REFURBISHMENT OF LA COMÉDIE-FRANÇAISE: A ROOM ACOUSTIC SOFTWARE ROUND ROBIN TEST TO IMPROVE ACCURACY IN MODELLING

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1 INTRODUCTION

The Richelieu room of La Comédie-Française, located in the Palais Royal in Paris, is a central venue for French-language theater. Rebuilt at the beginning of the 20th century following a fire, it is continually maintained and modified to meet the scenography, safety and comfort requirements of the time, with careful respect for its patrimonial character.

With a seating capacity of 879 and a volume of 4,500 m³ (auditorium) + 9,000 m³ (fly tower), it offers every member of the audience real intimacy – both visual and acoustic – with the comedians.

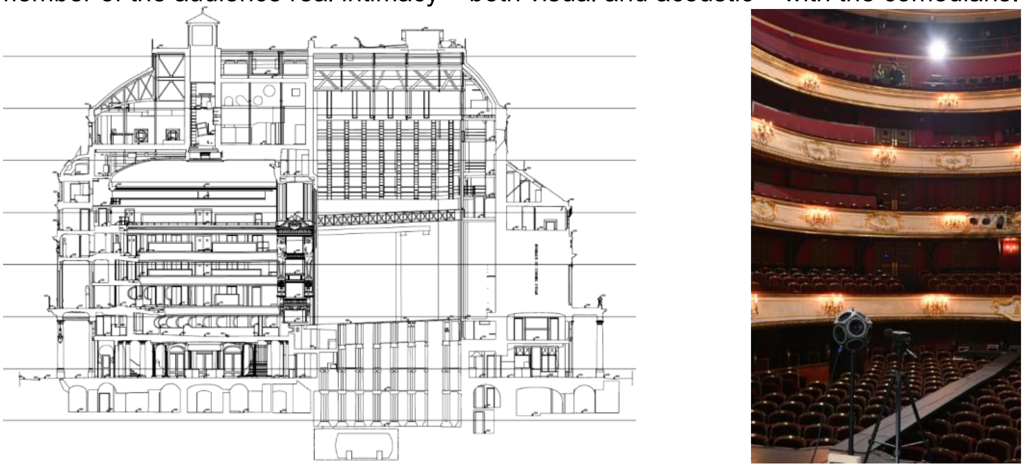

Figure 1: Section along main axis and general view of La Comédie-Française, Richelieu room

In February 2025, the authors carried out on-site measurements of acoustic criteria according to ISO 3382-1 standard[1]. The auditorium was at that time prepared for performances of Le Soulier de satin, a play written by Paul Claudel and directed by Eric Ruf. This stage version featured no fixed scenery, apart from the equipment stowed at the back of the stage cage and no curtain. For staging purposes, a slender stage in the proscenium extension crossed the audience.

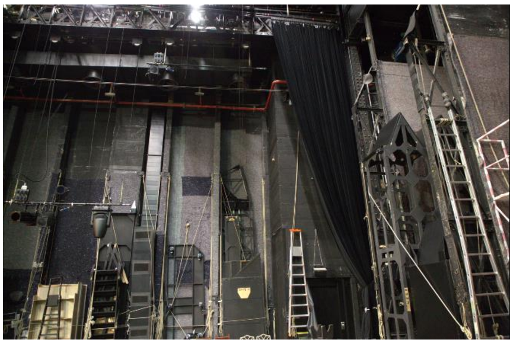

Figure 2: Stage setting during measurements

Figure 3: Stage and lower level of audience during measurements

These measurements are a prerequisite to the round robin test described in this article. They are briefly described in § 3.4.

2 KNOWN ISSUES, NEW QUESTIONS

In acoustic modeling, two primary approaches exist: numerically solving the wave equation or using geometrical acoustics (GA). GA assumes sound propagates as rays, a valid assumption at high frequencies but is less accurate at lower frequencies, where wave phenomena become significant. In the low register, wave-based modeling theoretically offers higher accuracy, while GA relies on more mature solutions and know-how from the acoustic community. Acousticians now face the choice of both methods, or a mix of both.

Previous round robins focused on existing GA softwares[2]. These software programs have since evolved and new actors come to market and challenge older ones.

A specific issue with existing room modelling is calibration of the model, as M. Vorländer[3] highlighted that prediction of reverberation times with accuracy better than the just noticeable difference requires input data in a quality, which is not available from reverberation room measurements.

This study addresses the following questions:
- How accurate is GA in modeling an existing classical theatre?
- What challenges arise during the modeling process, and how can they be addressed?

3 METHODOLOGY

3.1 General rules

The authors gathered in 3 independent teams, randomly named X, Y and Z. The test has been completed in 2 rounds:
- a first raw estimation based on a common geometrical model and a comprehensive set of photographs of room materials and components,
- a second round after calibration of the model based on ISO 3382-1[9] detailed measurement results.

After each round, all teams shared their calculated criteria and discussed the differences.

3.2 Geometrical model

La Comédie-Française provided a very refined geometrical model of the room, based on a professional laser survey, which was used by team Y to work out a simplified model, made of finite, plane surfaces. All 3 teams had agreed on a minimal face dimension of 0.2 meters and had set up principles on audience area and open balcony modelling.

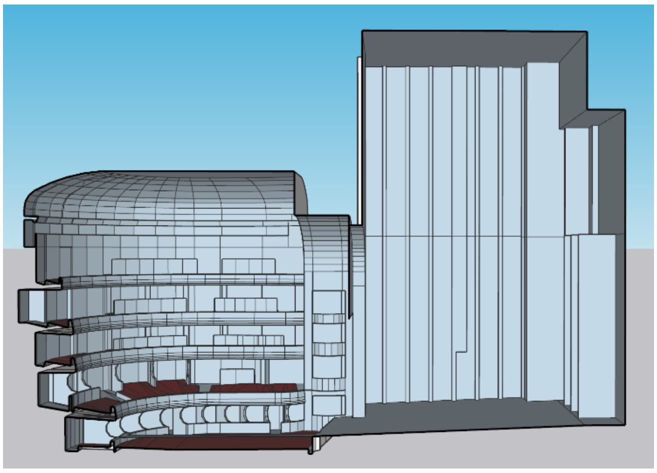

Figure 4: Geometrical model shared by all teams

3.3 Software set

Four acoustic modeling tools, among the most commonly used and here randomly named 1, 2 3 and 4, were pre-selected for the round robin test.

All simulation software programs are supposed to rely on common principles, although interpretation of each of them will turn out to be a key factor:

- Use of finite, plane surfaces.
- Use of omnidirectional sources, in the present test.
- Reflection-path-based GA: ray tracing, image source method, radiosity, or a mix of them
- Theoretically, a same user would use same input data for material properties in each tool: absorption, diffusion, diffraction and transparency. However, some of the latter properties are not always available in the calculation tool.
- Resulting impulse responses are interpreted according to ISO 3382-1 indexes[9]: reverberation time T_{30} and T_{20}, early decay time (EDT), clarity C_{80}, and definition D_{50}.

Variations included calculation capabilities as described in chapter 2, geometry adaptations to fit the software requirements, and diffusion calculation methods. Some software programs are already validated for large rooms, while some others originally focus on smaller spaces.

Software 4 turned out to need specific geometrical choices that could not be reworked on the common geometrical model in the available time of the study. Therefore, only software 1, 2 and 3 are compared in the following sections.

The teams agreed to run both rounds 1 and 2 on different software:

- Team X: software 1 and 2
- Team Y: software 1 and 2
- Team Z: software 1 and 3, although results regarding software 3 in round 2 weren't available at the time this article was submitted for publication.

3.4 Source and receiver positions

Measurements and calculations were performed on an identical set:

- 1 source position (S1) – on the proscenium, at 1.5 m height
- 5 receiver positions (R1, R2, R3, R5 and R6) dispatched around audience area, at seating height
- 1 receiver position (R4) on the stage, at 1.5 m height.

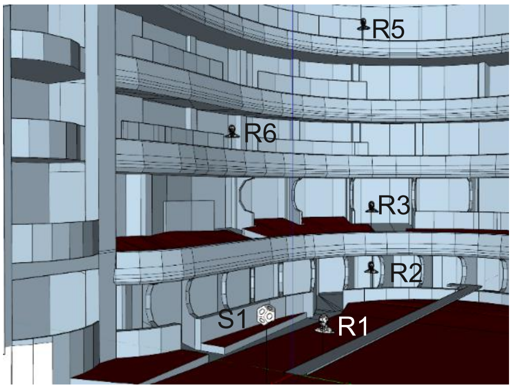

Figure 5: Source and receiver position across the auditorium

4 RESULTS

4.1 Round 1

T_{30} and EDT mean value on receivers R1 to R6 are compared for all teams and both 3 software with a 'reference value', i.e. the mean value of measurement results for the same criteria, obtained previously in the existing room[1].

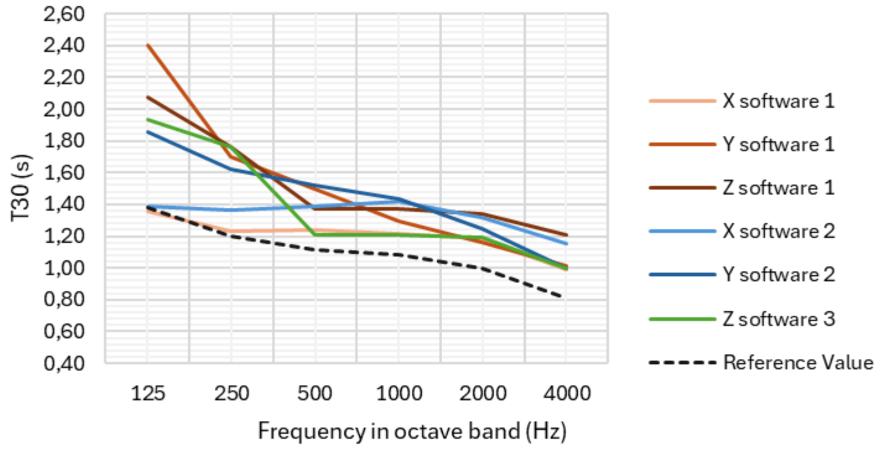

Figure 6: Round 1 - Variation of average T_{30} [s] with frequency

Table 1: Round 1 – Deviation of T_{30} from reference value (values complying with JND[9] = 5% are highlighted)

Frequency (Hz)	125	250	500	1000	2000	4000
X software 1	-1%	3%	11%	12%	19%	22%
Y software 1	75%	42%	34%	20%	16%	25%
Z software 1	51%	47%	23%	27%	34%	49%
X software 2	1%	14%	25%	31%	32%	42%
Y software 2	35%	35%	36%	32%	25%	23%
Z software 3	40%	47%	9%	12%	19%	23%

At low frequency, simulations of team X proved to be right, while other results show an important data deviation. At medium and high frequencies, all predictions overestimate T_{30}, compared to the measured value.

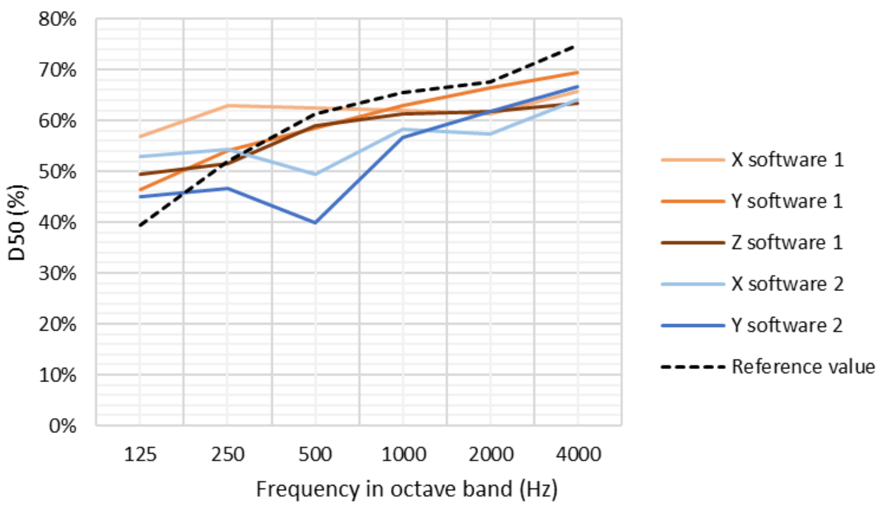

Figure 7: Round 1 - Variation of average D_{50} [%] with frequency

Table 2: Round 1 – Deviation of D_{50} from reference value (values complying with JND[9] = 5% are highlighted)

Frequency (Hz)	125	250	500	1000	2000	4000
X software 1	44%	21%	2%	-5%	-9%	-12%
Y software 1	18%	4%	-5%	-4%	-2%	-7%
Z software 1	26%	-1%	-4%	-6%	-9%	-15%
X software 2	35%	5%	-19%	-11%	-15%	-14%
Y software 2	14%	-10%	-35%	-13%	-9%	-11%

From 250 Hz up to 2000 Hz, some teams' D_{50} prevision with software 1 already stands within the ± 5% just noticeable difference. However, it is generally underestimated with software 2.

4.2 Round 2

T_{30} and EDT were after discussion between the teams agreed to be chosen as the indicators for model calibration. Mean values now exclude stage receptor R4, which deviated too much from other results.

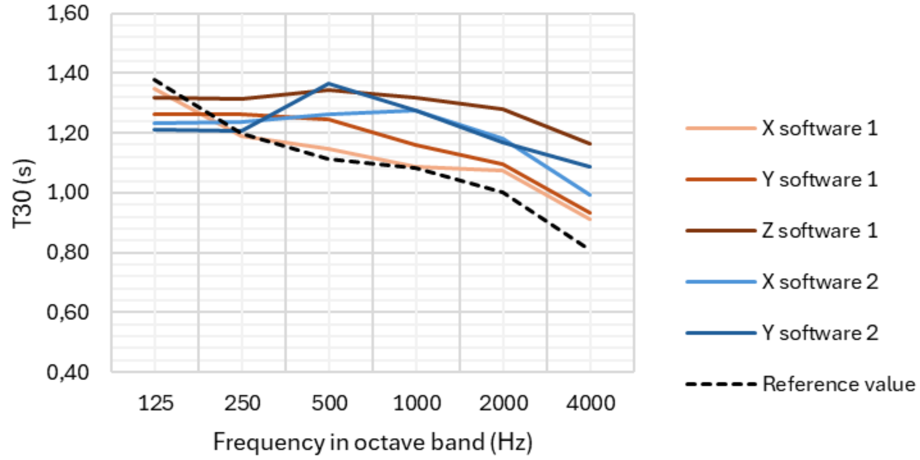

Figure 8 : Round 2 - Variation of average T_{30} [s] with frequency

Table 3: Round 2 – Deviation of T_{30} from reference value (values complying with JND[9] = 5% are highlighted)

Frequency (Hz)	125	250	500	1000	2000	4000
X software 1	-2%	1%	3%	1%	7%	13%
Y software 1	-8%	5%	12%	7%	10%	15%
Z software 1	-4%	10%	21%	22%	28%	44%
X software 2	-10%	3%	13%	18%	18%	23%
Y software 2	-12%	1%	23%	18%	17%	34%

After calibration, result deviation inferior to the just noticeable difference is multiplied by 3. Most predictions still overestimate T_{30} at 500 Hz and higher frequencies, yet overall accuracy is improved.

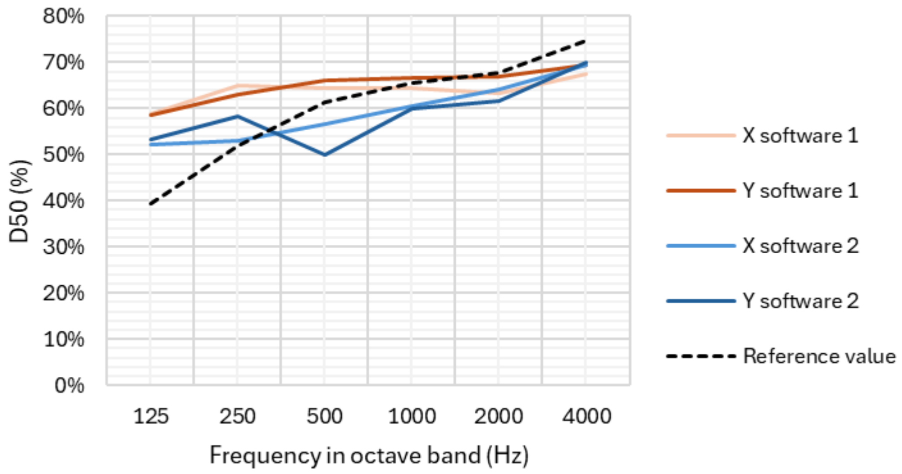

Figure 9: Round 2 - Variation of average D_{50} [%] with frequency

Table 4: Round 2 – Deviation of D_{50} from reference value (values complying with JND[9] = 5% are highlighted)

Frequency (Hz)	125	250	500	1000	2000	4000
X software 1	50%	25%	5%	-2%	-6%	-10%
Y software 1	49%	21%	8%	2%	-1%	-7%
X software 2	32%	2%	-7%	-8%	-5%	-6%
Y software 2	36%	12%	-18%	-8%	-9%	-6%

From 500 Hz up to 4000 Hz, D_{50} prevision stands within the ± 5% just noticeable difference. It is overestimated at lower frequencies. This discrepancy may be a consequence of calibration, as discussed here after.

5 DISCUSSION

Prediction of reverberation time in the classical theatre with a large fly tower tends to overestimate calculated values, compared to measurement survey performed according to ISO 3382-1. This is not only true in round 1, when simulations are run independently of measured data, but is still an issue after model calibration.

In round 2, team Z investigated the influence of absorption properties in the audience area on the overall reverberation time, while teams X and Y have focused on the fly tower absorption. It turned out that the latter had a much greater influence, as Chavez and Perigot[6] already described. Finally, both teams X and Y managed to predict T_{30} values within a 15 % maximum deviation with tool 1.

There are some important differences when comparing the different software packages. Despite their common aim to model room acoustics based on geometrical and physical properties that are generally expected to reproduce the real auditorium with a high degree of accuracy, the 3 software packages used in this study are based on different principles:

- Geometry of audience area: a closed surface has proven to give accurate results in GA modelling, with discussion on its preferred height, but some editors recommended to design the seats and benches, as they influence the ray incidence.
- Edge diffraction is not applied in the same manner and is still a matter of development for some editors.
- Volume coupling, which is of high importance in a theatre equipped with a fly tower, is inherently problematic for GA tools. Some contributors attempted to fix this using wave modelling, but did not succeed in improving results significantly in the time allocated. Moreover, calibration based on T_{30} and EDT values had a negative value on D_{50} prediction accuracy, compared with round 1 results.
- The choice of detail size in the geometrical model affects precision and even compatibility with some software. Simplifying models can mitigate some issues. Some 3D modeling software may also be more compatible with some prediction software.

Apart from these interpretations, material properties are one of the greatest factors of uncertainty. Not only is on-site material property assessment challenging due to equipment limitations and complexity, but their interpretation varies greatly, depending on the software and on the way acousticians use them:

- (Complex) impedance may be preferred to classical absorption coefficients.
- Scattering has a great incidence on prediction in some algorithms, a much smaller one in some others.
- Real materials are not always isotropic in the way they reflect sound rays. However, this particularity is still a subject of interpretation for software users, as parameters must be carefully adjusted, provided project context, data availability (e.g., lab results) and the way a given version of the software may interpret them.

Typical examples of difficult interpretation in the context of theatres of the classical era are old décors and open balconies: the modelling process necessitates a long calibration process, with careful adjustments of scattering and edge diffraction, plus critical choices regarding the relevant degree of simplification.

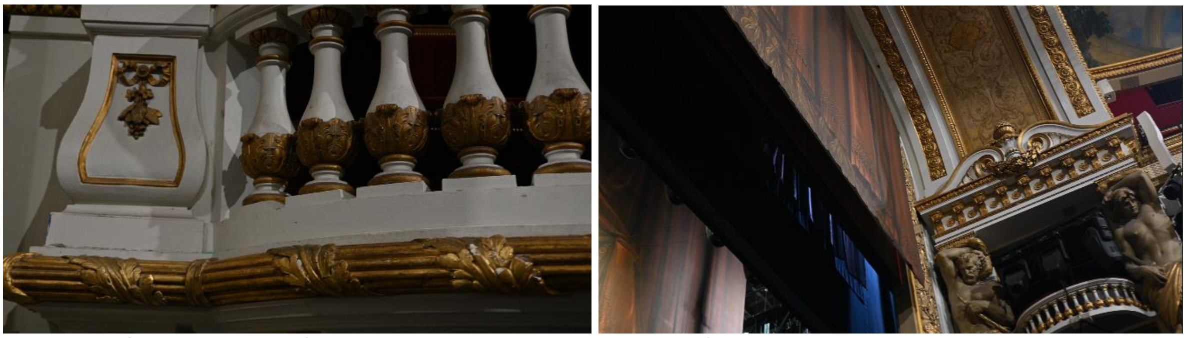

Figure 10: Open balcony (left) and old décor (right), causing specific modelling issues

Finally, the choice of number of rays has been mostly driven by calculation time and appears quite homogeneous throughout programs and teams involved in the present round robin test. But remote processing and novel algorithms expand calculations power, letting users to perform finer predictions than before.

6 CONCLUSION

Classical theatres present typical features that complicate the modelling process and require proficiency in both general acoustics physics and in the chosen software package. Nevertheless, good accuracy is achievable, provided a calibration phase, based on reliable on-site measurements. In conclusion, the limitation of the simulated result is highly impacted by the initial assessment of the expert acoustician and software parameters.

This study or round robin test draws a few ideas that may help improve the accuracy of similar projects:

- Use of specific geometrical modelling techniques for a given prediction software: element size, number of faces, watertightness, simplification of details are key factors that need to be finely tailored to match software requirements.
- Calculations should also be performed in the audience area alone, with a fully absorptive void at the stage opening surface, to avoid coupling effect issues.
- A 'human voice' source directivity, both for on-site measurements and modelling may improve accuracy.
- 63 Hz octave band is sought by most male voices and would benefit to be more precisely assessed. This would need to include wave-based calculation for better accuracy at these frequencies. This technique is still a newcomer in the game for most acousticians and more experience is necessary.
- Higher calculation speed and new optimization techniques theoretically allow finer predictions.

7 ACKNOWLEDGEMENTS

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