Acoustic Comfort Evaluation Based on Architectural Aspects in Atria

Majid Lavasani[1], Yannick Sluyts[2], Daniel Urbán[3], Monika Rychtarikova[4]

[1] Faculty of Architecture, KU Leuven, Leuven, Belgium.
MajidLavasani@Live.com
[2] Faculty of Architecture, KU Leuven, Leuven, Belgium.
Yannick.Sluyts@kuleuven.be
[3] Department of Materials Engineering and Physics, Faculty of Civil Engineering, Slovak University of Technology, Radlinského 11, 810 05 Bratislava, Slovakia.
[4] Faculty of Architecture, KU Leuven, Leuven, Belgium.
monika.rychtarikova@kuleuven.be

Abstract

In this paper, the acoustic quality of long multi-level atria covered with transparent materials is assessed. A parametric simulation study was carried out with a diversity of variables such as the shape of the roof, the presence of balconies, the outline of the plan, and the skylight material, which in the latter, the effect of ETFE cushions on the room acoustics is evaluated. In total 124 halls were compared in terms of different room acoustic parameters (EDT, T_{15}, T_{30}, D_{50}). The parameters were simulated with the Odeon software and the relationship between the variants and the acoustic parameters was analyzed and compared. General recommendations for better room acoustic properties of these spaces were extracted from this comparison. Finally, the observed influential factors were applied to an existing project (Lloyd passage, Bremen) to test their effectiveness.

Keywords: atria, architecture, room acoustics, reverberation time

1 Introduction

Architecture is a multidisciplinary practice that involves many factors in the project. Involving different participants in the project as soon as possible reduces the risk of a false decision in the early stage of the project and leads to the reduction of the cost and the time of the project and improve the final quality. In many cases, acoustical engineers are not involved in the architectural practices until the end of the project or only if a problem occurs, this is mainly true for spaces that are not designed specifically for music or speech. In public buildings like large corridors, shopping malls, plazas, swimming pools, etc. there is little information for architects to deal with the acoustic comfort of their design while this factor plays an important role in human wellbeing [1] [2]. Acousticians often have to apply acoustic remediation solutions to create a better sonic environment which potentially ruins the design value and increases the project cost.

1.1 Previous Research

A few studies have been conducted on the relation between architecture and sound in atria. Mei and Kang[3] have studied the effect of source-receiver distance on sound pressure level and reverberation time in multi-level large atria. Iannace et al.[4] represent the acoustic deficiency of large atriums in shopping malls in order to be used as a public music hall. Zhao et al.[5] demonstrated the Effects of geometry on the sound field in atria. Wang et al[6] represented that the total energy's exponential decrease in extra-large spaces is not only because of the direct sound, but also the reverberant energy. Additionally, to show the effect of balconies, Samodra F X T B [7] proposes an optimized location of electroacoustic loudspeakers for the interior mezzanines by simulating the balconies and sound field of vertical buildings. Furthermore, Nowicka[8] proposed a method for rapid acoustical assessment of the commercial spaces and buildings based on volume, shape, sound-absorbing objects, and sound-scattering architectural elements.
To present the advantages of the ETFE in acoustic comfort, Urbán et al.[9] investigated the acoustic conditions of three large atria covered by glass and foil in Bratislava. Rychtáriková et al.[10] compared acoustic conditions in an atrium covered by ETFE with a digital simulation in which the roof is realized by the glass. They concluded, Compared to glass or a hard surface such as concrete, a clear reduction in reverberation time is achieved in the middle and low frequencies in cases with ETFE systems. In another research by Rychtáriková et al.[11], they analyzed the impact of typical glass and ETFE cushion systems on sound reverberation and on noise levels when covering wide shopping streets by performing simulation on software Odeon.

1.2 Methodology

The method in this work was based on comparing the room acoustics parameters of the hall with the aid of parametric design, simulation, and conventional formulas. The first step was to produce a deliberated range of architectural halls including some geometrical variables, formal variables, and interior elements. The modeling process was carried out with the aid of parametric design that facilitates the production process and therefore the total number of simulations was increased which led to more reliable results.
The next step was performing the room acoustic simulation, each option was simulated separately. The simulations were performed in the Odeon room acoustics software version 16. Odeon is a Room Acoustic Software that uses the image-source method combined with a modified ray tracing algorithm for simulating the room acoustics of buildings.[12]
After that, the effect of each architectural element on the acoustic field was investigated with the help of statistics and charts. These charts were based on the architecture variables, certain acoustic parameters, e.g., T_{30}, T_{15}, EDT, D_{50}, etc, and at different frequencies. Then each chart was investigated individually and in comparison with other charts. Finally, as a conclusion, these explorations were applied and examined in an existing case study.

1.3 Configuration

In the first series of alternatives, the variables were the length, width, and height of the hall. Three different lengths of 30 meters, 60 meters, and 90 meters combined with two different widths of 8 meters and 16 meters, and then two different heights -3 level hall and 5 level hall which each level had 5 meters height-were added to these variables. Furthermore, for the material of the transparent roof two materials were used and compared: The conventional material versus ETFE cushions. Additionally, two different forms of the roof -arched versus inclined- were compared in every mentioned models. In total 124 models were compared in terms of four different room acoustic parameters (EDT, T_{15}, T_{30}, D_{50}) that some of the results are presented in this paper.

1.4 Materials

To simulate and compare the results, the same materials were applied to all the halls. The only variable material is the transparent roof which in this case was a glass roof (double glazing glass 2-3mm glass-10mm gap) compared to ETFE cushions. The case study presented in this paper was the Mediacité shopping mall in Liege so the absorption coefficient value(α) for the ETFE cushions and average of the α value for a storefront in the atria is based on in situ research and simulation validation by Yannick Sluyts (2020). *Figure* 1 shows the comparison of α values between mentioned materials at all frequencies.

In the previous studies, acoustic comfort in large atria is studied based on the fact that the floor is covered by hard and polished materials that are acoustically reflective [3] [5] [9], while in practice, the presence of people has a significant influence on the absorption coefficient(α (-)) value of the floor. In this study, the atria considered as a fully crowded space to investigate the opposite viewpoint. Therefore, the floor was simulated as ceramic tiles with the presence of many people standing [13] which is visible in *Table 1*. furthermore, in this paper the focus is on low to middle frequencies, therefore the high frequencies values are omitted in this table.

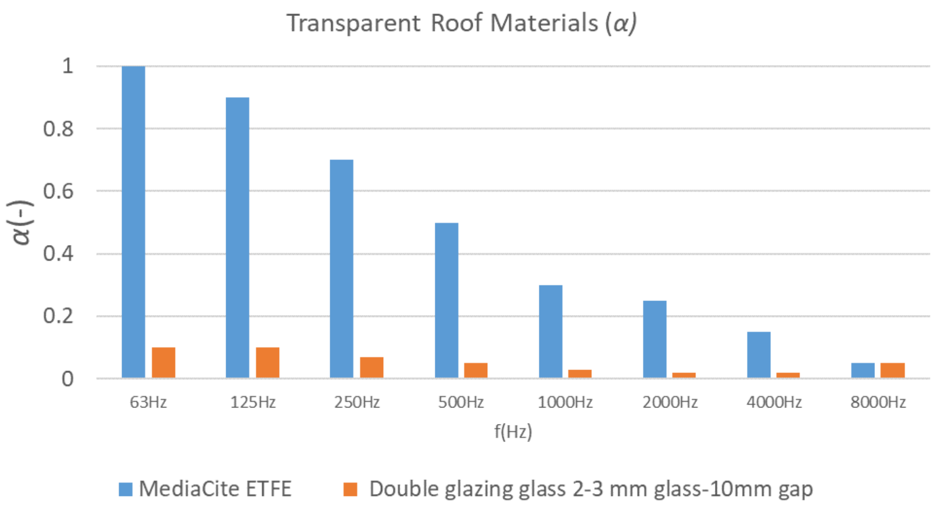

Figure 1 – Sound Absorption Coefficient ($\boldsymbol{\alpha}$(-)) of the ETFE and glass

Table 1 – Sound Absorption Coefficient (α (-)) of all materials

Material	**α(-)**	
f(Hz)	**250**	**1000**
MediaCite Storefront	0.07	0.07
MediaCite ETFE	0.7	0.3
Double glazing glass 2-3 mm glass-10mm gap	0.07	0.03
Artificial 5% absorptive	0.05	0.05
Ceramic tiles with the presence of people	0.44	0.79
Plaster	0.1	0.04

2 Results

2.1 Material comparison

The acoustics in halls covered by ETFE is different in low, mid, and high frequencies. *Figure 2* compares T_{30} between atria covered by ETFE with the similar atria covered by glass panels at 250Hz. In general, it shows at 250Hz, the average T_{30} of all 7 receivers is shorter in the atria covered by ETFE than the ones covered by glass. This figure also illustrates at this frequency the standard deviations are less in the models covered by the glass than the models covered by ETFE. Therefore, we might have a more homogenous sound field at low frequencies in the halls covered by the glass than in the halls covered by ETFE. There is no significant difference in reverberation time between the skylights made of ETFE and glass at the middle to high frequencies.
Similarly, comparing D_{50} shows that changing the material of the skylight from glass to ETFE often improves the clarity of the atrium at low frequencies, especially in wide halls without a balcony.

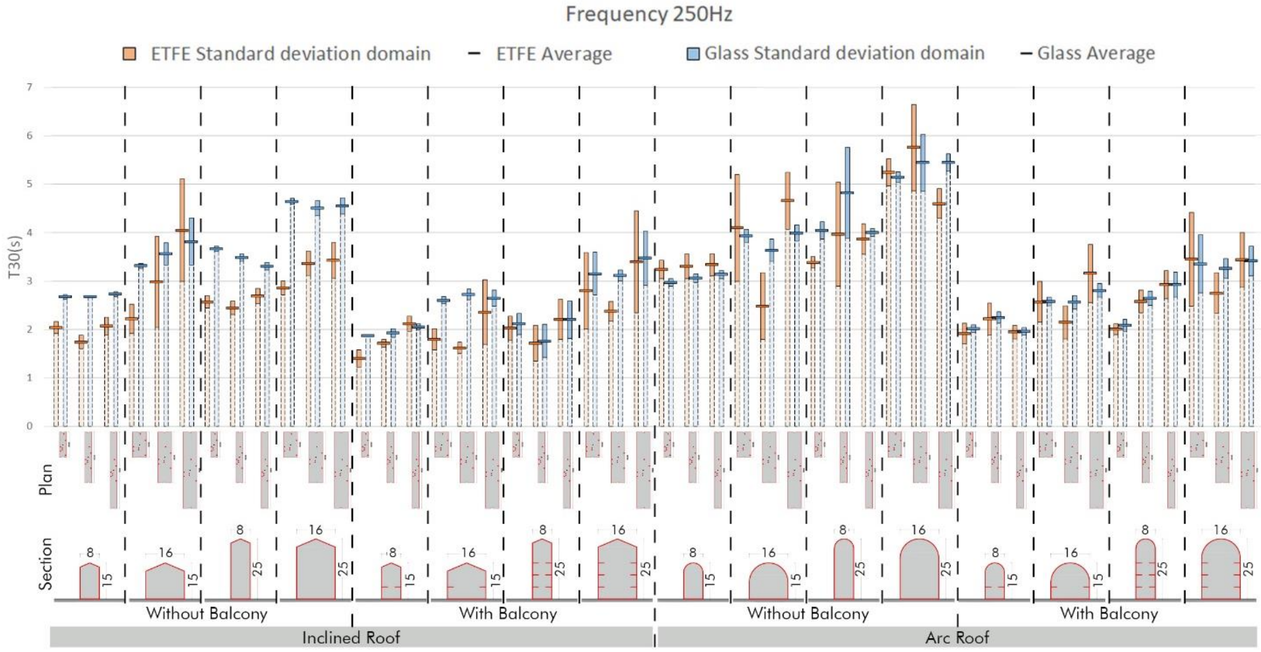

Figure 2 – Material Comparison T_{30} (250Hz)

2.1 Geometry Comparison

Figure 3 presents the length comparison of the T_{30} parameter between all the 48 models with ETFE at 1000Hz. The figure shows longer reverberation time in the models with 90 meters length but in general, there is no notable relationship between the T_{30} and the length of the atria since in long atria, by increasing the length of the hall, the ratio between the volume of the geometry and the area of surfaces remains almost intact.

In a long hall, the reflections from the end walls come back to the receivers much later than the reflections from the closer storefronts. Therefore, by increasing the length of the atria, the percentage of the early to late wave ratio grows which often leads to an increase in D_{50} value as is shown in *Figure 3*.

Results also show typically the increment in width of atria leads to longer reverberation time and less clarity. In general, results demonstrate if architects want to design wide atria, they should simultaneously add more surfaces or more absorptive materials to their design. For instance, we can see in the models with the presence of balconies, the increase of T_{30} is less high.

Results also indicate in general that by increasing the height from 15 meters to 25 meters, the T_{30} and *EDT* rise accordingly. Therefore, we might presume that we would have much better clarity in the options with less height, especially in the models without the presence of balconies. However, the D_{50} value is just slightly higher in tall halls. In the other words, although the increasing of the height often significantly increases *EDT* value. The height reduction does not contribute significantly to the improvement of clarity based on configurations of this study.

Figure 3 – Length comparison for T_{30} and D_{50} at 1000Hz

2.2 Shape of Skylight

Zhao et al. [5] examined the effect of skylight form on T_{30} by performing a simulation for different ceiling forms including flat, single pitched, double-pitched, and arched. They concluded the reverberation time is highest in flat roofs and lowest in pitched roofs either single pitched or double pitched. Looking at *Figure 4* illustrates that generally at medium frequencies, the results correspond to the Zhao et al.[5] studies and shows inclined roofs have shorter T_{30} while the results show no noticeable relationship between the shape of skylight and clarity,

2.3 Presence of Balconies

Figure 4 illustrates at the frequency of 1000Hz, the presence of balconies in the atrium usually leads to shorter T_{30}. Results at 250Hz also show the same thing but the value of reduction is often more intense at low frequencies. Furthermore, results illustrate the presence of balconies sometimes increases the D_{50} for more than 10 percent from 50-55% to more than 65% which significantly improves the speech intelligibility of place to be more understandable.

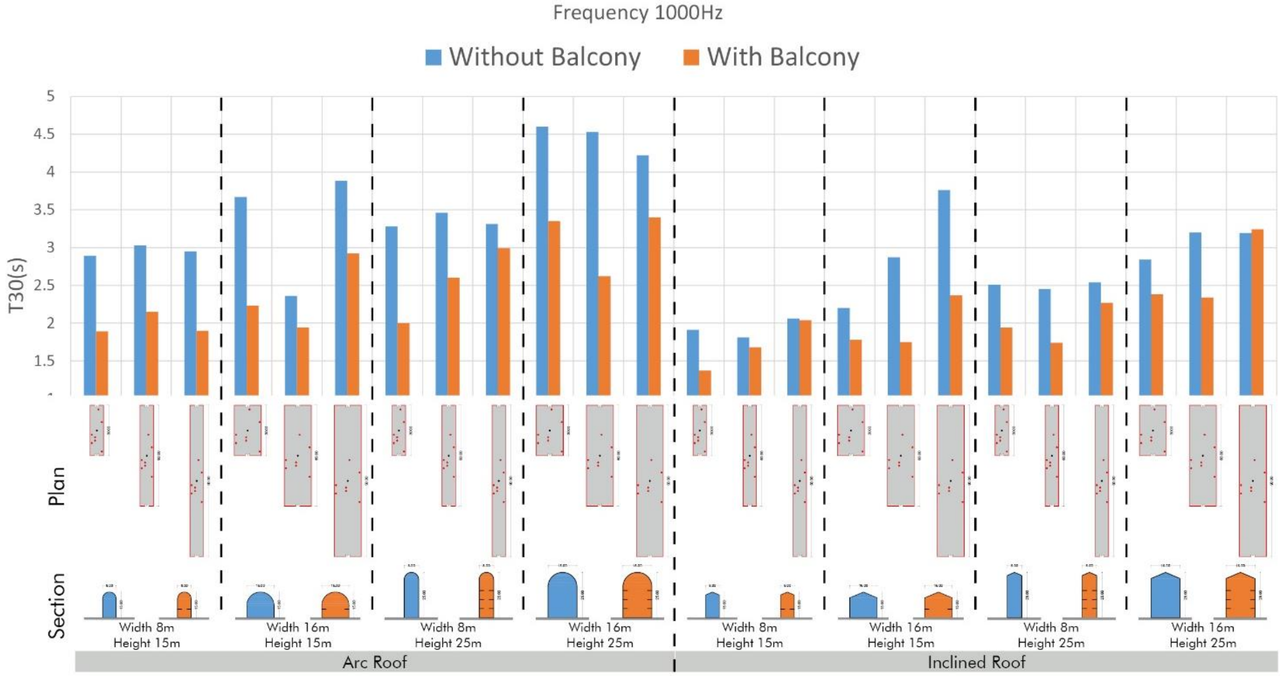

Figure 4 – Effect of Balconies in T_{30} at 1000Hz

In general, the presence of balconies has a positive effect on the sound acoustic parameters in the multi-levels atria. *Figure 5* visually compares the *Lp* in the section between the models with balcony and without balcony at 1000Hz. It shows balconies acting like "acoustic baffles" but in a vertical direction. However, the effect on the upper levels is not in the scope of this research and needs more investigation.

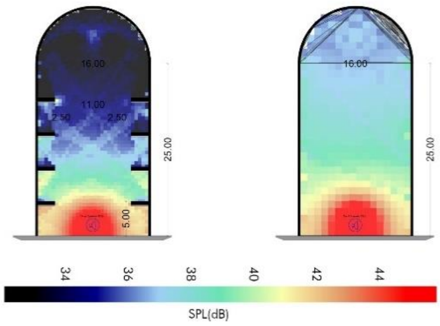

Figure 5 – Section of Sound Pressure level(*SPL*) comparison at 1000Hz

2.4 Case Study: Lloyd Passage, Bremen, Germany

As a real-world case study, we modeled Lloyd Passage in Bremen that matches our data set very well to demonstrate how design choices affect acoustic comfort drastically. The original roof was made out of glass and metal frames. In this study, we only modeled the first 90 meters of the western part of the hall which includes the widest part of the corridor and the octagon dome that is the highest point of the project.

The optimization was started from the most effective adjustments, therefore in the first step, the material of the skylight was changed from glass to ETFE. Additionally, balconies can notably improve the acoustic quality of the ground floor, in the second optimization, some balconies were added because most of the receivers that are impacted by the acoustic quality of this walking street are on ground level.

Figure 6 shows the comparison between T30between the passage in the current situation with the glass skylight and with these optimizations. It shows the reverberation time reduces significantly when we change the glass roof to ETFE especially at low frequencies. It also illustrates the second optimization (adding balconies) significantly reduces the reverberation time. Both the first and second optimization improves clarity and speech intelligibility. The influence of changing the glass to ETFE is more significant at low frequencies while at middle to high frequencies, the effect of balconies is more pronounced and can increase the D_{50} value by more than 10 percent which indicates that speech intelligibility is positively affected by this intervention.

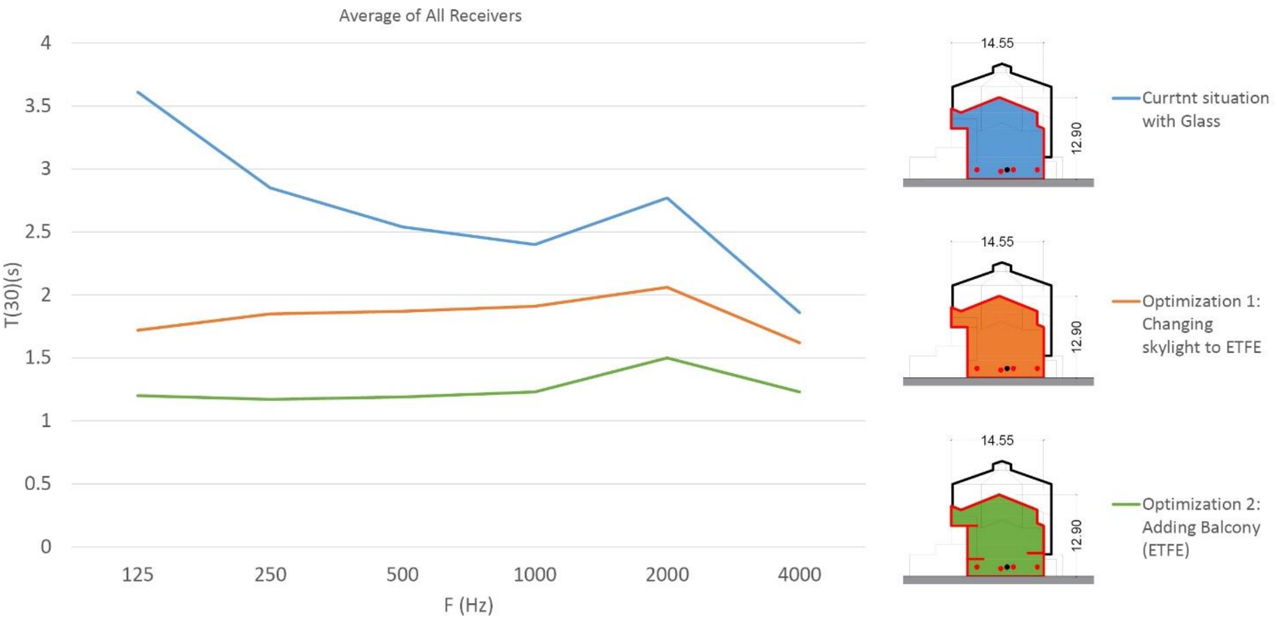

Figure 6 – T_{30} comparison between current situation and optimizations at 6 octave bands

3 Conclusion

Initially, the variability of results showed the consequence of early design stages to the acoustic comfort of atria in order to attract architects' attention to this issue. In terms of skylight material results indicated generally at low frequencies using the ETFE material rather than glass makes T_{30} shorter and increases D_{50}. However, the introduction of glass resulted in more homogenous results across all positions. In terms of geometry comparison, this study did not find any significant relationship between acoustic comfort and the length of a long hall with the chosen absorption properties, while a difference of the width or the height of the hall often made T_{30} longer and declined the clarity.

In addition, results demonstrated generally an inclined skylight with an angle of 22 degrees has a shorter T_{30} value rather than an arched roof, with the same material of ETFE, but this improvement did not necessarily lead to an increase in clarity for the halls with an inclined roof. This study also investigated the presence of balconies has a strong positive effect both on the reverberation time and clarity in ground floors. Therefore, if architects want to design a multi-level atrium that the ground floor is more crowded than the upper floors and they do not need communication to happen between the levels, they should not hesitate to use exposed balconies in order to decrease the sound transmission between levels.

Finally, the observed influential factors were applied to an existing project (Lloyd passage, Bremen) to test their effectiveness. The results illustrated that by changing the material of the skylight from glass to ETFE and adding some balconies to this shopping street, the acoustic comfort of the space could be significantly improved.

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