# A Project Focused on Sound Diffusion: The Acoustics of the Auditorium Yves St Laurent of Marrakech in Combination With its Innovative Architectural Design

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## Abstract

Yves St Laurent Auditorium was built at the core of Morocco as part of the museum that honors the French fashion designer. The interior and architectural design of the Auditorium evokes the colors and the materials typical of Marrakech, with bricks and wood being the primary structural resources of construction there. The shoebox envelope was modeled to accommodate ergonomically the select audience attending specific performances oriented towards fashion design. The sound diffusion was realized with the application of quadratic residue diffusers (QRD) installed on all the walls in a vertical configuration. These acoustic panels increase the phenomenon of sound scattering in all directions, making listening very warm and comfortable. This paper deals with the assessment of the main acoustic parameters gathered by the acoustic simulations of a digital model. The simulated values were compared with the optimal values of performing arts spaces of similar room volume.

## 1. Introduction

Auditoria have often been considered multi-purpose places thanks to their suitability for hosting conferences and musical performances (Bettarello et al., 2021). The challenges that architects and acousticians have to face are varied, going from interior design to materials selection based on geometrical characteristics, as well as for energy building and musical instruments simulation, (Fabbri et al., 2014; Manfren et al., 2021a, 2021b, and 2022; Tronchin et al., 2020) and lighting comfort for all the different events. The YSL Auditorium of Marrakech summarises all the aspects that a design project finds as opportunities to extract the best architectural product from certain constraints. This paper deals with the acoustic simulations of the Yves St Laurent Auditorium based on different absorption coefficients assigned to different materials of the 3D models. The results of the simulated values were compared based on the main acoustic parameters.

## 2. Historical Background

Yves St Laurent Auditorium is located in the Saint Laurent Museum in Marrakesh, which was built in memory of the famous French fashion designer, Yves Saint Laurent (Sabbah, 2021; Vorländer, 2007) (www.museeyslmarrakech.com/en/auditorium/).
The main purpose of the museum is to encourage cultural projects by displaying Yves Saint Laurent's masterpieces, and to preserve and disseminate his works in France and the rest of the world.
Fondation Pierre Bergé launched the Musée Yves Saint Laurent Paris project in 2017. However, this was not enough to show all the designer's artistic heritage, so they found another place to display Yves Saint Laurent's works.

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Fig. 1 – Internal view of the Auditorium YSL of Marrakech

The Auditorium, jointly designed by the consulting experts of theatre projects and Ko architectural office studio (Sabbah, 2021), is located at the center of the museum with the aim of hosting conferences, screen shows, concerts, plays, films and other activities.

## 3. Architectural Characteristics

Seen from the outside, the entire building is composed of cubical shapes dressed in terracotta bricks as a reminder of the fabric of the local place, as shown in Fig. 1.

The auditorium was designed for a total capacity of 113 seats, with a total volume of 650 $m^3$ and a high degree of flexibility, high acoustic quality and a lighting system capable of fulfilling a variety of activities (Sabbah, 2021). This multi-functionality is visible by the integration of a series of design elements with the technical tools to create a perfect experience for both performers and audience. The streamlined organization inside the auditorium is very logical and highly accessible. The adjustable sound-diffusing panels in the acoustic walls have excellent flexibility (for controlling reverberation time based on several different needs: natural or amplified musical shows, conference hall, or cinema screen (Tronchin, 2005; Tronchin et al., 2021a). Figs. 2 and 3 show the longitudinal section and the internal view of the auditorium, respectively.

Fig. 2 – Longitudinal section of Yves St Laurent Auditorium of Marrakech

Fig. 3 – Internal view of Yves St Laurent Auditorium of Marrakech

The ceiling of the auditorium is equipped with motorized wooden slats to regulate the sense of spaciousness based on the diffusing geometry that they can assume (Tronchin & Bevilacqua, 2022). The lateral walls are characterised by quadratic residue diffusers (QRDs), which contribute to the uniform distribution of the sound across the sitting area (Farina et al., 1998; Tronchin, 2021). The purpose of the diffusing panels is to spread uniformly sound energy in all directions and to reduce energy concentration and/or undesired reflections across the volume (Manfren et al., 2019). In the case of the QRDs, the reflections are spatially dependent and follow a numerical sequence provided by a uniform spatial Fourier transform (Tronchin et al., 2021b). The external envelope is composed of a double skin wall able to provide enough airborne sound insulation to stop intrusive noise (Bettarello et al., 2010).

## 4. Acoustic Simulation Setup

A digital model was created by using AutoCAD software (Caniato et al., 2020a and 2020b), where the 3D face entities were grouped based on type of material (Tronchin et al., 2020, 2021c; Vorländer, 2007). A view of the digital model is shown in Fig. 4.

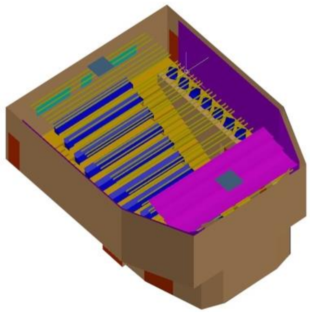

Fig. 4 – Digital model of Yves St Laurent Auditorium of Marrakech

The 3D model was exported in dxf format ready to be employed in the acoustic simulations. An omnidirectional sound source was placed on the stage, while 113 receivers were placed at different heights by homogeneously covering all area of the stalls.

The simulation process was undertaken in two different steps: the first by applying the absorption coefficients as per the literature (Caniato et al., 2019; Farina et al., 1998; Tronchin & Bevilacqua, 2021; Tronchin & Farina, 1997), the second by calibrating the absorption coefficient based on experience of similar auditoria of comparable volume size. The difference between the two simulations is in the adjustment of the spectra related to the fabric, lowered by up to 0.6, and to the ceiling panels, lowered by up to 0.4.

## 5. Simulated Results

The main acoustic parameters were analysed by considering the bandwidth ranging from between 125 Hz and 8 kHz to be considered the average values of all the receivers.

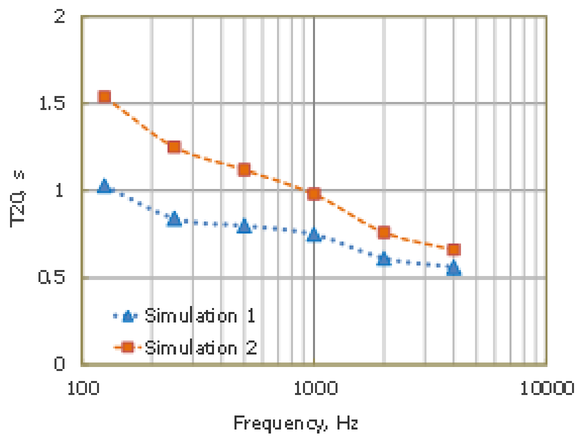


Fig. 5 – Simulated values of $T_{20}$

Fig. 5 indicates the simulated $T_{20}$ values. The first simulation had absorption coefficients of the fabric close to 0.9, while the second one had absorption coefficients fluctuating around 0.3. Considering that the fabric covers a surface area equal to 58 m², it is considered the main determining factor of the $T_{20}$ difference, highlighted especially at low frequencies (Wang et al., 2004).

Due to the multipurpose function assigned to this auditorium, intended to be suitable for both musical and conference events (Mickaitis et al., 2021; Tronchin & Knight, 2016), the overall $T_{20}$ value of the two simulations was compared to the room volume, as indicated in Fig. 6.

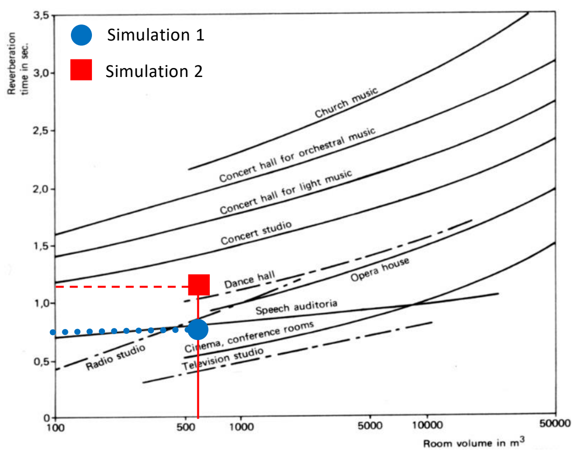


Fig. 6 – Optimal $T_{20}$ values based on room volume

Fig. 6 highlights that the first simulation meet the criteria of a speech auditorium, while the second one turns out to be closer to a musical performance.

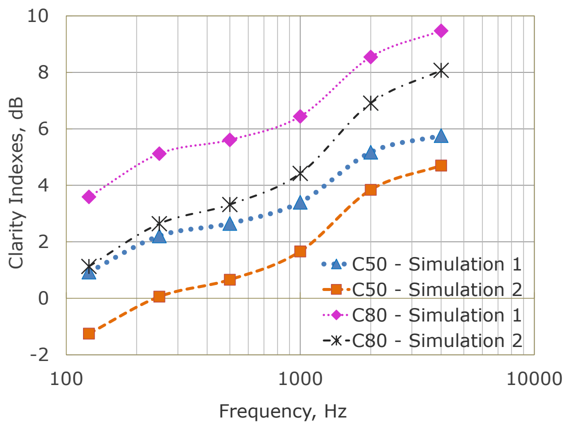


Fig. 7 – Simulated values of Clarity Indexes

Fig. 7 indicates the results of clarity indexes. In relation to speech ($C_{50}$), the values of the second simulations are within the optimal range (-2 dB < C < +2 dB) (Tronchin et al., 2020) for the octaves ranging from between 125 Hz and 1 kHz, while the higher frequencies are up to 4 dB above the upper range limit. In terms of music, ($C_{80}$), the results of both simulations were found to be up to 7 dB above the upper range limit across all the spectra.

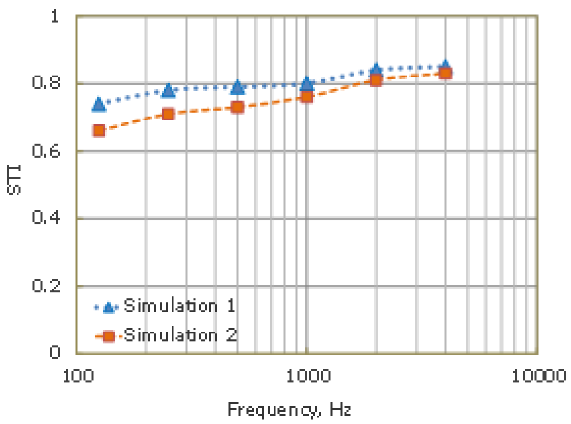


Fig. 8 – Simulated STI values

Fig. 8 shows the results related to speech comprehension. The simulated values of both simulations have been found to be above 0.6 for all octaves. This means that the overall result falls into a "good" category, even "excellent" at mid-high frequencies, as defined by the intelligibility rating according to ISO 9921.

## 6. Conclusion

This paper deals with two acoustic simulations of the YSL Auditorium of Marrakech. The contained room volume, allocating 113 seats, was designed with motorised wooden slats on the ceiling that can optimize the reverberation time based on the required functionality. The multipurpose hall, intended to be suitable for both speech and musical performances, also involves the design accuracy of the construction elements, like the side walls characterised by the QRD panels.

Two acoustic simulations were carried out by changing mainly the fabrics and the diffuser absorption coefficients. The difference between these is more evident at low frequencies for the $T_{20}$, while the clarity index for speech and music both proved to be up to 6 dB above the upper range limit, especially at mid-high frequencies. The STI values, found to be more than 0.65 across all the spectra, fall within the excellent category rating.

Further research studies will deepen the investigation by comparing the simulated values with the on-site acoustic measurements (Caniato et al., 2021) in order to define the tuning process.

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