DESIGN OF A LIGHTWEIGHT ACOUSTIC SHELL TO MEET THE STAGE DESIGN REQUIREMENTS OF STORAGE AND QUICK ASSEMBLY

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Abstract:

This paper presents the development of the technical solution designed for the new acoustic shell of the Victoria Eugenia Theatre in San Sebastian, Spain. An opera house with more than 100 years of history, currently operating as a multi-purpose hall, hosting performances ranging from theatre to cinema, opera recitals, orchestral music and amplified music.

The aim of the project with regard to the acoustic shell is threefold, to free up storage space in the theatre, to facilitate set-up by reducing the time and cost of personnel required, and finally to provide adequate acoustics for the musicians and the audience.

With the bespoken design of the new acoustic shell, the overall weight of the shell will be reduced by 44%, which will allow the possibility of storing all the elements inside the fly tower with motors, also making it possible to reduce the assembly time by 44%.

From an acoustic point of view, work has been carried out on the choice of materials and its geometry, by means of acoustic tests and computer simulations, with the aim of improving the feeling of connection between musicians and also with the audience, leading to better performances with natural acoustics.

1 INTRODUCTION

The Victoria Eugenia Theatre, located in San Sebastian, Spain, is a historic venue with over a century of cultural significance. Originally designed as an opera house, the venue now functions as a multi-purpose hall that accommodates a wide range of performances: from theatrical productions and film screenings to orchestral and amplified music concerts. Such versatility imposes demanding requirements in terms of acoustic adaptability and stage logistics.

To support performances requiring natural acoustics, such as orchestral and chamber music, an acoustic shell is typically used. This structure surrounds the musicians with reflective surfaces that enhance sound projection, ensure musical cohesion among performers, and improve the listening experience for audiences. However, the original shell at Victoria Eugenia was bulky, labour-intensive to assemble, and occupied valuable storage space.

The aim of the new acoustic shell project was threefold: to free up storage space in the theatre, facilitate a quicker and more efficient assembly process, and improve acoustic quality for both performers and audiences. This paper presents the design process and the expected performance improvements of the new lightweight modular shell from an operational and acoustic point of view.

2 PROJECT BACKGROUND

2.1 Existing Venue Conditions

Prior to the redesign, the venue employed a traditional acoustic shell composed of modular panels made of 21 mm MDF panels attached to extruded aluminium profiles. It comprised two angled lateral walls, a rear wall, and three suspended ceiling frames, incorporating 117 halogen light fixtures. When disassembled, the components occupied approximately 270 m^3 and weighed over 5,200 kg.

This configuration created significant logistical issues. The panels required extensive manual labour for setup and disassembly, and the stage storage area was nearly fully occupied by the shell components.

The design of the current acoustic shell—its acoustic performance, geometry, and overall dimensions—is generally considered satisfactory by both visiting orchestras and the audience.

2.2 Operational and acoustic challenges for the new design

Operationally, the main challenges were to shorten assembly and disassembly times, while also freeing up storage space in the theatre.

Acoustically, the main challenge was to maintain the current acoustic performance of the existing solution while reducing its weight to enable suspended storage using motorized stage rigging.

3 DESIGN CRITERIA

3.1 Main goals

The new shell was designed to meet strict technical requirements:

- Total weight reduction of at least 30%
- All elements storable in the fly tower using motorized stage rigging
- Minimized manpower requirements for setup

3.2 Acoustic Objectives

The acoustic design focused on achieving optimal stage support and clarity to ensure effective sound communication between musicians and with the conductor to enhance the performers' interpretative potential on stage.

In order to achieve that we were targeting the following ideal ranges, based on ISO 3382-1 [1] and Gade [2]:

Stage support	Min (ISO 3382-1)	Max (ISO 3382-1)	**Targeted values**
ST_{early}	-24	-8	**-11 a -13 dB**
ST_{late}	-24	-10	**-12 a -8 dB**

Table 1. Stage support targeted values

Acoustic shells panels were targeted to meet specific acoustic performance:

- Sound reduction index: $R_w > 20$ dB
- Absorption coefficient: $\alpha < 0.1$ between 500 Hz and 4 kHz
- Weight between 4 and 7 kg/m² to ensure reflectivity and compatibility with motorized stage rigging

4 ACOUSTIC SHELL DEVELOPMENT

4.1 Material selection

The selected construction material was a lightweight honeycomb panel composed of an aluminium core of 10 to 20 mm thickness and 3 to 5 mm okume plywood sheets. The wood surface ensured adequate aesthetics and acoustic reflection, while the aluminium core along with the two sheets of wood provided structural integrity with minimal weight.

4.2 Acoustic measurements and calculations

A sample of the proposed material has been calculated, manufactured and measured to check compliance with the requirements, with regards to sound insulation. Special thanks to ALUCOAT conversion SAU (Spain) for supplying the core material to undertake the sample test.

Acoustic measurements have been undertaken based on ISO 10140-2:2021 and ISO 717-1:2021. Sample size was 1.2 x 0.6 m.

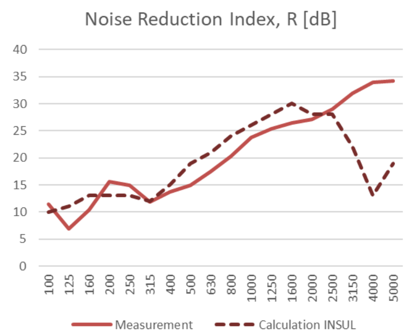

Figure 1. Sample test image and comparison between acoustic calculation and measurement

Noise reduction index obtained from calculations and measurements are the following:

- Calculation: Rw (C, Ctr): 23 (-2, -4) dB
- Measurement: Rw (C, Ctr): 22 (-2, -4) dB

Values are complying with the preliminary expectations. It must be said that R reduction at critical frequency (around 4300 Hz) is not as severe as expected in the calculations.

4.3 Acoustic simulation model and calibration

A 3D geometrical acoustics model of the hall was developed using CATT-Acoustic®. Calibration was based on in-situ measurements of reverberation time (RT) using impulse response recordings taken in October 2023. RT measurements for the empty hall were:

Frequency (Hz)	125	250	500	1000	2000	4000	RTmid
RT (s)	1.4	1.3	1.1	1.1	1.0	0.8	**1.1**

Table 2. Reverberation time of the Theatre without audience (theatre mode)

Acoustic model input parameters were introduced and adapted slightly to match measured values, maximizing the actual hall's acoustic behaviour in order to be able to compare and simulate a few acoustic parameters with and without the proposed acoustic shell.

4.4 Acoustic simulation results

Without acoustic shell (Theatre Mode):

- ST_{early}: -20.2 dB
- ST_{late}: -18.6 dB
- RT_{mid}: 1.1 s
- Brightness: 0,82
- Warmth: 1,22
- EDTmid: 1.15 s
- C80 (clarity): range from 2 dB to 6 dB at high frequencies (better for speech)

With acoustic shell (Concert Mode):

- ST_{early}: -10.2 dB
- ST_{late}: -13.6 dB
- RT_{mid}: 1.55 s (audience area)
- Brightness: 0,83
- Warmth: 0,96
- EDT_{mid}: 1.65 s (audience), 1.2 s (on-stage)

- C80 (clarity): range from -1.6 to +2.3 dB

These results show a noticeable acoustic enhancement in concert mode, compared to Theatre mode. The ST_{early} and ST_{late} parameters improved significantly, aligning with ideal ranges. Reverberation time increased significantly, while warmth was moderately reduced. Musical clarity improved for musical performances with acoustic instruments.

It must be noted that values obtained from the digital model should be regarded more as a trend than as absolute values.

4.5 Implementation and modularity

The final system consists of modular panels installed via motorized fly bars. Ceiling panels are equipped with adjustable angles to fine-tune reflections. All components fit within the fly tower, freeing up 135 m² of stage storage.

Figure 2. Stage general front view and stored acoustic shell detail (folded)

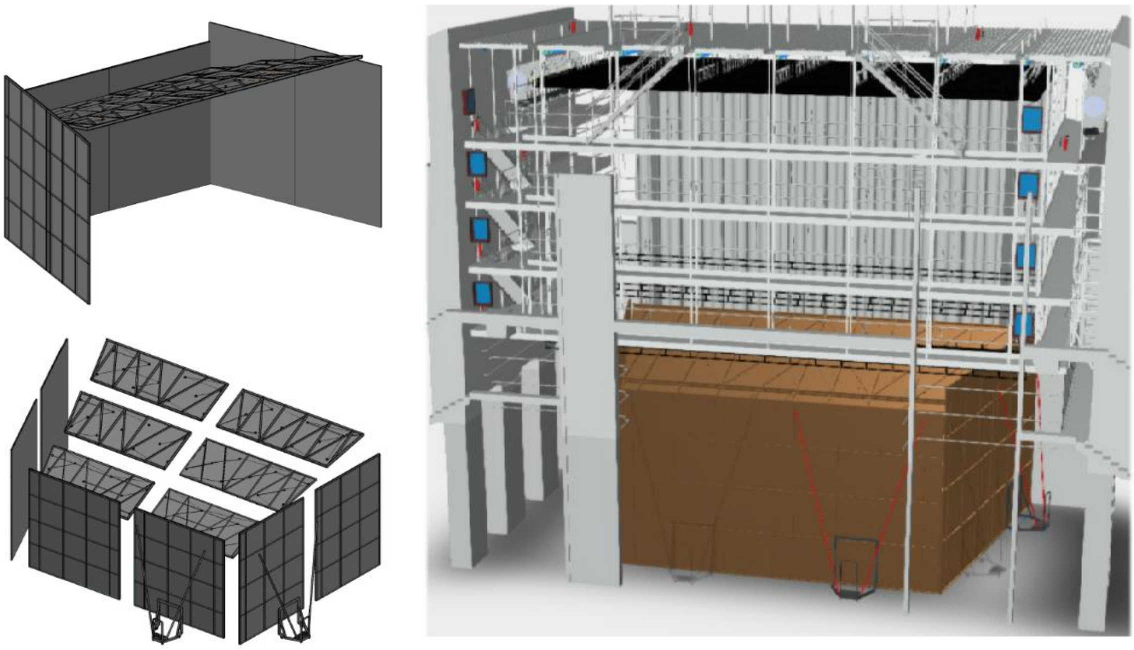

Figure 3. Stage general rear view and acoustic shell detail (unfolded)

Assembly time was reduced. The shell's modularity allows configurations tailored to different performance types and ensemble sizes.

4.6 Operational improvements comparison

	Previous acoustic shell	Proposed acoustic shell
Total Weight	5.267 kg	2.937 kg **(-44%)**
Assembly Time	2.25 days (4 people)	1.25 days (4 people) **(-44%)**
Electric power requirements	58.500 W	1.680 W **(- 97%)**

Table 3. Operation improvements (weight, assembly time and electric power)

5 DISCUSSIONS

5.1 Stage support

The ST_{early} values obtained show a clear improvement in terms of the musicians' ability to hear one another. This includes being able to hear oneself strongly enough in relation to the others to maintain a personal reference of what is being played, as well as hearing the other musicians clearly and loudly enough to follow and complement each other during the musical performance. This significantly enhances the ensemble's ability to express itself and emotionally engage with the audience.

The case without the shell makes it particularly difficult to perform instrumental music without electroacoustic reinforcement, as the musicians are unable to hear each other.

ST_{late} also shows a clear improvement. This parameter describes the sensation of reverberance, the sense of space on stage. The level of late reflections increases, enriching the musical sound—shifting it from dry and direct, as if playing outdoors, to a sound that is more full-bodied and refined.

Acoustically, the shell transformed the stage from a dry, acoustically isolated platform to a resonant, balanced environment that supports musical expression.

5.2 Reverberation time

The reverberation time of the hall increases slightly when using the new acoustic shell, which is beneficial for listening to symphonic or chamber music. This is particularly important given that the hall was originally designed for theatre use and therefore has a shorter reverberation time—advantageous for speech intelligibility, but less so for music.

Warmth is slightly reduced (balance between low and mid frequencies), as the shell is lightweight and some of the low-frequency energy is partially absorbed by the shell itself. Nevertheless, the tonal curve remains balanced.

5.3 C80

Regarding musical clarity (C80), it improves slightly compared to the use of the hall in its theatre configuration. Typically, a C80 value between -2 and +2 dB in the mid frequencies is expected for concert halls, while values of +6 dB or higher are considered favourable for theatre.

C80 represents the ratio between the early energy received within the first 80 milliseconds and the late energy received after 80 milliseconds up to infinity. Higher values indicate less late energy and a more present (direct) sound, while lower values correspond to a more reverberant sound.

5.3 Logistics

Logistically, the lightweight, storable design introduces a new level of operational efficiency.

6 CONCLUSIONS

This project highlights how multidisciplinary design teams working in cooperation can address both technical and artistic challenges in historical venues. The design respects architectural constraints while significantly enhancing stage usability and providing proper acoustic conditions.

The new acoustic shell at Victoria Eugenia Theatre represents a major advancement in stage management while maintaining acoustic quality.

It reduces labour and storage demands, while providing the acoustic needs for performers and audiences alike. The integration of predictive modelling, lightweight materials, and modular design offers a replicable solution for similar venues seeking functional flexibility and appropriate natural acoustics.

7 REFERENCES

1. ISO 3382-1:2009, Acoustics — Measurement of room acoustic parameters — Part 1: Performance spaces.
2. Gade, A. C. Investigations of musicians room acoustic conditions in concert halls. II field experiments and synthesis of results. Acustica, 69, 1989.
3. Halmrast, T. Orchestral timber: Comb-filter coloration from reflections. Journal of sound and vibration (2000) 232(1), 53-69.
4. Virginelli, A. Rolla, S. Influence of a lightweight acoustic shell with diffusive surface in a multiple use theater audience area. Inter-noise 2012. NYC. USA.
5. Bradley, J. S. Some effects of orchestra shells. Journal of the Acoustical Society of America, 100, (2), pp. 889-898, July 01, 1996.
6. Shtrepi, L. Badino, E, Lancia. D. Measurements on stage acoustics in four configurations of an open-air performance acoustic shell. Forum acousticum 2023.
7. Toyota, Y. Komoda, M. Beckmann, D. Quiquerez, M. Bergal, E. Concert Halls by Nagata Acoustics. Thirty years of acoustical design for music venues and vineyard-style auditoria. ASA press. Springer Nature. 2020.