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DEVELOPMENT OF "BUDGET" AUDITORIUM SEATS – CHALLENGES IN DESIGN CONCERT HALL AUDITORIUM SEATS DURING PANDEMIC

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ABSTRACT

This paper discusses the design, realization and acoustical performance of a budget chair design for a newly opened small music school concert hall, located in Jastrzębie Zdrój, Poland. Several design aspects are discussed: choice of seats foam and upholstery fabric based on airflow resistance, as well as the influence of the fabric lamination process on the acoustical properties of the seats. Chair design, as well as the reverberation chamber measurements of the absorption characteristics of several chair variants are also described, followed with the acoustical performance of the finished seats as installed in the auditorium. Finally, it is described how we managed to measure the absorption of the occupied seats within the pandemic restrictions regarding human-to-human contact.

Keywords: *auditorium chair, air flow measurements, sound absorption.*

1. INTRODUCTION

The design of auditorium seats typically focuses on aesthetics (the type of upholstery, its colour, and "touch"), durability (fabric abrasion resistance), ergonomics (foam stiffness and elasticity), and cost. Acoustical properties are generally not considered important, hence sound absorption measurements, both for complete chairs and their components (fabric, foam), are only known for the most expensive products intended for concert halls. In a small 350-seat music school concert hall, which opened in 2021 in the mining city of Jastrzębie Zdrój, Poland, the cost of a single seat was limited to approximately 200 Euros. This eliminated all products with sound absorption data declared by the manufacturers. The first two authors, who were responsible for the acoustic design of the hall, were then involved in the selection of materials for a local seat manufacturer. The manufacturer accepted the challenge of producing audience seats at this price, without compromising high aesthetic and acoustical requirements. Below, we briefly describe what we have learned from this cooperation.

2. SEAT SHAPE, FOAM AND FABRIC SELECTION

The design process began by identifying a relatively compact seat (55 cm wide) from the manufacturer's portfolio of pre-existing chair designs, which had a wooden (non-absorbent) back and base, a reclining seat bottom and solid armrests (Fig.1). Given the limited volume of the Jastrzębie concert hall, the aim was to design a lightly-absorbing seat, with potentially high absorption primarily at low frequencies. This was required to compensate for the limited low frequency absorption in the hall, as large areas of the walls were finished with smooth concrete (see separate paper at FA2023). In order to investigate the possible influence of the position of the seat bottom when not in use (vertical or inclined), and the size of the 'gap' between the back and base on absorption at low

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frequencies, two versions of the seat bottom were developed (Fig.2). Architecturally, the seat was intended to be finished in black painted wood, with black 'woven' fabric (Fig.2, right).

Figure 1. Preliminary seat design

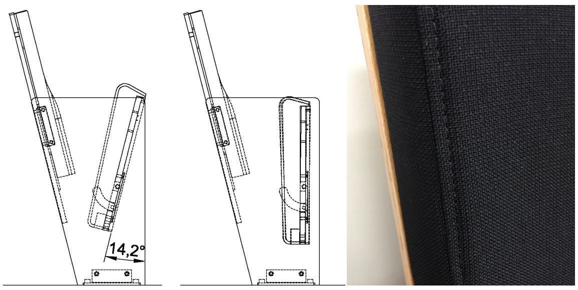

Figure 2. Left: two types of seat bottom inclination angle prepared for final measurements of sound absorption of a block of 20 seats in reverberation chamber; Right: fabric “Type 1” used in all seats in those measurements (Rs=115 Pa×s/m).

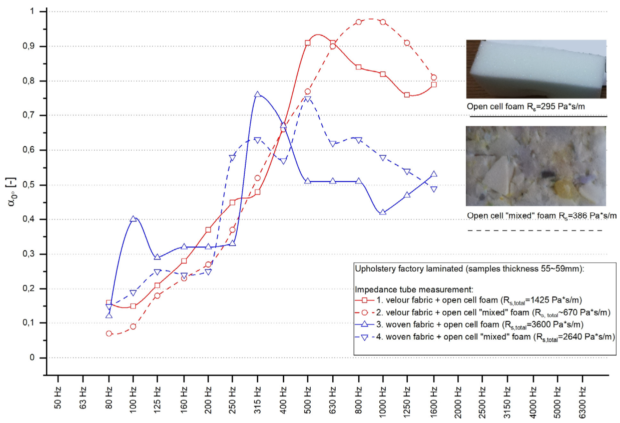

Figure 3. Influence of the lamination process on the sound absorption coefficient, as measured in an impedance tube, for two types of foams (typical open-cell foam, and a 'mixed' open-cell foam from 'rebnd' processing of different types of recycled foams), and two types of fabrics: velour 135 g/m^2 with 200 Pa×s/m ('Type 2') and woven 354 g/m^2 with 2560 Pa×s/m ('Type 3').

The next step was to select the appropriate foam [1]. Typically, low-cost chair manufacturers utilise closed-cell PE foam (injected into moulds), as it is cheaper, easier to shape, and more durable than open-cell foam. Acoustically, closed-cell PE foams have significantly higher airflow resistance (1400 and 6300 Pa×s/m in our case) than open-cell PE foams, so closed-cell foams were dismissed for this project. After further measurements, a softer open-cell foam (~29 kg/m^3 and ~300 Pa×s/m – see Fig.3, upper image) was planned to be used for the seat backs, whilst a slightly firmer open-cell "mixed" foam created from “rebond” processing (~63 kg/m^3 and ~390 Pa×s/m – see Fig.3 lower image) was designated for the seat bases. Firmer foams are favoured for seat bases due to durability requirements, whilst softer, more elastic foams are necessary for comfortable backrest support. The subsequent step – arguably the most aesthetically important – was the selection of fabric. The architects desired a "wavy" appearance for the chair fabric, but around 10 different fabrics selected by the architects, based purely on visual preference, had excessively high values of airflow resistance when measured (range of 1000 ~ 2560 Pa×s/m). It is worth noting that none of these fabrics provided any information about their airflow resistance in the datasheets, so access to equipment allowing frequent measurements of airflow based on ISO 9053 (part 2 in our case) was vital. Eventually, a slightly more expensive, but highly permeable polyester fabric “Type 1” was found with an airflow of only ~115 Pa×s/m. This fabric, with its "wavy" pattern, was approved by the architects and it was decided that the chairs would be upholstered in this material (see Fig.2).

3. INFLUENCE OF LAMINATION

Assessing fabric and foam airflow resistance, we anticipated the upholstery's total airflow to be around 500-600 Pa×s/m, providing strong absorption (α_W=0.95 when calculated for a 50mm sample thickness). This was substantiated in measurements with fabric atop foam. However, the manufacturer opted for a heat lamination process using 'laminating foam' to bond fabric and foam, crucial for durability. The lamination's adverse impact was first noted while evaluating the absorption coefficient in an impedance tube for two preliminary upholstery types, as depicted in Fig.3. Fig.3 clearly shows a significant reduction in the absorption coefficient from about 500Hz upward, more pronounced with the heavier woven fabric (Type "3") requiring more heat for lamination, compared to the lighter velour fabric (Type "2"). The measurements also highlight that the absorption curve for velour fabric (Type "2"), laminated to "mixed" foam, aligns more closely to the predicted sound absorption based on it's airflow resistance than when laminated to the lighter open-cell foam. Though our initial tests used small samples (25x25 cm), we hoped the final process might vary. However, as Table 1 indicates, airflow measurements on 10 final samples (with fabric "Type 1"), cut from several full-scale seat cushions, displayed the lamination process's considerable impact. The process increased airflow resistance and its inconsistent quality (varying heat and pressure?) led to a wide spread in airflow readings depending on the sample's origin, raising concerns of unpredictable sound absorption in the final seats. To further investigate these concerns, we requested measurements of 20 seats in a reverberation chamber with two backrest variants (both foam types), to examine sample variation and the lamination process's impact on the final seats and a broader selection of chairs. We also noted that the denser open-cell "mixed" foam was less susceptible to lamination than the more elastic open-cell foam. Hence, from an acoustical perspective, "mixed" foam presents a safer option for fabric lamination. Therefore, we considered replacing the less dense foam, typically preferred for backrests due to audience comfort, with "mixed" foam.

Table 1. Airflow resistance measured for 10 samples (50mm thick) cut out from several different seat samples.

10 samples	Airflow resistance [Pa×s/m] fabric "Type 1"	
	laminated to open cell foam (50mm)	laminated to open cell "mixed" foam (50mm)
average	1277	509
min-max	521 – 2030	442 – 612
std.dev.	575	53

4. REVERBERATION CHAMBER AND IN-HALL MEASUREMENTS

Before mass-producing 350 seats, we tested a sample group of 20 in the Silesia Technical University's reverberation chamber in Gliwice (Fig.4). The setup comprised four rows of five 55cm seats each (total size 288x364 cm) with a 90 cm distance between rows. Employing the K&K method [2,3], the seats were positioned in the room corner, flanked by 90cm high plywood screens on two sides. Due to time constraints, we only measured a single unoccupied configuration both with and without screens, akin to [4]. We evaluated two seat bottom versions (vertical and inclined, as depicted in Fig.2) and tested backrests with three different foam thicknesses (50 mm, 30 mm, and 0 mm - just wood). In total, we measured 14 configurations, including 4 with an audience. Based on these tests, we selected a design with a vertical seat bottom and 50 mm open-cell foam on the backrest and 50 mm "mixed" foam on seat bottom. The results for this configuration alone are discussed further below.

Figure 4. Seats in reverberation chamber, before installation of screens on two sides.

During installation of all seats, we also measured their's sound absorption in-hall, and compared it (Fig.5-6) with our earlier lab measurements and Beranek curves [5]. We also used Bradley [6,7,8] P/A correction taken from [8, Table 4] to compare lab measurements to Beranek [5,9] absorption coefficients. What was observed from in-hall measurements (Fig.5), that sound absorption of choir seats (which were installed at choir balcony with slope ~33º) is higher in low frequencies, than sound absorption of other seats located at much flatter parterre (~19º) and flat side galleries. Therefore, sound absorption data from ISO354 measurements of flat seat samples should be cautiously applied to steeper audience areas when calculating reverberation time (RT). As sound field in a concert halls is not perfectly diffuse, placing absorbing audience area on a steep slope, especially high-up in the hall, might reduce reverberation time more than expected, as this introduce absorption into the upper reverberation volume, which otherwise can be used as a "reservoir" for longer RT [10].

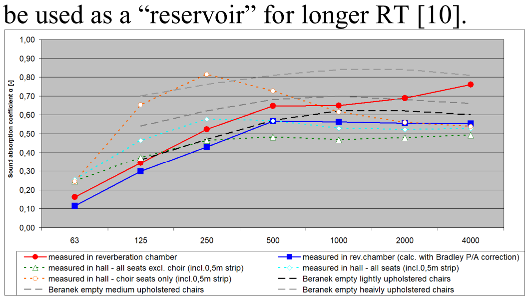

Figure 5. Sound absorption of empty chairs measured in reverberation chamber and in hall.

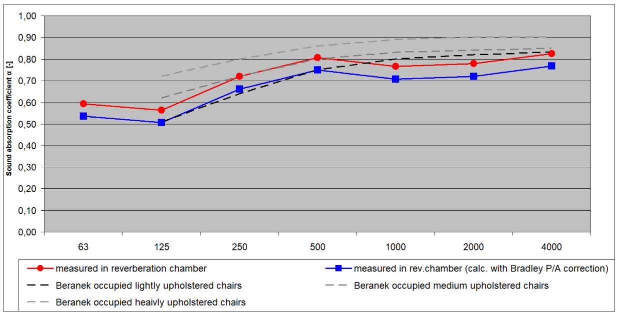

Figure 6. Sound absorption of occupied chairs measured in reverberation chamber.

As we found ourselves amidst the pandemic in April 2021, we were unable to permit individuals to occupy the reverberation chamber for reasons that were clearly apparent. In order to simulate the sound absorption of a seated audience, we utilised twenty polypropylene mannequins [similarly as in 11], each weighing 5kg and dressed in realistic clothing – dress 20 mannequins was really a refreshing experience!

Figure 7. Our "pandemic-proof" audience !

5. SUMMARY

1. When designing new concert hall seats, full acoustic oversight, including airflow component measurement, is key to anticipate final product sound absorption.
2. Smaller chair manufacturers often lack understanding of the link between manufacturing and acoustic properties.
3. Lamination reduces airflow and chair sound absorption (above 500Hz in our case). Could be acceptable in specific venues (like Jastrzębie Hall), but can cause issues elsewhere, especially if fabric is laminated to lower-density foams.
4. Sound absorption coefficient of steep audience areas in final hall, can be underestimated when measured in reverberation chamber for a group of chairs placed flat on a floor.

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