ACOUSTIC DESIGN OF THE SHAKESPEARE NORTH, A JACOBEAN THEATRE IN LIVERPOOL

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1 INTRODUCTION

The Shakespeare North Playhouse is a unique project which sees historic plans produced based on the famed 17th Century Royal Architect Inigo Jones design, brought to life in Prescot, Liverpool. Housed within a new energy efficient wrap-around building, the venue comprises a historic Jacobean playhouse, a fully accessible outdoor performance garden, exhibition gallery, 60-seater studio theatre, learning centre, foyer, and a café and bar with an outdoor piazza.

With authentic materials, dimensions and staging arrangements the Shakespeare North Playhouse gives a truly authentic Jacobean Playhouse experience, while providing optimised acoustic conditions that modern audiences expect.

This paper includes the background to the project, the acoustic design brief as well as our acoustic design strategies, modelling and final measurement results.

2 PROJECT BACKGROUND

2.1 Inigo Jones' Cockpit-in-Court Design

Prescot was home in the 1590s to one of the first free standing purpose-built indoor playhouse outside London with its strong connections to the home of Earl of Derby who was a patron of theatre companies related to Shakespeare. The Prescot Playhouse is the inspiration behind Shakespeare North to build a Shakespearean theatre in Prescot, however, the plans for the Prescot Playhouse no longer exist, therefore the new theatre's layout was reconstructed by Nick Helm based on the 1629 design by Inigo Jones for the Cockpit-in-Court theatre in the Palace of Whitehall, London, which existed for approximately 100 years before his reconstruction.

The reconstruction comprises two components: firstly, the octagonal cockpit structure from the late medieval/early modern period, and secondly, the English Palladian additions by Jones. These are highlighted by the inclusion of a faceted frons scenae, which presented an exciting challenge for room acoustics design due to its octagonal geometry. Whilst there were historic accounts of the acoustic ambience that existed in the Cockpit-in-Court, obviously there were no recording of what the theoretical designs would have sounded like.

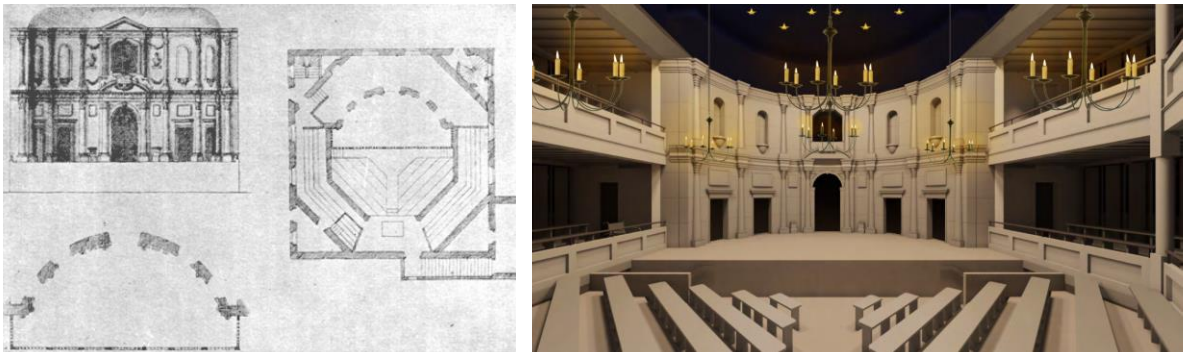

Figure 1 – Inigo Jones' Cockpit-in-Court Drawings and Nick Helm's Interpretation

2.2 Modern Design Standards

Besides the authentic historical playhouse design, the Shakespeare North project adheres to modern inclusive design principles and aims to achieve best practice to create a highly energy-efficient and environmentally friendly building. It demonstrates compliance with contemporary building regulations, incorporating 21st-century mechanical ventilation and smoke extraction strategies. This combination has resulted in a distinctive building featuring a historically referenced, traditionally constructed Tudor-come-Jacobean auditorium at its centre, embraced by a modern "wrap-around" structure which houses the foyers, a bar, a contemporary studio space, and educational facilities.

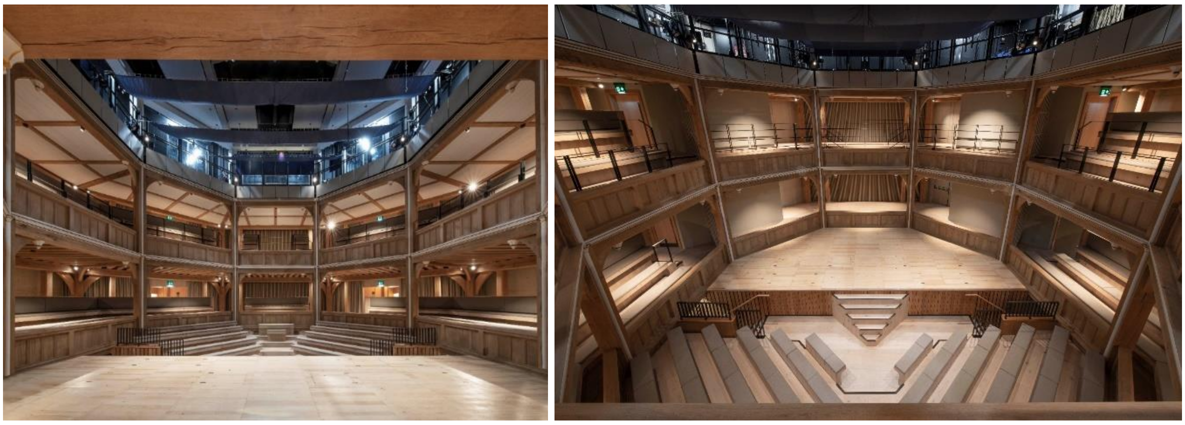

Figure 2 – Shakespeare North Playhouse (Photo: Beccy Lane)

2.3 Acoustic Design Brief

2.3.1 Criteria

Table 1 – Theatre Specifications

Seating Capacity	346 + 6 wheelchair-Cockpit theatre end-on (without frons) 326 + 5 wheelchair-Cockpit theatre end-on (with frons) 479 + 5 wheelchair-Cockpit theatre in-the-round
Room Volume	up to 2100m^3
Surface Area	up to 2900m^2
Stage Configurations	In-the-Round, End stage with/without frons scenae, Thrust stage
Internal Background Noise Criteria	20 – 25 dB L_{Aeq}
Stage & Audience Floor	Demountable Timber Rostra
Walls	Concrete and timber
Rear Walls	Hidden fabric upholstered mineral wool treatment
Main Coffered Ceiling	Octagonal reflective ceiling
Balcony Soffits	Structural timber (Section 3.1)
Seats	Upholstered wooden benches (Section 3.6)
Variable Treatment	Adjustable Curtains (Section 3.7)

2.3.2 Design Goals

Shakespeare North is primarily designed for unamplified theatre performances. Therefore, our main acoustic objective was to ensure optimal intelligibility for unamplified speech in the main stage configurations (In-the-Round and End Stage). Considering variable stage configurations and adjustments in volume by modifying the coffered ceiling, our target was to establish a stable reverberation time response within the playhouse, a crucial factor for the optimal speech intelligibility. We aimed for an optimal reverberation time of 0.8 seconds between 125 Hz and 4000 Hz, with a relaxation at low frequencies due to the constraints of the octagonal geometry. For speech intelligibility, our minimum targets were an STI of 0.65 and ALcons of 5%.

2.4 Design Team

Table 2 – Design Team

Client	Knowsley Metropolitan Borough Council
Architect	Helm Architects
Executive Architect	Austin-Smith:Lord
Main Contractor	Kier Group
Theatre Consultant	Arup
MEP	Dodd Group
Structural Engineer	Mott McDonald

3 DESIGN

3.1 Stage Configurations

One of the design goals in merging authentic design with modern methods was to create flexible room acoustic conditions to suit different types of performances to serve performances beyond the comprehension of Inigo Jones or the Bard. As a result, Shakespeare North's stage can seamlessly transition between In-the-Round and End Stage configurations, with a recent installation of a demountable frons scenae in August 2023 which is described as an elaborate backdrop for the stage. The In-the-Round configuration can accommodate up to 484 seats, providing the audience with a closer view of the stage and fostering an exceptionally intimate atmosphere. On the other hand, when configured as an End Stage, the seating capacity reduces to 331, allowing for more space both in the front and backstage areas.

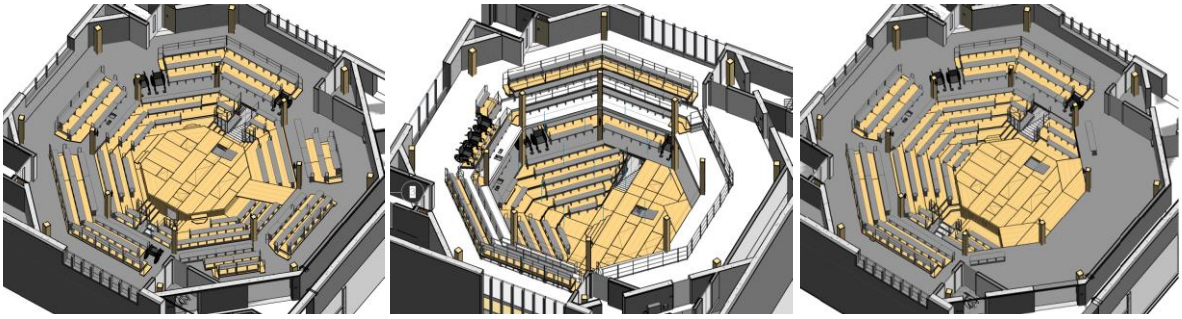

Figure 3 – In-the-Round, Frons Scenae and Thrust Stage (Models by Arup and ASL)

3.2 Volume Studies

The fundamental design of the room takes the shape of an octagon, featuring rear, side, and front balconies to accommodate the in-the-round stage setup. The playhouse's overall dimensions span approximately 19 x 19 meters. In the End Stage Mode, the stage measures 10.3 x 8.6 meters, while in the in-the-round stage configurations, it falls to 5.7 x 5.7 meters. The highest point to the top of the technical attic, with the trap doors on the coffered ceiling open, reaches approximately 13 meters from the stage level. However, in the main stage configurations with the trap doors closed, the ceiling height stands at around 10 meters.

The maximum volume of the playhouse was initially estimated at 2100m^3 with a seating capacity of 6.5m^3 per seat. However, a more impressive outcome was attained when employing an in-the-round stage setup, accompanied by an increase in the seating count to 484. This stage arrangement also leads to a variation in the volume occupied by the audience, achieving 4.8m^3 per seat. This volume per seat range is deemed optimal when considering the adaptable stage configuration. Furthermore, there is a potential increase in room volume by 20% through the use of trap doors, however, this supplementary volume enhancement is not regarded as highly effective considering the dimensions of the openings.

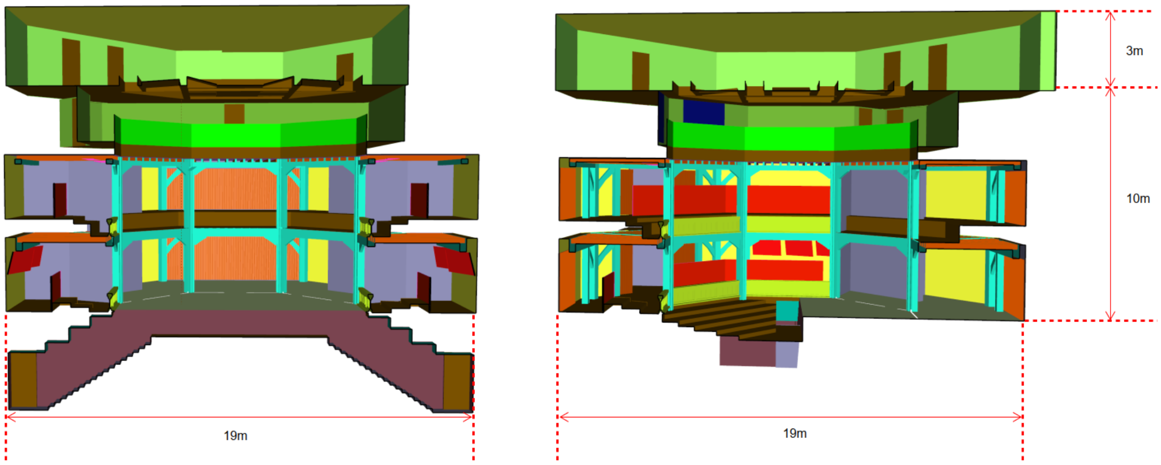

Figure 4 – Playhouse dimensions

3.3 Hit-And-Miss Panelling

Room acoustic design of the Cockpit Theatre presented an exciting challenge as the structural timber frame left very little space for acoustic treatment to be incorporated and any acoustic finishes that were included needed to be ‘invisible’ so as not to detract from the Shakespearean replica environment. Final solutions make use of the limited areas between beams and the rear of balcony seating areas. Working closely with the architect and structural engineers on the historic timber frame, hit and miss type panels were designed to have absorbing and diffusing functions. Considering different timber thickness, spacing and different absorptive backing, this approach provided very effective diffusion across mid to high frequencies and prevents the sound energy travelling to other places in the theatre.

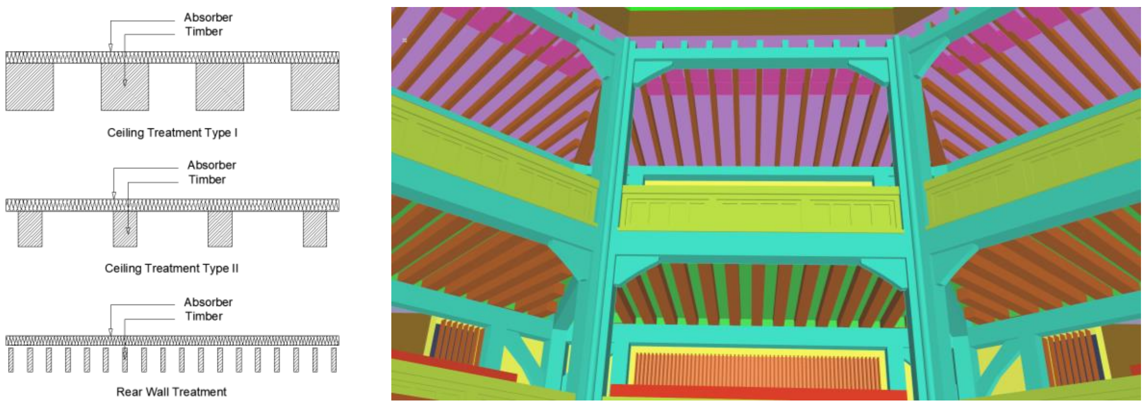

Figure 5 – Hit-and-Miss Paneling

3.4 Early Reflections

With authentic Shakespearean plays relying on actors to use their natural voices, every surface needed to be carefully designed to have the correct acoustic properties. Prior to introducing any absorption elements into the space, our intention was to maintain the early reflections from the significant horizontal and vertical surfaces. This would make sure they offer useful early sound energy to both the audience area and the stage, particularly when the in-the-round stage configuration is implemented. These surfaces included the main coffered ceiling, balcony fronts and the suspended ceiling on the first level, positioned behind the historic timber frame.

3.5 Ceiling Optimisation

Unlike the Shakespeare's Outdoor Globe Theatre in London, the North Playhouse design includes a roof and adjustable ceiling to allow modern technical theatre equipment to travel in and out of the space which has a triple acoustic function:

- decreasing the relative volume of the space to a level that's ideal for unamplified speech;
- helping to direct early reflections onto the audience; and
- providing additional protection from external noise and from rooftop building services equipment.

The octagonal coffered ceiling geometry was optimised using iterative methods through parametric optimisation software to improve reflections during the in-the-round stage configuration. Constrained by architectural requirements such as trap door dimensions and overall ceiling height, the geometry of the remaining ceiling areas were optimised to mitigate acoustic defects and improve speech clarity across the audience planes, especially on the first level balcony level where the reflections were not obstructed by the suspended ceiling and balcony overhangs.

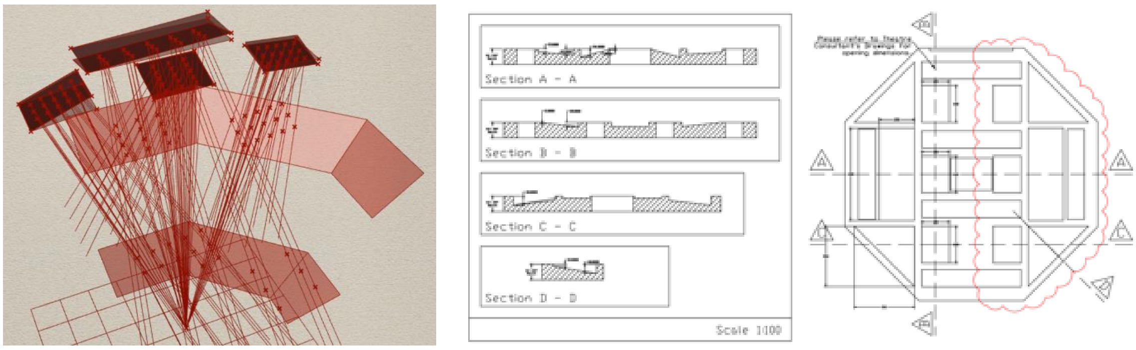

Figure 6 – Parametric Optimisation for Early Reflections from the Coffered Ceiling

3.6 Seats

In general, the primary source of absorption in performance spaces comes from the seats and the audience. In mid-size theatre halls (for a room volume smaller than 5,000m^3) reaching the desired reverberation time is often achievable without having to add additional absorption. However, historical designs feature acoustically reflective benches, which possess a narrower row distance compared to modern upholstered seating standards. Consequently, this leads to notable distinctions in scattering and absorption coefficients between occupied and unoccupied scenarios. As a result, our foremost recommendation for the audience benches is the incorporation of well-cushioned seats, along with rear backings for the rear seats following stakeholder prototyping. This strategy aims to minimise the contrast between occupied and unoccupied conditions while reflecting the balance between historic replica and modern acceptable comfort standards.

Figure 7 – Seats and adjustable curtains

3.7 Adjustable Curtains

In addition to seating upholstery and the inclusion of 'invisible' acoustic finishes between the structural beams, heavy acoustic curtains were introduced to provide variable room acoustic conditions for the various stage configurations. This measure also addressed acoustic anomalies stemming from variations in scattering caused by changes in theatre occupancy.

3.8 Control of Background Noise Levels

Noise from ventilation systems and typical modern city noise sources, would not have been part of the Jacobean theatre experience and they had the potential to seriously detract from the atmosphere inside. The building services systems and the envelope constructions were therefore carefully designed to minimise noise from these sources. This required a fully integrated design approach to make sure optimum conditions were achieved within.

For example, the smoke extract strategy for the building required large openings through the wall on the noisiest façade of the building. This made it challenging to prevent noise from road traffic and overflying aircraft from breaking into the auditorium. Therefore, to meet the very low internal background noise level target in the cockpit theatre, a bespoke attenuation design was adopted which uses high performance smoke vents in combination with a sound lock-type, large airgap between these and the playhouse itself creating a performer crossover space behind the stage.

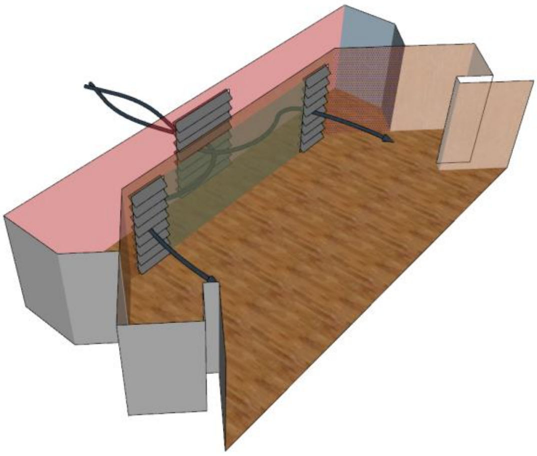

Figure 8 – Smoke Extract Strategy

3.9 Sound Insulation

Sufficient sound insulation is essential for ensuring privacy and minimising disruptions caused by noisy activities in adjacent spaces. Given the concurrent usage of both the studio theatre and the playhouse, the internal sound insulation requirements were established based on noise levels in the receiving room and typical sound levels in the source rooms. To meet the sound insulation requirements, the design incorporates high-performance walls, utilising high-density blockwork and independent high-density plasterboard linings. In addition, all doors to the playhouse consist of lobbied doors 35 to 42 dB R_w with at least a 1.5 m separation forming fully treated sound locks.

The roof is the most critical construction acoustically, primarily due to the presence of numerous plant units situated directly above the playhouse. To effectively manage noise transmission from these plant items, such as air handling units and extract fans, a floating floor construction has been employed. By adopting this approach, a successful solution has been achieved to mitigate both airborne and structure-borne noise transmission.

Because of the critical adjacency of the ground floor toilets and the cockpit passage, which is open to the Playhouse, particular attention was given to the control of structure borne noise from the toilets. The project was advised to avoid directly fixing cisterns and sinks to the walls adjoining the Playhouse and a double-layered wall structure was recommended for this purpose. Additionally, the inclusion of an independent acoustic lining on the side facing the cockpit passage was suggested.

4 MODELLING RESULTS

Using state-of-the-art acoustic modelling and auralisation techniques, we were able to build a virtual version of Inigo's 'perfect' theatre with notable uncertainties from the existing plan and to listen to how it would have sounded in real life. Combined with the benefit of greater acoustic understanding developed over the intervening centuries, we were able to objectively assess the resulting room response and visualise how speech would have travelled throughout the theatre. Using a variety of acoustic techniques including ray-based room acoustic modelling, we then balanced this with the higher expectations of modern audiences to eliminate obvious acoustic defects and to develop a truly authentic, but optimised, version of the playhouse.

Our simulations indicated that the criteria for both the RT and STI would be satisfied for the majority of seats in the Playhouse, a small number of lateral seats fell slightly below the criteria. Based on the results from ray tracing solutions, we also determined that the increased volume from the additional attic level, when the trap doors are open, would not compromise speech intelligibility.

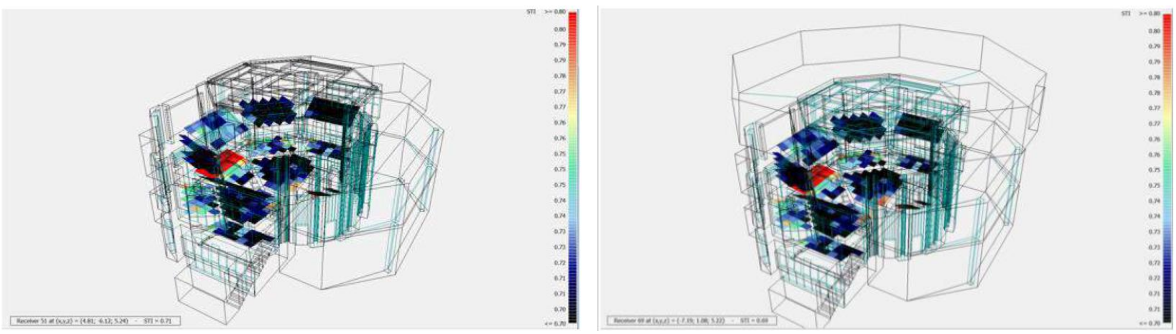

Figure 9 – Change in speech intelligibility

5 COMMISSIONING TESTING

Testing for room acoustics was carried out in-line with the appropriate testing guidance contained within ISO 3382-1:2009 Acoustics — Measurement of room acoustic parameters — Part 1:

Performance spaces and DIN18041 Acoustic quality in rooms – Specifications and instructions for room acoustic design.

The playhouse was empty during the measurements, but the fixed end stage was in place without frons scenae. The curtains located at the ground and first floor were opened and closed during the testing respectively, with results provided for each scenario given in Figure 10. Given the relative symmetry of the space, measurements were undertaken across one half of the audience at 7 receiver positions.

The main parameter measured during the room acoustics testing was reverberation time (RT), however, other room acoustical parameters such as speech transmission index (STI), articulation loss of consonants (ALcons), early decay time EDT and clarity (C80), and Definition(D50) have also been measured.

The reverberation time results are very consistent for all receiver locations with open and closed curtains and in line with the design target. Based on the reverberation time results, the targeted reverberation time performances covering speech frequencies were achieved at all locations, however, some locations show a peak in the low-frequency reverberation time under the empty conditions. It is expected that low frequency absorption will be improved when the space is occupied such that the small exceedances are expected to be within the target range. This is because the audience provide further absorption.

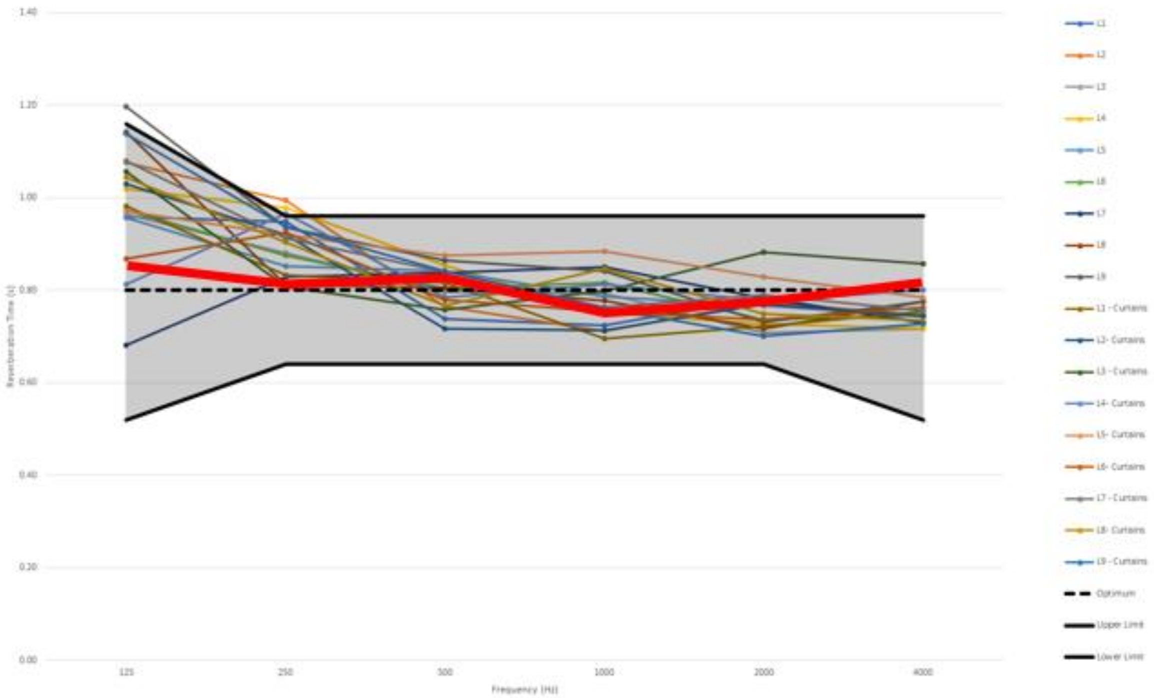

Figure 10 – Measured vs. Predicted Reverberation Time Results

In terms of the use of curtains, the measurement results showed that the additional absorption played a significant role when controlling the reverberation time at side seating locations on the ground and first floor. It was noted that the curtains in front of concrete walls with an airgap improved the low-frequency absorption, and provided a flatter reverberation time curve when deployed. It is therefore concluded that curtains should be drawn across the walls to achieve broadband absorption within the volume, especially when the playhouse is not fully occupied.

Commissioning tests undertaken on completion showed a high level of correlation with the room response predicted using acoustic modelling. The levels predicted during the design stage were accurate at mid to high frequencies, however in practice the response at low frequencies were up to 15% higher than predicted. As the measured reverberation time averages are still within the specified range, the room response is considered to be compliant at the assessed seat locations for the in-the-round arrangement. In addition, it is expected that the frons scenae would improve the diffusion at mid and high frequencies, which would be helpful for speech events.

Impulsive signal measurements were analysed for the measurement of energy parameters STI, ALcons, C_{80}, D_{50} and EDT. The results were recorded and post-processed using a signal acquisition package. Table 3 shows the measured average values at 500-1000 Hz calculated in accordance with ISO 3382-1 guidance.

The Early Decay Time (EDT) is a reverberation time derived from the initial 10 dB of decay. It is known to be more closely associated to the sensation of reverberance than a T_{20} reverberation time (decay time over 20 dB drop) and is an important metric indicating the proportion of beneficial reflections that arrive at a listener's location. An ideal target is for EDT to be similar to T_{20} reverberation time. As the results in the below table show, the EDT is very similar to the 0.8 s measured for this parameter and is therefore sufficient for a playhouse. In addition, the EDT/RT ratio of 93% indicates sufficient early reflections in the playhouse due to the balcony fronts and coffered ceiling geometries.

Clarity, C_{80}, is a measure of how easily individual notes in music can be heard and Definition, D_{50}, is a similar parameter for speech, being an indicator of how easily different parts of speech can be clearly heard. As a venue primarily designed for unamplified speech, the optimum value for definition and Clarity in the 2000m^3 playhouse is provided in the below table.

Based on the STI and ALcons measurement results, the intended levels were successfully attained at most positions. Nonetheless, a few specific locations exhibited minor exceedances under empty conditions, which also aligns with our predictions derived from room acoustic studies conducted during the design phase.

Table 3 – Summary of room acoustic measurement results

RT (Reverberation Time)	0.80 s
EDT (Early Decay Time)	0.75 s
EDT/RT Ratio	93%
STI	0.67
ALcons	5%
D50 (Definition)	64%
C80 (Clarity)	6 dB

Aside from the room acoustic measurements, the background noise levels and sound insulation performances have also demonstrated compliance with our designated design targets:

Table 4 – Summary of other measurement results

Playhouse Background Noise Levels with Building Services	24 dB L_{Aeq}
Sound Insulation between Playhouse – Foyer	56 dB D_{nTw}
Sound Insulation between Playhouse – Loading Bay	58 dB D_{nTw}
Sound Insulation between Playhouse – Exhibition Space	71 dB D_{nTw}

6 WHAT'S ON?

The Shakespeare North Playhouse opened on the 15th July 2022 with the octagonal end-stage form of Henry VIII's Cockpit, and went into the in-the-round form in September 2022. The exciting opening season included; A midsummer Night's Dream, A Christmas Carol, Serious Nonsense Festival, An Evening with Johnny Vegas, Rubbish Romeo and Juliet and As You Write It, a collaboration between Shakespeare North Playhouse and BBC's The One Show to find and showcase new young writers. An interpretation of Inigo Jones's frons scenae was recently installed, and the new season will open its doors with "Macbeth" as the first production against this historical backdrop. With the recent reconstruction works the Cockpit Theatre, nestled within the heart of Shakespeare North Playhouse, is now the only other Frons Scenae in the UK outside of London, the other being situated in the Sam Wannamaker Playhouse in Shakespeare's Globe.

Since its opening last year, Shakespeare North has achieved remarkable success, effectively utilising its adaptable stage configurations to accommodate a diverse range of performances. This successful arts project has already seen significant energy and investment being brought to the area and will continue to leave a lasting legacy as a world class performance venue.

"*Its acoustic is spot-on and it feels cosy but not claustrophobic.*"(Robert Gore-Langton, The Spectator)

7 ACKNOWLEDGEMENTS

AECOM Acoustics would like to thank those who have made substantial contributions to the achievement of acoustic excellence of Shakespeare North.

- Audra Ross, Siobhan Bird (Knowsley Metropolitan Borough Council)
- Corinne Ballarini (AECOM)
- Nick Helm (Helm Architecture)
- Rhiannon Davies (Austin-Smith:Lord)
- Ed Elbourne (Arup)
- Peter McCurdy (McCurdy & Co)

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