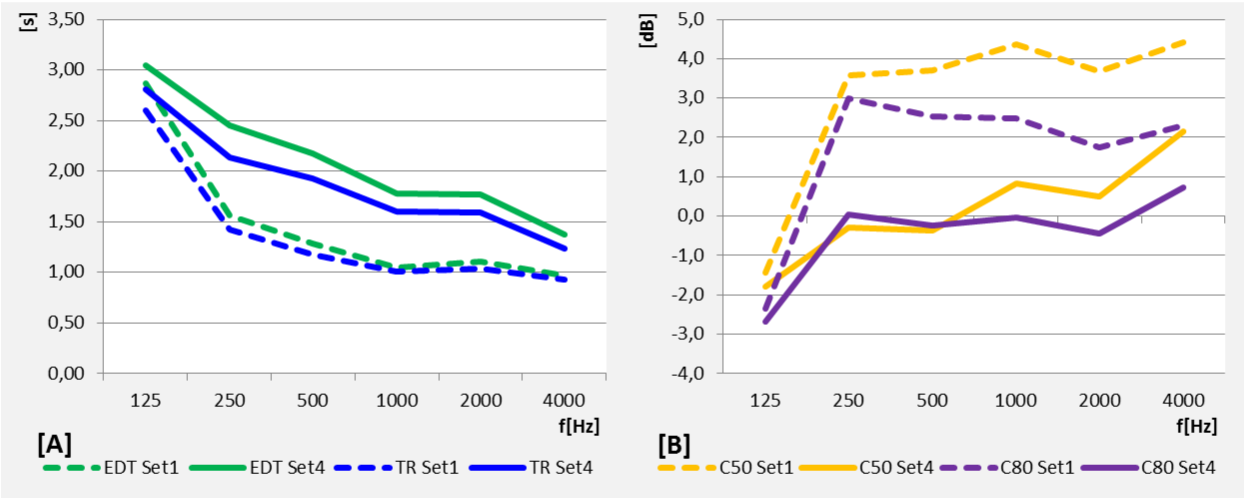
**Log average of stage only

Comparing results for Sets 1 and 2, the change for QRD as the surface for the orchestra pit had a strong impact on C_{80}, reducing it from 2.5 dB to -0.1 dB. This change improved orchestra balance and the sensation of group. It also contributed to increase in 1 dB the overall sound strength (G).

Comparing results for SETs 1 and 3 showed that making the walls of the stage box reflective increased the overall RT and EDT of the hall. Although C_{50} was reduced in 1 dB, the values are still excellent. This change probably was beneficial for the singers since studies show their preference for more reverberation when performing [7]. Also, sound strength (G) had a slight increase, probably benefitted by the reflections provided by the live stage box.

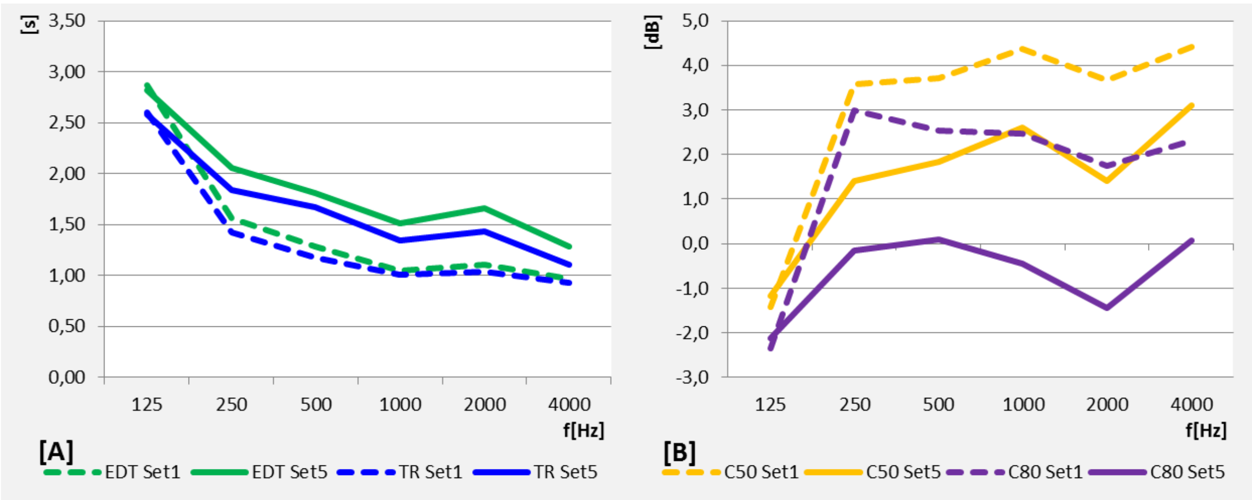
Comparison between SETs 1 and 4 shows that changing the materials at the audience area allowed the greatest change in the overall acoustic performance of the theatre. Graphics (a) and (b) of Figure 3 show the comparison of results of SETs 1 and 4.

There is an increase in RT and EDT to values closer to recommendations of the literature [8]. Values of C_{80} decreased, improving the sensation of group, and values of C_{50} are still positive, within the recommended ranged. Sound Strength (G) also had a 1.7 dB increase. That shows that sound strength is very sensitive to absorption and in order to decrease reverberation time without compromising G, it would be feasible to decrease volume instead of increase absorption as done for example in [9]. The values of SET 4 are very close to the ones found at the Semperoper in Dresden in an unoccupied situation. However, when occupied, RT in Dresden is around 1.6 s. This is also the average recommendation of the literature for opera houses [8]. As stated in [4], seats suitable for the price range stipulated at the public bidding are medium upholstered seats. The problem with this kind of choice is that the acoustic performance of the theatre will vary according to the number of people attending a performance. In order to overcome this, highly upholstered seats are recommended.



Source: the authors.

Figure 3: Comparison of results for Sets 1 and 4: (A) EDT and RT, (B) C_{80} and C_{50}.



Source: the authors.

Figure 4: Comparison of results for Sets 1 and 5: (A) EDT and RT, (B) C_{80} and C_{50}.

For this reason, simulation of SET 5 took that into consideration. Besides changing the original materials for the simulated materials of SETs 2 to 4, a highly upholstered seat was also included. Results of the simulation of SET 5 can be seen on Graphic (a) and (b) of Figure 4.

Graphic (a) of Figure 4 shows an increase of RT and EDT on SET 5, with EDT a little higher then RT, which would, in theory, increase the sensation of reverberance in the room, benefitting musical performances. Graphic (b) of Figure 4 shows a great decrease of C_{80} of more than 2 dB. However, the new values are within the preference range proposed by the literature [7]. Actually, it is in a more appropriate range, improving the sensation of group. C_{50} also had a decrease of approximately 2 dB, but values are still in a positive range, good for speech and vocal clarity.

Sound Strength (G) had a small decreased in SET 5 when compared to SET 4, but it is still 1 dB higher than SET 1. These results show again that G is sensitive to absorption. In order to increase the sound strength, other approaches such as done in [10] should be used.

4 Conclusions

A computer simulation of an opera house was made in order to improve its acoustic performance. Original absorbent materials were replaced with reflective and diffuse ones in different areas of the theatre. Results showed that changing absorbent materials improved the overall acoustic performance of the room. Average results of RT and EDT reached values close to Semperoper in Dresden with 1.7 s for EDT and 1.5 s for RT, improving the sensation of reverberance. Clarity of speech (C_{50}) is in a positive range, over 0 dB, with an average result of 2.2 dB indicating good clarity. Clarity of music (C_{80}) decreased from the original value of 4.1 dB to -0.2 dB, which is still in the range of preference according to literature, improving the sensation of group in the audience. Sound strength (G) improved but it is still a parameter very sensitive to absorption. There was an increase of 1 dB in its overall result with the proposed changes, but it still needs some attention. The probable solution is to add reflective panels, which would promote early reflections to some parts of the audience, improving sound strength.

Acknowledgments

We would like to thanks to the Laboratory of Applied Physics and Environmental Comfort of Unicamp for gently allow the use of Odeon.

References

[1] Silva, E. *Uma introdução ao projeto arquitetônico*. 2 ed. Porto Alegre: UFRGS, 2006.

[2] Barroso-Krause, C. Ciência e concepção arquitetônica: reintegrando tecnologia e arquitetura. In: Vicente Del Rio. (Org.). *Arquitetura: Pesquisa & Projeto*. 1ed. São Paulo: Editora Pro-Editores, 1998.

[3] Ferraro, S. W.; Ortega, A. R.; Ferraro, N. A Lógica Poética do Croqui no Processo de Ensino do Projeto Arquitetônico. In: *IV Seminário Nacional Sobre Ensino e Pesquisa em Projeto de Arquitetura - PROJETAR 2009*, São Paulo. Proceedings. São Paulo: [s.n.], 2009.

[4] Smiderle, R.; Rocha, R.; Maiorino, A. Teoria x prática: análise da acústica arquitetônica de um teatro de opera. *Proceedings of the XIII Encontro Nacional e IX Encontro Latino-americano de Conforto no Ambiente Construído*, Campinas, Brazil, October 15-17, 2015.

[5] Beranek, L. *Concert Halls and Opera Houses: Music, Acoustics, and Architecture*. Springer, NY (USA), 2nd edition, 2004.

[6] Cox, T.; D'Antonio, P. *Acoustic Absorbers and Diffusers: Theory, Design and Application*, Taylor & Francis, New York (USA), 2nd edition, 2009.

[7] Barron, M. *Auditorium Acoustics and Architectural Design*, Spon Press, Oxfordshire (U.K.), 2nd edition, 2003.

[8] Hidaka, T.; BERANEK, L. Objective and subjective evaluations of twenty-three opera houses in Europe, Japan, and the Americas. *The Journal of the acoustical Society of America*, vol 107 (1), 2000, pp 368-383

[9] Luykx, M.; Metkemeijer, R.; Vercammen, M. Variable acoustics of theatre De Spiegel in Zwolle (NL). *Proceedings of the International Symposium on Room Acoustics, ISRA 2007*, Sevilla, Spain, September 10-12, 2007

[10] Kim, J.; Seo, C.; Yoo, H.; Jeon, J. The effect of reflectors on Sound strength (G) and IACC in a fan-shape hall. *Proceedings of the International Symposium on Room Acoustics, ISRA 2010*, Melbourne, Australia, August 27-31, 2010