A 350 SEATS CONCERT HALL AUDITORIUM WITH "BUDGET" VERSION CONCRETE SIDE WALLS; ACOUSTIC DESIGN AND PERFORMANCE

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1 INTRODUCTION

At the close of 2016, the outcomes of a second architectural competition for a new 1700 square meter Music School complex were revealed. 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. The project, located in the mining city of Jastrzebie Zdrój, Poland, included a 350-seat concert hall spanning a volume of 4630 cubic meters. The victorious party was SLAS Architekci, a local architectural firm from Silesia. The authors were subsequently enlisted to aid the architects in acoustically designing the concert hall. The hall was inaugurated with much acclaim in December 2021.

Initially, the construction costs were projected at 2.0 million Euros, with a budget of 100k allocated towards the complete design, inclusive of acoustics. However, following several hiccups and a shift in the general contractor, the final building costs escalated to 3.6 million Euros (However, there is typically no proportional increase in the design fee in public tender projects in Poland). ¾ of the building cost was subsidized through EU funds.

The completed building's exterior is illustrated in Fig.1, while the plans, section, and interior from the competition phase are depicted in Fig.2 and Fig.3. More information and visuals are available in reference[1].

Figure 1. Jastrzębie Zdrój hall – exterior (finished)

Figure 2. Concert hall interior (at competition phase)

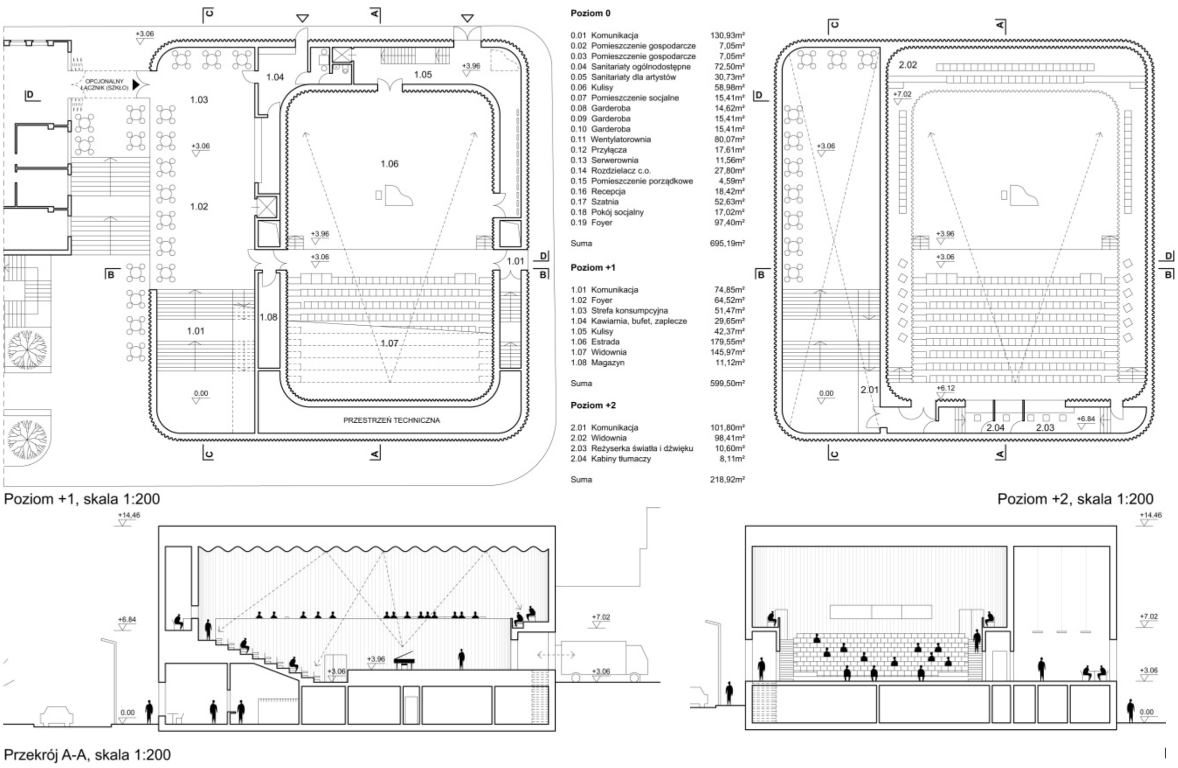

Figure 3. Plans/sections (from competition phase)

As shown in the competition proposal (Fig.1-3), the building's beauty comes from a strong wave-like, or sinusoidal, shape. This shape is similar to sound waves and moves vertically up the front of the building, continuing inside, across the walls and the ceiling of the hall.

During the design process, the authors talked with architects about various possible materials and claddings. These included curved fibre-gypsum boards, curved plywood, curved plasterboards, fibre-reinforced gypsum panels, and prefabricated glass-reinforced gypsum. All these materials could be used inside the hall, allowing the preservation of the wave-like shape, without harming the sound requirements.

These sound requirements mainly include the ability to change the material's weight to control low frequency absorption; the ability to bend the material into any needed shape without having to use the same patterns over and over; and the ability to hide fixtures and fittings behind the material. Sadly, picking any of these materials would make the cost go up a lot, on top of the cost of the building's reinforced structure. 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.

Just covering the walls (about 950 square metres) and the ceiling (about 500 square metres) with high-quality cladding would use up a quarter of the total building cost! So, the decision was made to keep the amount of cladding as low as possible, to save money.

Slightly curved, high-quality plywood was only used on the lower parts of the walls (about 150 square metres). The ceiling was made up of several flat panels, painted black, and hung at slightly different heights. This was done to gently scatter ceiling reflections and make them slightly out of phase. Normal, cheap plasterboards were used with mineral wool on top, to absorb as much low frequency sound as possible. 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.

Most importantly, and this was a challenge for the acoustical design, the whole of the upper wall area was planned to be finished in smooth concrete, cast in place and shaped like a wave. As these walls were a key part of the hall's structure, in the architects' minds, the extra cost was just a bit more concrete and more detailed formwork.

2 REINFORCED CONCRETE WALLS

There have been designs for auditoriums with concrete walls in the past. Some examples include the Bavarian hall in Blaibach, designed by Peter Haimerl Architektur with Muller-BBM as the acoustic consultant[2]. Another is the Cultural Centre in Cartaxo, Portugal, designed by CVDB Architects with Certiprojecto serving as the acoustic consultant[3]. There's also the Polish Jordanki Cultural and Convention Centre in Torun, designed by Fernando Menis with Pedro Cerda as the acoustic consultant[4]. Lastly, there's the Dora Stoutzker Hall in The Royal Welsh College of Music & Drama, designed by BFLS Architects with ARUP as the acoustic consultant[5].

Designing with concrete side walls can bring several challenges. Firstly, once they're built, they can't be changed or improved, so any design mistakes can't be fixed. Secondly, they don't absorb much sound energy. This can be good or bad. On one hand, you might like the strong sound reflection from a concrete wall. But on the other hand, reflections could be too harsh. Also, unlike typical cladding used in concert halls, concrete can't 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 too much low-frequency absorption. However, it's always better to have the option to reduce it than to be unable to increase it.

Thirdly, shaping reinforced concrete walls to spread sound in the best way is a tough task, especially when the look of the building and how it's built limit what you can do for the acoustics. Fig.4 shows the first shapes, while Fig.5 shows the final shape of the reinforced concrete walls and the geometrical idea behind their design it.

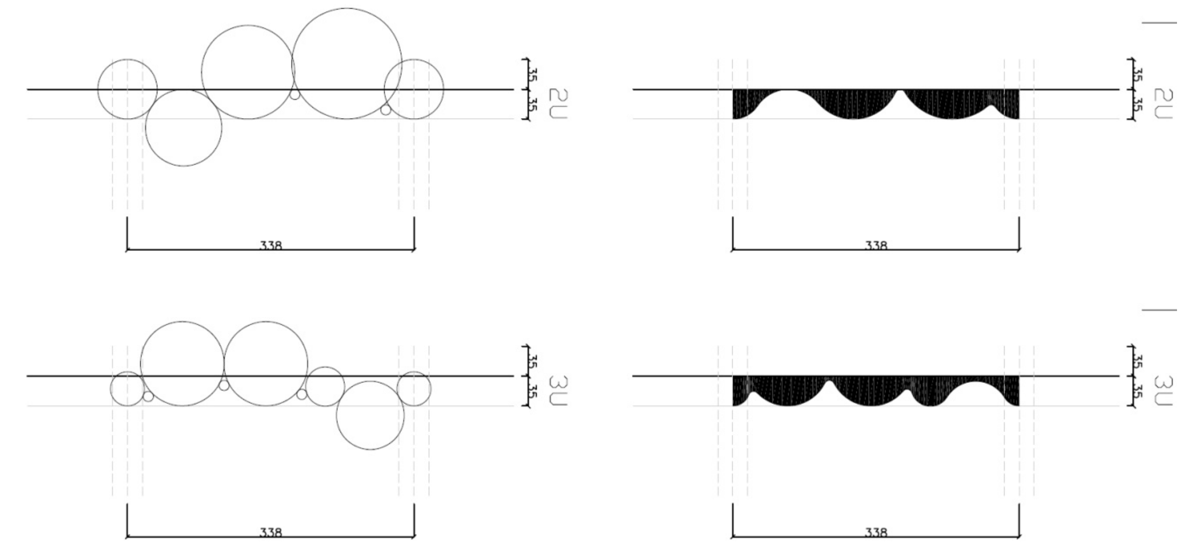

Figure 4. preliminary acoustical proposals for sinusoidal-like shape of reinforced concrete walls

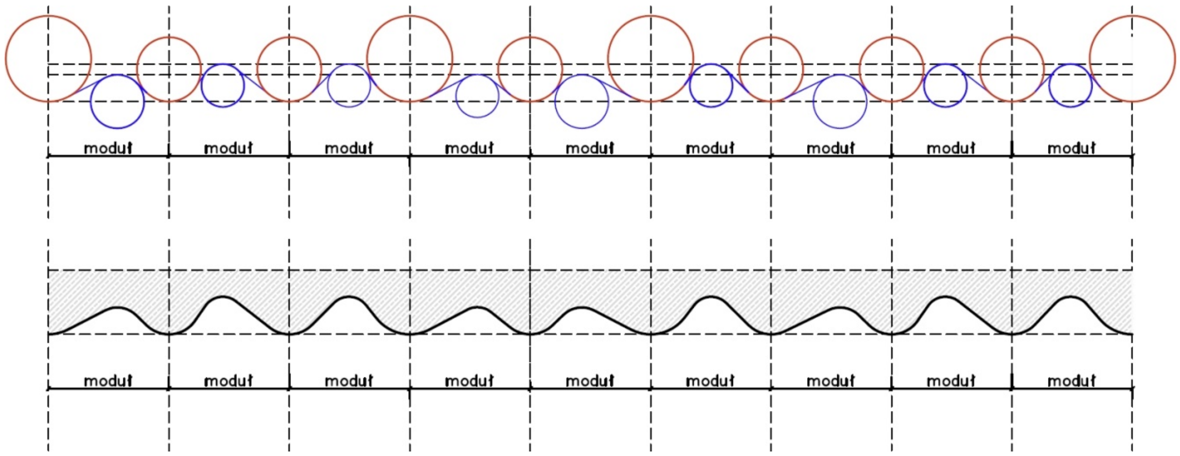

Figure 5. final acoustical design of walls (module=112,5cm; max. depth of modulation=35cm)

The design of the shapes shown in Fig. 4 and Fig.5 were primarily guided by sound diffusion. A number of factors were weighed up for the final shape (Fig.5) of the Jastrzębie walls. These included maximizing the depth of modulation and increasing the 'repeat distance'[6], minimizing repetition[6], and using simple shapes like circles to make the building of the formwork easier.

The final depth of around 35cm should allow sound diffusion from around 500Hz and upwards, much like we have measured in some previous halls[7]. We, as acousticians, crafted the wall shape and then discussed it with the architects to make sure it looked good as well. It was agreed with the architect that all the peaks of the wave-like shape needed to be in line with each other, so we only varied the depth of modulation.

Since these walls are only in the top part of the hall (away from the audience), the main aim of the diffusing upper walls is to prevent echoes from bouncing back to the audience or stage from long reflection paths that include the upper walls and flat ceiling. This can be achieved with wall diffusion in just one plane - either horizontal or vertical.

It's worth noting that the diffusion from the Jastrzębie wall shape is only 2-dimensional (in the horizontal plane). This was most noticeable in the hall before the roof was put on, leaving the room with 500 square metres of "perfectly absorbing material" on the ceiling. Without the roof, one could easily hear the extended reverberation building up in the upper part of the hall, slowly coming down and fading out. 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. If the upper walls had been flat and vertical, the effect of prolonged reverberation probably would have been much the same.

In an effort to cut down on the expense of the formwork structure (templates with frames), the design of the walls was optimized. This way, during the building phase, only one formwork needed to be used symmetrically in each corner of the hall for pouring the concrete (Fig.7). This meant that the same formwork had to be used multiple times.

We carried out tests on mock-ups (Fig.8) to work out how many times the surface of one formwork could be used before the concrete surface became too rough. This roughness could be due to the plywood bending and excessive moisture, and it might lead to undesirable high-frequency absorption. In the end, the same plywood surface was used for a maximum of two pouring sessions.

Once the wall surface was finished, it was then painted black using silicate glazed paint (Fig.9). This was the final touch to complete the aesthetic and acoustical requirements of the concert hall.

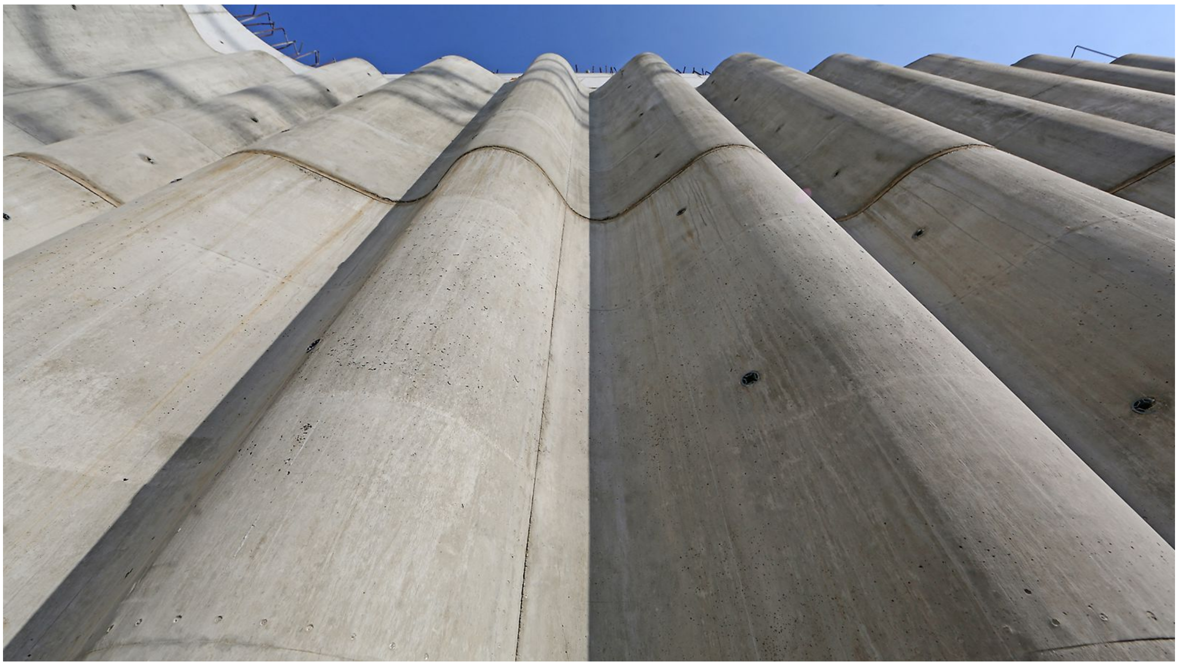

Figure 6. Concrete walls before installation of the roof.

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 serves as a music school hall. In our opinion, the ability to alter the acoustical environment is crucial in order to teach students how to adapt to varying acoustical conditions. To allow for such acoustical variability, around 290 square metres of highly absorbent banners (in 17 sections) were fitted on the walls, with an additional 30 square metres of banners and 30 square metres of curtains placed around the stage. Our aim during the design phase was to achieve roughly 2.2 seconds of reverberation in the empty hall with the orchestra on stage (or slightly higher for choir recordings) and to be able to reduce the reverberation time down to 1.4 seconds for amplified concerts. The locations of the banners on the walls (1-17), the banners around the stage (18,20) and the curtain behind the stage (19) are displayed in Fig.10.

After the construction was complete, we evaluated the acoustical performance of the finished hall using standard ISO3382 measurements. Here, we only report in detail on the Reverberation Time (T_{20}), which was measured without an audience in various hall configurations (Fig.11). The Reverberation Time (T_{20}) can be adjusted using mechanical banners, from 2.5 seconds 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) during the opening concert, with about 50% of the audience spread out throughout the hall due to COVID restrictions. We added the T_{20} curve with 50% of the audience to Fig.11 (in red). To indicate the changes in Reverberation Time over the audience area, we also showed the Standard Deviation of T_{20} measurements.

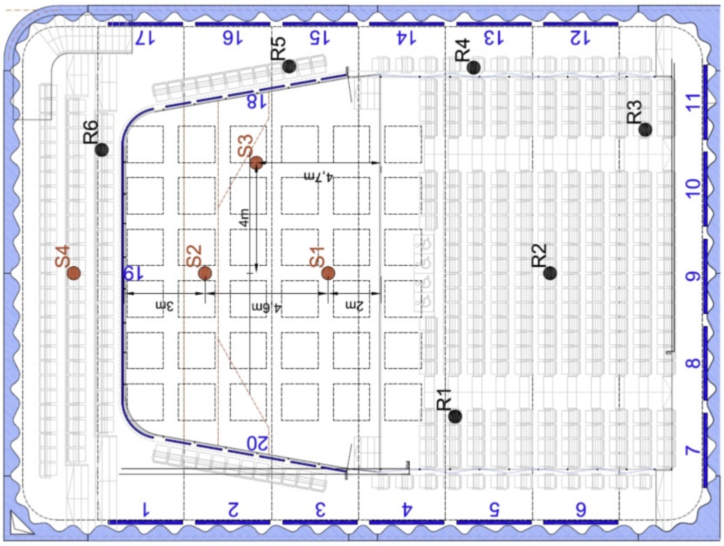

Figure 10. Location of banners & curtains in the hall. Each individual banner can be mechanically deployed.

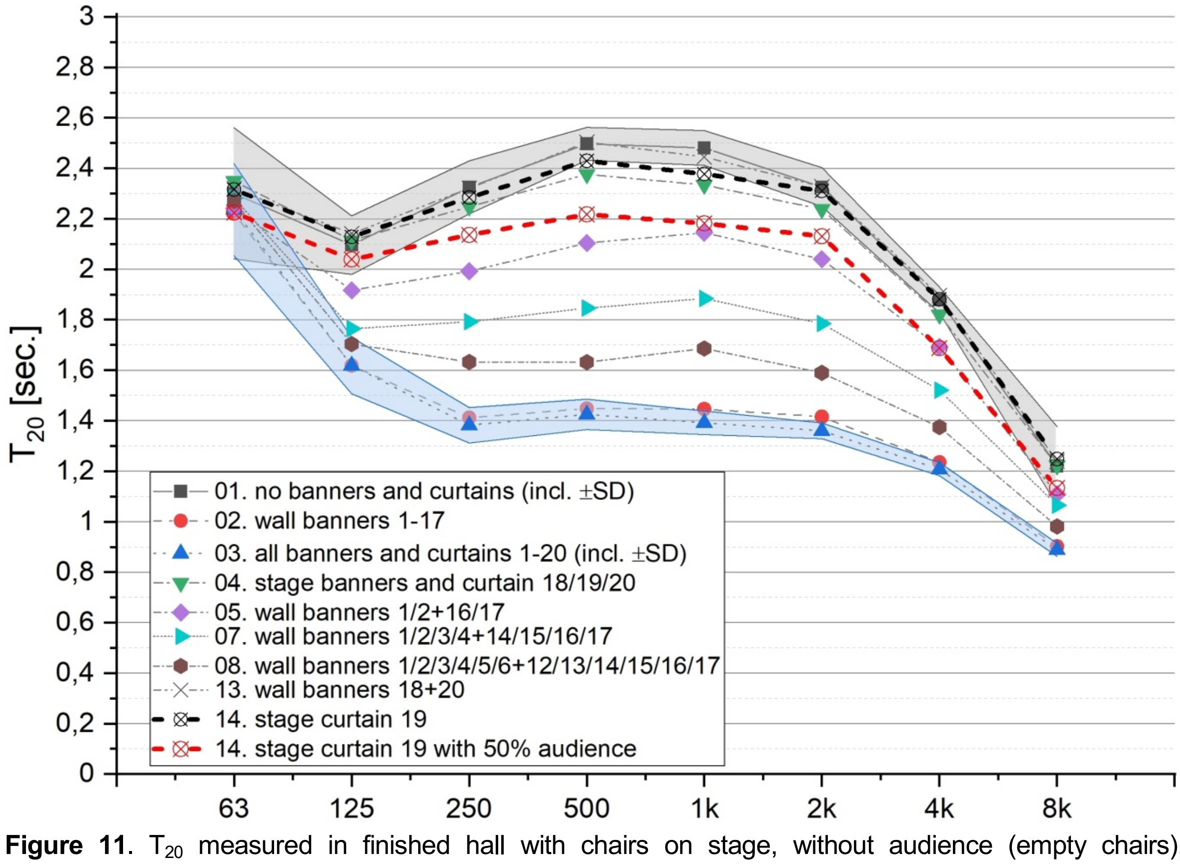

Figure 11. T_{20} measured in finished hall with chairs on stage, without audience (empty chairs), compared with measurement for "Configuration 14" (with only stage curtain), but with the presence of 50% of the audience. For "Configurations 01 and 03" also a ±1 Standard Deviation is shown.

One point worth noting is that in the final hall, the entire stage was constructed with a much thicker and denser wood covering (45mm oak wood) than we had recommended in acoustical design. This decision was made with durability in mind, as it's much cheaper to varnish the thick planks every few years than to replace the thinner wooden covering when it starts to look 'worn'. As a result, the sound absorption of the area of the stage in low frequencies was less than we had originally hoped for.

4 SUMMARY

The concert hall in Jastrzębie Zdrój exemplifies how modern halls can be successfully designed with architectural concrete interiors, without compromising acoustic performance.

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.

The design of a minimalist hall, such as the one in Jastrzębie, utilising only three materials (concrete, wood, and plasterboard), each within its own clearly defined space, presents more challenges compared to halls where the placement of materials is more varied. In halls like the one in Jastrzębie, acoustic designers can't visually alter part of a wall or ceiling, even if necessary, because such alterations will be perceived negatively at a visual level. This is why fine-tuning such halls at the final stage is challenging, as any changes to the material surfaces are usually visually unacceptable.

For the Jastrzębie hall, the decision to utilize architectural concrete across large internal surfaces was justified by architects as a cost-saving measure. However, based on our experience, architectural concrete is highly favored among modern architects, suggesting that similar halls may be constructed in the future. We hope that our experience will help others prepare for similar challenges.

5 ACKNOWLEDGMENTS

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