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Acoustics of a selection of famous 18th century opera houses: Versailles, Markgräfliches, Drottningholm, Schweitzingen

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This paper presents the analysis of the acoustical measurements conducted in 8 renowned baroque Opera Houses located in France and Germany. Still in authentic condition to their time of usage, and incorporating the historical changing scenery system (shutter and groove), these Houses have undergone little renovations. The acoustical analysis investigates the performances of these great Houses using energy parameters, balance between stage and orchestra parameters, 3D intensity plots, new spatial distribution parameters and timbre frequency analysis. The objective of the study is to deduce (for the Constellation Project) design targets for a medium size Opera House against these benchmarks and also to revisit the use of the lateral changing scenery system as used in the Baroque era, as an original scenery design concept for a new House. The paper presents the unique qualities of the rooms, illustrates some of acoustical benefits of the 18th century Opera House design characteristics, discusses some differences in the design approach between the Italian and the French traditions and proposes new perspectives for modern Opera Houses design.

1 Introduction

Opera house design evolved rapidly in the 17th century across most countries in Europe. By the 18th century, characteristic design practices had emerged. This study investigates the design traditions of the 18th century by using new scientific tools to test the acoustics of some of the most renowned opera houses of this era.

The tested houses include L'Opéra Royal in the Chateau de Versailles, France; Markgräfliches Opernhaus in Bayreuth, Germany; Drottningholms Slottsteater near Stockholm, Sweden; and Rokokotheater in Schwetzingen, Germany. Still very much in use today, these houses were selected for their authentic conditions representative of their time and for their renowned acoustics over their long history. These famous opera houses, as well as several others, have been identified as benchmarks for the ConstellationCenter project, a new performing arts center to be located in Cambridge, MA.

The initial research visits took place in 2004. The acoustic measurements included music recordings, including a soprano singing with anechoic music accompaniment, along with B-format and binaural measurements (Soundfield ST-250 and Neumann KU-100). The test signals were sine sweep played through a dodecahedron and a subwoofer and recorded digitally (Zaxcom Deva II).

2 Historical Data About the Houses

All of these houses integrate the 18th century “shutter and groove” scenery system that consists of regularly spaced slots on a raked-floor stage and painted scenery on flats that move together in a synchronized manner. This scenery was used to create spectacular scenic effects, including the visual illusion of perspective scenes to a vanishing point or points in the rear of the stage. Other scenic elements included flying machines (such as for flying angels) and sound making instruments (for thunder, rain, wind, etc). Such theatres were built into palaces and civic structures throughout Europe. Several family traditions had established a famous reputation such as the Galli da Bibiena family of Bologna.

It is Guiseppe Galli da Bibiena and his son Carlo who designed the interior of Markgräfliches Opernhaus in

Bayreuth, Germany for Margravine Wilhelmine of Prussia (an artist herself), sister of Frederick the Great, who had decided to create a miniature Versailles in Bayreuth. The Markgräfliches Opernhaus opened in 1748; it seats 800 people and includes many classic 18th century opera house characteristics. The auditorium is curved and elongated. The balconies with boxes and galleries are lined-up vertically, reducing the sound absorption of the audience. The balconies do not connect with the proscenium. Decoration is in the Baroque style.

It was Lully's *Persée* that inaugurated L'Opéra Royal of the Chateau de Versailles on 16 May 1770 for the celebration of the marriage of the Dauphin, the future Louis XVI, with Marie-Antoinette. Built by Ange-Jacques Gabriel, the theatre had a seating capacity of 1000 (it now seats 712) and it incorporated some of the best scenery equipment. The architect had chosen an elliptical form for the auditorium, with the King's box at the visual and acoustical focal point, with a parterre, avoiding deep balcony recesses and a continuation of seats along the sidewalls to the stage. The room is decorated in a neo-classical style with painted wood to imitate the effect of stone.

Drottningholms Slottsteater was opened in 1766. It was constructed by the architect Carl Fredrik Adelcrantz at the request of the Swedish Queen, Lovisa Ulrika. Part of the palace complex that is still the private residence of the Swedish royal family, it has been classified as a UNESCO world heritage site. The architect had chosen an original elongated rectangular shape for the auditorium, a form that he also used for Confidencen Theater, also near Stockholm. This shape results in an auditorium acoustics that benefits from some of the qualities of rectangular rooms like the great music rooms of the same era. Its interior is decorated with French patterns painted on stucco and papier-mâché. Drottningholm is also very famous for its complete stage scenery system still very much in use.

Today, the Rokokotheater in Schwetzingen is rarely mentioned in books on acoustics, and this opera house is one of the surprising discoveries of this study. The house opened in 1752 for Karl Theodor Prince-Elector, Count Palatine and Duke of Bavaria, and was used for drama and opera. It has a capacity of 450 seats. It was conceived by Nicolas de Pigage, French sculptor and architect. One of the most interesting characteristics of this opera house is the second balcony recess above the first one which, combined with the sculpted under-balcony surface between the arches, creates the most powerful acoustical effect at most seats as explained later in the acoustical analysis.

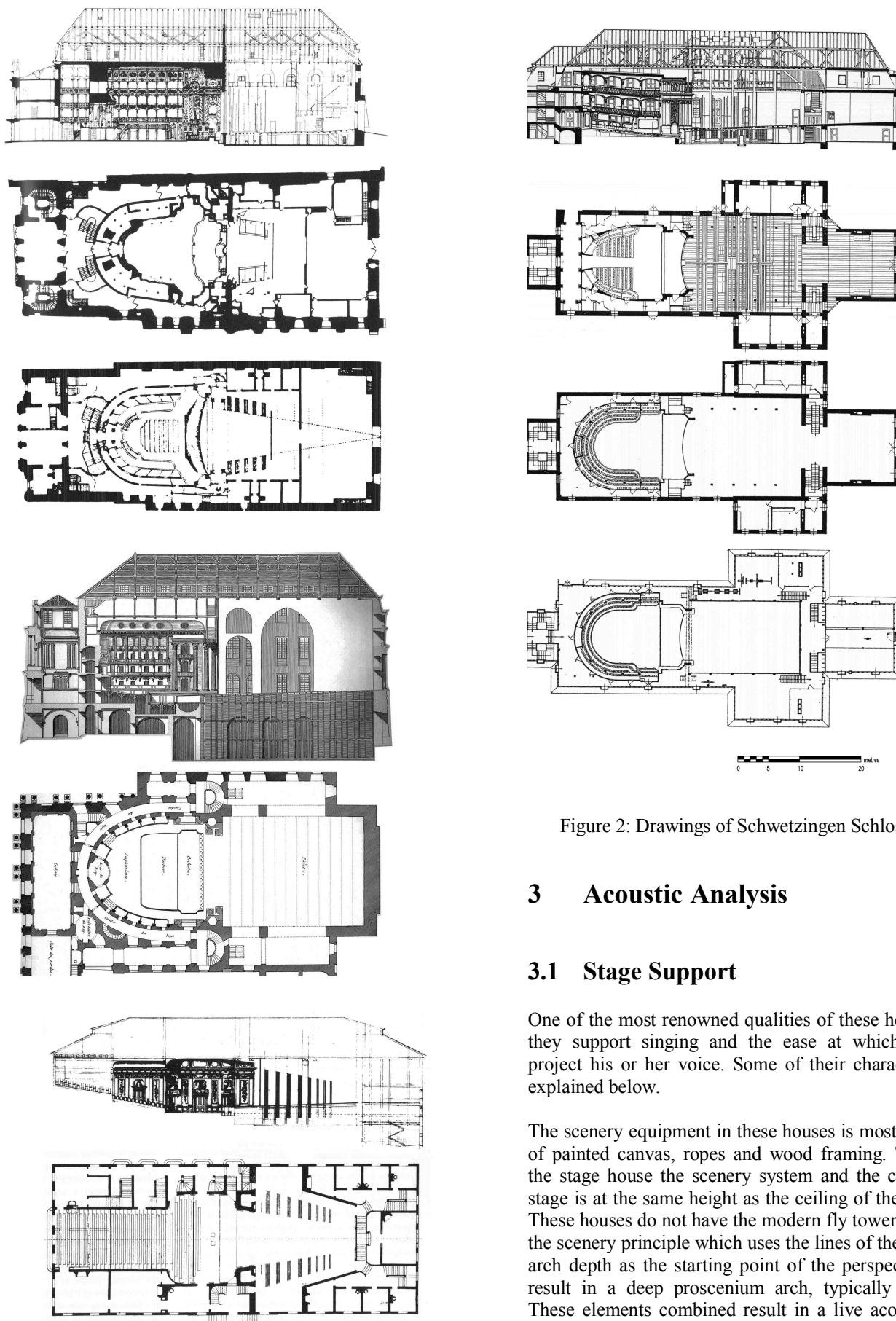


Figure 1: Drawings of Markgräflisches Opera House top, L'Opéra of the Palace of Versailles middle, Drottningholm Palace Theater bottom

Figure 2: Drawings of Schwetzingen Schlosstheater

3 Acoustic Analysis

3.1 Stage Support

One of the most renowned qualities of these houses is how they support singing and the ease at which singer can project his or her voice. Some of their characteristics are explained below.

The scenery equipment in these houses is mostly composed of painted canvas, ropes and wood framing. The sides of the stage house the scenery system and the ceiling of the stage is at the same height as the ceiling of the auditorium. These houses do not have the modern fly tower. In addition, the scenery principle which uses the lines of the proscenium arch depth as the starting point of the perspective illusion result in a deep proscenium arch, typically around 3m. These elements combined result in a live acoustics inside the stage house due to the low amount of sound absorption created by the scenery (RT in these stage houses is 20% longer than in their auditorium), to a low and solid sound reflective surface above the head of the singers (loudness measurements inside these stage houses range from +4dB to +10dB from downstage to upstage), and to near and wide

sound reflective proscenium surfaces around and above the singers.

The effect of reverberation on stage can be shown with the calculations of RT30 at 3m from the source (singer accompaniment position). At this distance, the early decay of the reverberation is already within 85 to 100% of the reverberation indicating the liveness quality on stage. Values of support parameters ST1 early were calculated from measurements conducted in the middle of the proscenium arch. Compared to measurements conducted in recently completed opera houses [2, 3], these values exceed by 3 to 10dB numbers typically measured in modern opera houses and are indicative to the important sound reflectivity of the proscenium arch and stage. Versailles and Bayreuth have the longest reverberation (“longest resonance”) but lower early support due to their size; Drottningholm and Schwetzingen show the highest early support values (highest “engagement”) but have shorter reverberation time, especially in Schwetzingen. In Drottningholm, the EDT equals RT30 at 3m, which suggests that the sense of liveness on stage would be the strongest.

3.2 Energy Balance in the Auditorium

The average loudness parameter for a source on stage ranges from +1dB to +5dB while the loudness difference between the stage and the orchestra ranges from -1.5dB to -2.5 dB. These houses were smaller and louder and therefore require less vocal energy from singers. This might also have allowed a wider variety of singing techniques as voice would not have to be forced.

The orchestra is located on the floor in front of the stage instead of a deep pit. Compared to measured data in modern opera houses [2, 3], the orchestra loudness is higher than the stage loudness while it is the opposite in modern venues (typically louder by 0 to +2dB on average). This indicates that the loudness of these houses would have helped to compensate for the musical instruments of the 18th century, which were quieter than modern. The highest values of loudness are calculated in Drottningholm which exceeds Schwetzingen with a similar volume. This is the consequence of the shoebox shape of the auditorium creating strong sound reflections between the large and exposed parallel surfaces.

The vocal clarity indicated by D50 parameter fluctuates on average around 50% (omni-directional source). Minima are experienced in Drottningholm showing the influence of the shoebox shape creating late sound build-up resulting in lower vocal clarity, (predictions indicate that D50 would rise up to 45% under occupied conditions). Maximima are achieved in Schwetzingen due to its short reverberation time and its sound reflective surfaces (see section 3.3).

Orchestral clarity varies from +1dB to +4dB. This is higher than in modern opera houses (typically between -4dB to 0dB) because the modern pit usually shields some of the direct sound and reduces the orchestra clarity. Higher musical clarity in these houses would have supported music performances integrating substantial amount of musician ornamentalations and which would have been more suited for 17th century musical compositions that were more melodic than chromatic.

The “running reverberance” parameter represented by EDT shows very small variations in Bayreuth. This demonstrates a uniform distribution of energy across the auditorium and a density of sound reflections. This could show the combined effects of the circulation of sound due to both the reflections on the balcony fronts and the architecture ornamentation creating sound diffusion as shown by the values of 1-IACC late which are highest in Bayreuth. The EDT parameter is the highest in Versailles, and the lowest in Schwetzingen. The ratio of EDT versus RT is the highest in Drottningholm, indicative of liveness and also confirming the influence of the rectangular shape of the auditorium.

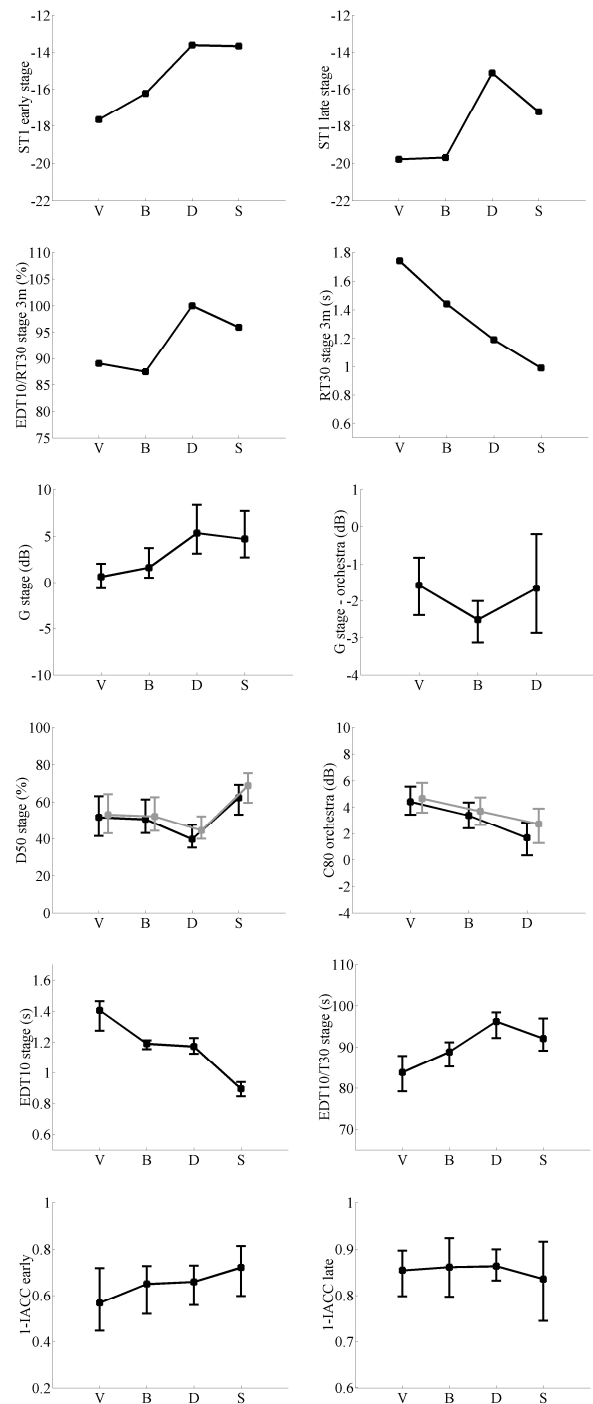


Figure 3: Source on stage or in the orchestra. Grey lines indicate predicted occupied condition. Versailles (V), Bayreuth (B), Drottningholm (D), Schwetzingen (S)

3.3 Reflection Sequence

One of the most interesting characteristics of these houses comes from the development of their form and shape, which creates the most beautiful acoustical effect. A 3-dimensional impulse response is plotted at one of the most representative position in each hall, using a graphic technique as explained in [4]. The source is located on the stage in the middle of the proscenium, with the exception of Bayreuth, where the source is located in the orchestra.

Versailles is shaped as an ellipse to focus the sound at the rear on-axis. The plot of the 3-D impulse response at this position clearly shows the effect of the focused reflections occurring from the side walls. These reflections arrive within the first 15ms of the room response, which would create a significant increase of the sensation of intimacy (acoustical illusion of proximity), loudness, vocal clarity and early envelopment (source size). At this position, the room response is then characterized by the ceiling reflection (occurring within the 15 to 40ms time frame) and by the upper corner sound reflections (40 to 100ms) which would contribute to the sense of late envelopment.

A 3-D impulse response is plotted in Drottningholm for a position located 4 rows behind the King's position (the King and Queen's boxes are at the front of the house). Side wall and ceiling reflections are occurring within 15 to 40ms closely spaced in arrival time. The impulse response then shows strong reflections within 40 to 100ms, evenly distributed in the lateral space, which demonstrates the effect of the parallel wall surfaces of the auditorium. The experience at this seat would be loud, live as explained above (EDT) and very enveloping, both in terms of source size impression and late envelopment due to the bouncing of late reflections between the side walls.

It is in Schwetzingen that one of the most remarkable sound reflection sequences can be experienced. Firstly, the auditorium incorporates large sound reflective surfaces around and in front of the proscenium and on the side walls. Secondly, the room has a curved sound reflective surface underneath each balcony following the "U" shape form of the auditorium and is cut into arches between the columns. This, combined with the second balcony recess, creates a quick reflection of sound at every seat on the balcony and on the orchestra level. The 3-D impulse response measured in the real room is plotted for a seat on the orchestra level at the rear. It shows the reflection coming from the side walls and the rear because of the "U" shape of the hall, along with the upper portion of the hall including the second balcony underside and the ceiling. This creates a composition of reflections balancing the front/rear and low/high lateral sound within 40ms as rarely achieved in other venues, and at most seats in the auditorium, as shown by the I-IACC early parameter illustrated on Figure 4.

3.4 Materials

Some of the renowned qualities of these houses concern their "resonance", which is often attributed to their finishes. The inside of these houses are mostly made of soft materials such as thin wood, papier-mâché or stucco. These materials were shaped and painted to create the illusion of

real decorations and a deep field of perspective. By observing the plots of reverberation decay in narrow frequency bands in these houses at a representative position in the hall, a drop-off below 200Hz can be noticed in Versailles and Drottningholm, with a gap between 63 and 125Hz at Schwetzingen and Bayreuth, which is relatively flat above that frequency range. These results could reveal the effect of the sound absorption of the soft finishes as it could be predicted, and that these soft finishes would control the low frequency build-up that would have occurred otherwise with harder materials. In each of these houses, a low frequency rise below 63Hz is also apparent. An assumption could be made that the soft finishes become acoustically transparent to sound at such frequencies which would then be reflected back in the auditorium by the heavy and thick stone masonry walls supporting the hall. It is also notable that the transmission of vibrations through the soft finishes was used for certain theatrical effects such as the use of a faceted stone ball that was rolled on the stage to make the entire house resonate creating a "thunder effect".



Figure 4: Top left: Versailles, top right: Bayreuth, bottom left Drottningholm, bottom right Schwetzingen

5 Conclusion

Towards the end of the 19th century, the opera house became larger, and its form more circular bringing the audience closer to the stage and improving sightlines. The proscenium was enlarged, the perspective scenery effect was abandoned and the deep orchestra pit starts to be used. These are the elements that define our modern opera house archetype. The houses analyzed in this study were created at the pinnacle of the perspective scenery era. They are smaller and easier to sing in, tend to be more elongated with a smaller proscenium for the perspective scenery effect, do not use an orchestra pit, and therefore had different acoustic characteristics than the later houses. This study demonstrates the richness of their acoustics, including the diffused reverberation of Bayreuth created by the lined-up balcony fronts and ornamentation derived from the Italian tradition, the musical acoustics of Drottningholm with its shoebox shape derived from music rooms, the sound focusing combined with reverberation using an elliptical shape at Versailles, and the remarkable reflection sequence of Schwetzingen indicative of the early departure toward a more democratic design and maybe a French

approach. The analysis of these rooms demonstrates several acoustical benefits from their elongated form: The deep proscenium and for-stage surfaces between the stage and auditorium which increase singer support and voice projection, the channelling of reflections along the balcony underside of Schwetzingen, and the side reflections in Drottningholm and Bayreuth. The remarkable acoustics of these houses, as demonstrated by this acoustical analysis, is an invitation to reconsider the characteristics of these spaces as precedents in the context of the modern design process.

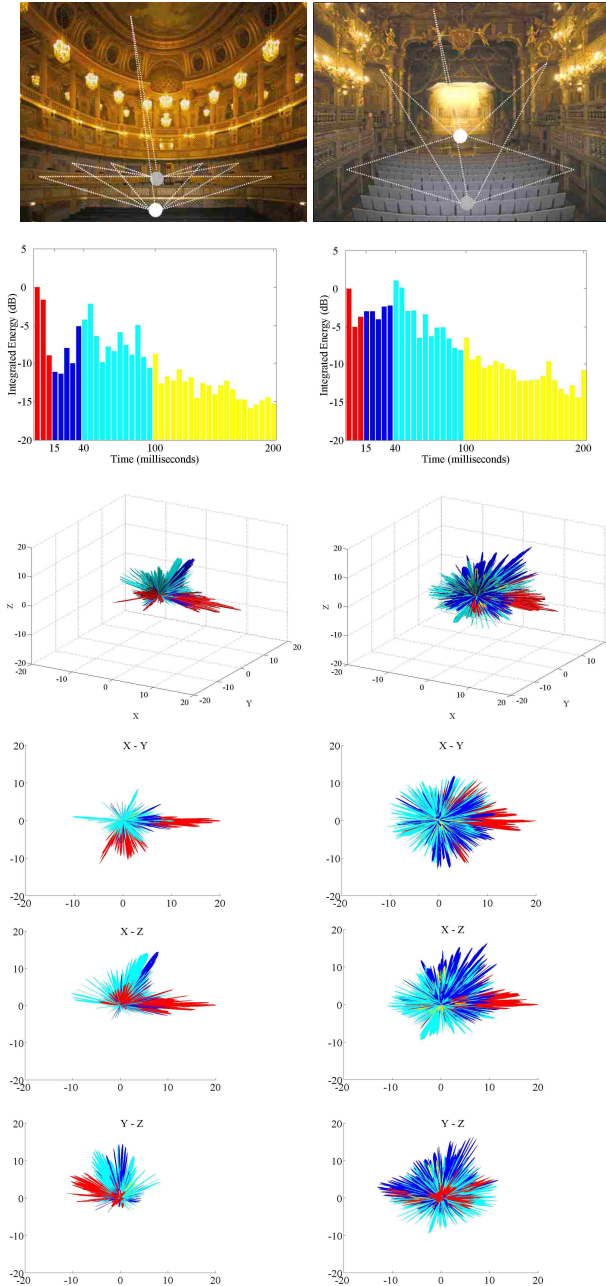
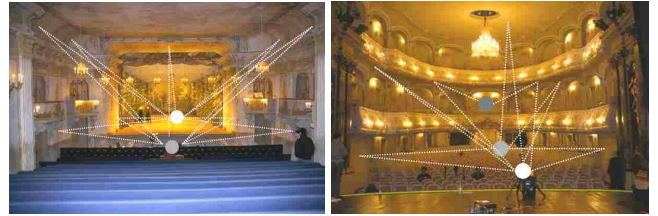


Figure 5: Reflection sequence in Versailles and Bayreuth. Range of 3D plots is dB. Colours of reflection timing and 3-D plots are matched

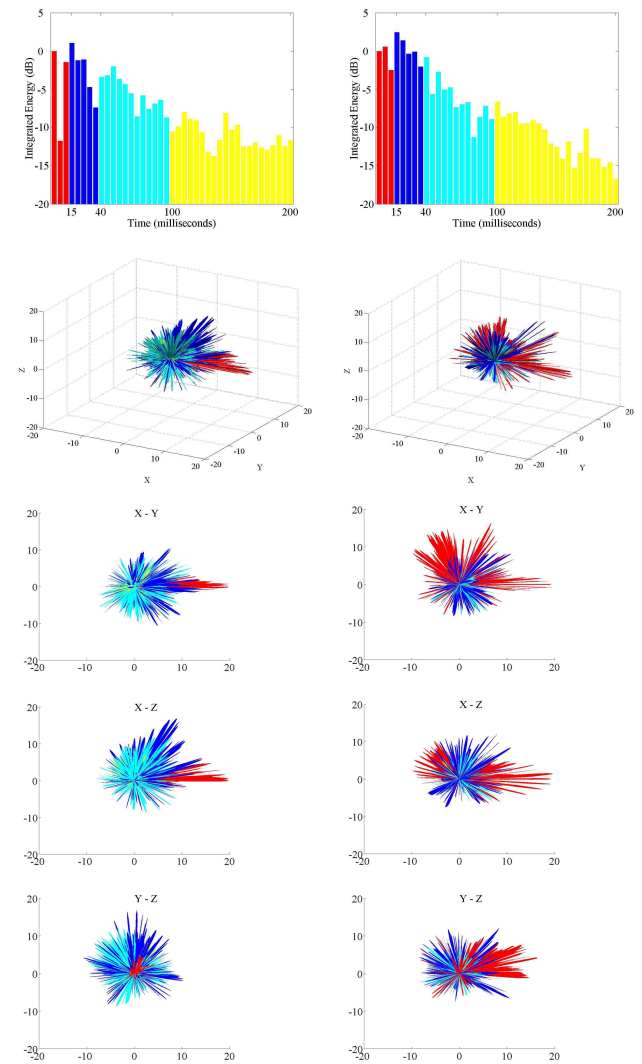


Figure 6: Reflection sequence in Drottningholm and Schwetzingen.

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