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ARCHITECTURAL CONCRETE IN AUDITORIUM DESIGN OF A 350 SEATS CONCERT HALL: ACOUSTIC DESIGN AND PERFORMANCE

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ABSTRACT

This paper discusses the design, realization and acoustical performance of a recently opened 350 seats music school concert hall, located in Jastrzębie Zdrój, Poland. Several design aspects are discussed: building budget restrictions (< 2mil. Euro), how the design developed since the competition entry, and restrictions due to cost optimization in material selection. Geometrical design of "wavy" reinforced concrete walls is detailed as well as the acoustical performance of the finished auditorium. Construction details of the interior surfaces their influence on the acoustics are also discussed.

Keywords: *concert hall, concrete walls, reverberation time, room acoustics.*

1. INTRODUCTION

At the end of 2016, the results of a second[1] architectural competition for a new 1700 m^2 complex of a Music School, including a 350-seat/4630 m^3 concert hall in the mining city of Jastrzebie Zdrój, Poland, were announced. The winner was a local Silesian architectural company, SLAS Architekci. The authors were asked to assist the architects in acoustically designing the concert hall. The hall successfully opened in December 2021. The preliminary building cost was 2.0 million Euros, with 100k allocated for complete design (including acoustics). The building cost finally increased (after troubles and a change of general contractor) to 3.6 million Euros[2]. 75% of the building cost was financed by EU funds. The finished building exterior (Fig.1) and plans/section/interior from the competition phase (Fig.2-3) are shown below. More can be found in [1].

Figure 1. Jastrzębie Zdrój hall – exterior (finished)

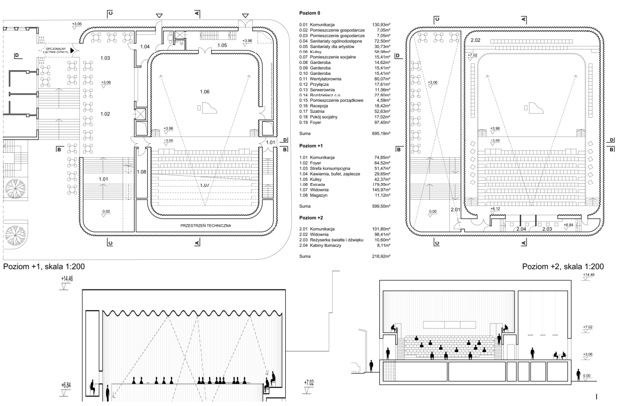

Figure 2. Plans/sections (from competition phase)

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[1] The first competition, which concluded in 2014, was won by Konior Studio, the designer of the well-known NOSPR concert hall in Katowice, Poland. However, after winning, the architect requested an increase in the design fee, and the competition was subsequently cancelled.

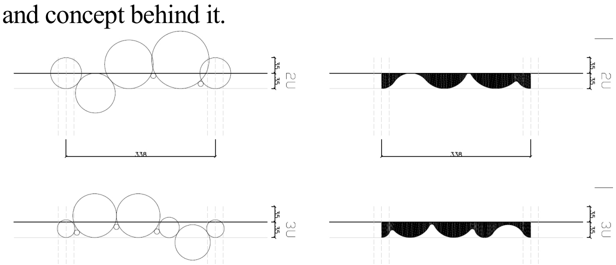
[2] There is typically no proportional increase in the design fee in public tender projects in Poland.

Figure 3. Concert hall interior (at competition phase)

As can be seen from the competition proposal (Fig.2-3), the building's aesthetics is created by a strong sinusoidal shape, visually linked to sound waves, flowing vertically on the façade and then continuing inside the hall, onto walls and the ceiling. During the design process, authors discussed with architects several possible materials and claddings (curved fibre-gypsum boards, curved plywood, curved plasterboards, fibre-reinforced gypsum panels, prefabricated glass-reinforced gypsum, etc.), all of which could be used inside the hall, allowing the preservations of a wavy shape, without compromising acoustical requirements. These are primarily: the ability to adjust mass to control low frequency absorption; the ability to shape the material to any required curvature without being forced to use a limited number of repeating patterns; and the ability to hide installations behind. Regrettably, choosing any of these materials would generate high additional costs[3], on top of the reinforced building structure. Finishing just the walls (approx. 950 m2) and the ceiling (approx. 500 m2) with high-quality cladding would consume ¼ of the total building cost! Hence, the decision was taken to keep the area of cladding to a minimum, to save costs. Slightly curved high-quality plywood was used only on the lower parts of the walls (approx. 150m2). The ceiling was constructed as several flat panels, painted black, hung at slightly different heights (to gently diffuse ceiling reflections and make them slightly out of phase). Typical, inexpensive plasterboards were used with mineral wool on top, to maximise low-frequency absorption[4]. Most importantly, and acoustically challenging, the entire upper wall area was designed to be finished in smooth cast-in-place concrete in a sinusoidal-like shape. As these walls were structural to the hall, in the architects' minds, the additional cost was just a few more cubic metres of concrete and more elaborate formwork.

2. CONCRETE WALLS

Auditoriums with concrete walls were designed before. Examples could be Bavarian hall in Blaibach by Peter Haimerl Architektur with Muller-BBM as acoustical consultant [2], Cultural Centre in Cartaxo, Portugal by CVDB arqutectos with Certiprojecto as acoustical consultant [3], Polish Jordanki Cultural and Convention Center in Torun, designed by Fernando Menis with Pedro Cerda as acoustical consultant [4] or Dora Stoutzker Hall in The Royal Welsh College of Music & Drama designed by BFLS Architects with ARUP as acoustical consultant [5]. Concrete side walls pose several challenges for design. Firstly, once constructed, they cannot be altered or optimized, thus any design error is permanent. Secondly, they absorb almost no sound energy. This can be both advantageous and disadvantageous. One might appreciate the strong sound reflection from a concrete wall. However, in contrast to typical cladding used in concert halls, they cannot absorb low-frequency sounds. Their mass cannot be manipulated to fine-tune required low-frequency absorption, so if concrete covers a large area in a concert hall, there's always a risk of prolonged reverberation time at low frequencies. It could be argued that in many concert halls where walls are finished with typical light-weight cladding, there is excessive low-frequency absorption, but it's always preferable to have the ability to reduce it than not being able to increase it[5]. Thirdly, shaping reinforced concrete walls for optimal sound diffusion is challenging, especially when aesthetic and construction constraints limit acoustic needs. Fig.4 displays preliminary shapes, whilst Fig.5 illustrates the final shape of reinforced concrete walls and concept behind it.

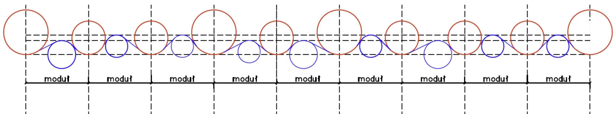


[3] For example: price of wooden cladding was estimated around 500€/m^2; price of glass reinforced gypsum elements for similar hall in Switzerland was around 400€/m^2; that's just material prices, excluding installation cost.

[4] To further increase low frequency absorption, two out of eight ceiling sections (125m^2) and all canopy backs (70m^2) were also designed as dedicated low frequency absorbers tuned to 63-125Hz octaves.

[5] For example in Blaibach hall low frequency absorption is achieved by slits between concrete panels and dedicated low frequency absorbers behind. But that requires subdividing the concrete elements, which was not possible in Jastrzebie due to aesthetical constrains.

Figure 4. preliminary acoustical proposals for sinusoidal-like shape of reinforced concrete walls



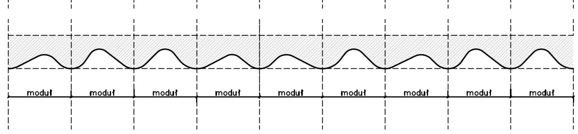


Figure 5. final acoustical design of walls (module=112,5cm; max. depth of modulation=35cm)

Acoustical criteria behind the design of shapes shown on Fig.4 and Fig.5 were primarily linked to diffusion. Several factors were taken into consideration for final shape of Jastrzębie walls (Fig.5): maximizing the depth of modulation and increasing the “repeat distance” [6], minimizing periodicity [6], use of simple geometrical shapes (circles) to make formwork manufacturing easier. Final depth of around 35cm should allow sound diffusion from around 500Hz up, similarly like we measured in some previous halls [7]. We as acousticians designed the wall shape, and consulted with architects for aesthetical approval. It was agreed with architect that due to aesthetical demands, all peaks of the sinusoidal-like shape needed to be aligned in one plane, so we only varied the depth of modulation. As these walls are only situated in the upper part of the hall (distant from the audience), the need of the diffusing upper walls is primarily to avoid echoes back to the audience or stage from long reflection paths including upper walls-flat ceiling. This can be achieved with wall diffusion only in the horizontal (or vertical) plane. Notably, the diffusion from Jastrzębie wall shape is only 2-dimensional (in the horizontal plane). The consequences were most evident in the hall prior to the roof installation, leaving the room with 500 m^2 of "perfectly absorbing material" on the ceiling. Without the roof, one could easily hear the extended reverberation generated in the upper volume of the hall, gradually descending down and fading. The higher RT-values recorded in the case without the roof in the balcony positions compared to the parterre (stalls) positions confirms the existence of this 2D sound field. It would probably have looked much the same had the upper walls been plane and vertical.

To reduce the cost of the formwork structure (templates with frames), the shape of the walls was optimized so that during construction, only one formwork could be used symmetrically in each corner of the hall for concrete pouring (Fig.7). This resulted in the need to reuse one formwork multiple times. We conducted tests on mock-ups (Fig.8) to determine how many times the surface of one formwork could be used before the concrete surface became too rough (due to the bending of the plywood and excessive moisture), which could result in unwanted high-frequency absorption. Ultimately, the same plywood surface was used for a maximum of two pouring sessions. The finished wall surface was then painted black using silicate glazed paint (Fig.9).

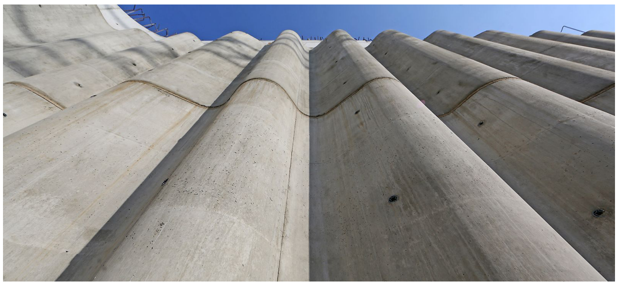


Figure 6. Concrete walls before installation of the roof.

Figure 7. Creation of formwork for concrete works

Figure 8. Verification of concrete quality

Figure 9. Jastrzębie Zdrój – finished hall interior

3. ACOUSTICAL PERFORMANCE

Jastrzębie is a music school hall, so the ability to change the acoustical environment is, in the authors' opinion, crucial for teaching students to adapt to different acoustical conditions. To allow acoustical variability around 290 m^2 of highly absorbing banners (in 17 sections) were installed in the hall on walls, with additional 30 m^2 of banners and 30 m^2 of curtain were placed around stage. At design we aimed at achieving around 2,2 sec of reverberation in empty hall with orchestra on stage (or even slightly higher for choir recordings) and allowing to reduce reverberation time down to 1,4sec for amplified concerts. The locations of banners on the walls (1-17), banners around the stage (18,20) and the curtain behind the stage (19) are shown in Fig.10.

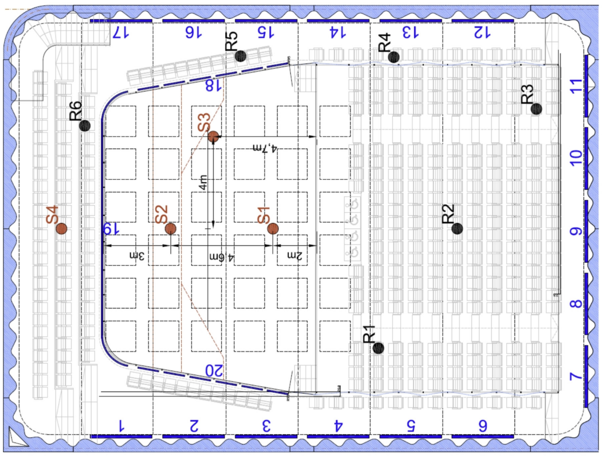


Figure 10. Location of banners & curtains in the hall. Each individual banner can be mechanically deployed.

After construction was completed, the acoustical performance of the finished hall was evaluated using typical ISO3382 measurements. Only Reverberation time (T_{20}), measured without an audience in different hall configurations, is reported here in detail (Fig.11). Reverberation time (T_{20}) can be adjusted using mechanical banners, from 2.5sec down to 1.4 seconds. Clarity (C_{80}) is around -1dB without banners, and up to 2dB with all banners. We also measured the hall with an audience in configuration 14 (only with stage curtain and chairs on stage). This was conducted during the opening concert with approximately 50% of the audience scattered throughout the hall due to COVID restrictions. T_{20} curve with 50% of audience is added to Fig.11 (in red colour). To indicate the changes in RT over the audience area, Standard Deviation of T_{20} measurements was shown on Fig.11 for two configurations with highest and lowest reverberation time. It should be noted that in the final hall, the entire stage was constructed with a much thicker and denser wood covering (45mm oak wood) than was recommended from an acoustical perspective. This decision was based on durability, as it's much cheaper to varnish the thick planks every few years than to replace the thinner wooden covering when it becomes visually "worn". Consequently, the sound absorption of the area of the stage in low frequencies was less than we desired.

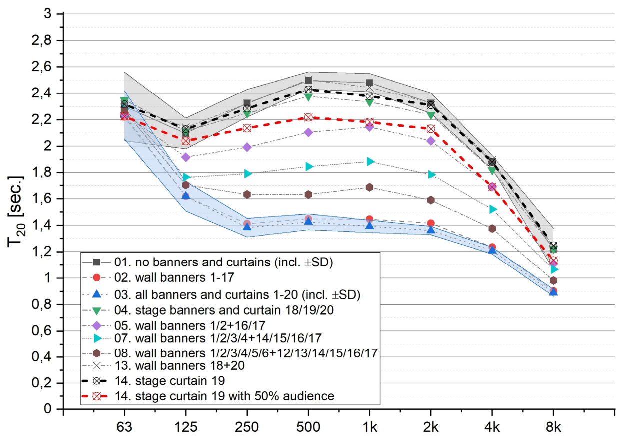


Figure 11. T_{20} measured in finished hall with chairs on stage, without audience (empty chairs), compared with measurement for "Configuration 14" (with only stage curtain), but with the presence of 50% of the audience. For "Configurations 01 and 03" also a ±1 Standard Deviation is shown.

4. SUMMARY

1. The Jastrzębie Zdrój concert hall exemplifies how the interiors of modern halls can be successfully designed with architectural concrete without compromising acoustic performance.
2. Controlling low-frequency reverberation requires that approximately an equal area of the hall interior, covered in architectural concrete, be designed as efficient low-frequency absorbers. This requirement should be agreed with architects from day one of the design process.
3. The design of a minimalist hall, like the Jastrzębie hall, using merely three materials (concrete, wood, plasterboards) each occupying its own, clearly defined space, poses more challenges compared to halls where

the placement of materials is more dispersed. In halls like the Jastrzębie hall, acoustical designer cannot, even if necessary, to visually alter a part of the wall or ceiling, as this will be perceived negatively on a visual level. That is the reason, why fine tuning such halls at final stage is difficult, as any changes to material surfaces are visually unaccepted.

4. For the Jastrzębie hall, the decision to use architectural concrete across large internal surfaces was justified by architects as a cost-saving measure. However, the authors' experience suggests that architectural concrete is highly favoured among modern architects, indicating that similar halls may be constructed. We hope our experience will help others prepare for similar challenges.

5. ACKNOWLEDGMENTS

We wish to express our sincere gratitude to Bartlomiej Ziarko and Gaja Raputa for conducting most of reverberation time measurements, and to the Head of the Jastrzębie Zdrój Music School, mrs. Gabriela Jaworska, for her unwavering support and granting us access to the concert hall.

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