Acoustics Considerations in the Construction of Sibelius Hall

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Summary

Sibelius Hall is a 1250 seat concert hall and congress center which was built by the City of Lahti, Finland with the sponsorship of the Finnish wood industry. The wood industry's support in this construction project was conditional based on using wood in new and experimental ways, not only as a finish material, but as a structural material. A proprietary product called “Kerto-Wood” was used in a wide variety of structural and finish applications.

Acoustics being one of the prime considerations in the design of the Concert Hall, research was conducted to explore the physical properties of Kerto-Wood to help determine its suitability for use in the project. Sand-filled Kerto-Wood panels 300mm thick were used in the slanted exterior walls. Details of the sand filled panels’ construction, the joining details, and the sound transmission loss testing of the assembly are presented. Prefabricated Kerto-Wood elements were also used to construct the ceiling, balconies, and reverberation chamber doors. The sound absorbing properties of Kerto-Wood are also discussed.

1. Sibelius Hall Complex

Sibelius Hall Congress and Concert Center is a complex consisting of four building sections. An existing brick building which previously served as a carpentry factory was converted into an exhibition space, rehearsal and seminar rooms, administrative spaces and a restaurant. The newly constructed lobby called the Forest Hall was attached to the Carpentry Factory, serving as a central gathering space and linking the Carpentry Factory to the new Concert Hall and Congress Wing. The Congress Wing has four large spaces that can used for conferences of all types. The Concert Hall is the new home of Sinfonia Lahti and can also serve as a meeting place for congresses of up to 1100 people.

One of the most challenging design criterion for Sibelius Hall was the stipulation that the new construction use wood in new and experimental ways. As a result, the Forest Hall, Concert Hall, and Congress Wing get their structure from massive laminated wood trusses. For instance, the roof of the Forest Hall is supported by nine enormous pylons which branch out at the top to give the impression of the native Finnish forest. The trusses which hold up the walls and the roof of the Concert Hall are a significant architectural element inside the reverberation chambers. Concrete towers were used to encase the fire exit stairs and to assist the building in wind resistance, but the majority of the rest of the complex is constructed of wood.

2. Concert Hall Basic Design

The interior shape of the Concert Hall is an acoustic design by Artec Consultants Inc of New York. The audience chamber boundary surfaces are, for the most part, parallel, giving the room the classic “shoebox” shape that is commonly associated with superior acoustics. The gross dimensions of the shoebox are approximately 42m L × 23m W × 19m H, giving the inner audience chamber a volume of about 18,000m³.
Reverberation chambers totaling 7,000m$^3$ in volume may be acoustically coupled to the performance space through a series of 188 “valves” or reverberation chamber doors. By carefully adjusting the number of open doors, choosing the location of each open door, setting the degree of openness, or through a combination of these techniques, the desired acoustic for a wide range of repertoire can be achieved. Those who are familiar with Artec’s previous concert hall designs in Dallas, Birmingham, and Luzern will notice changes in the location of the coupled volume and the valves in relation to the audience chamber. In Sibelius Hall the reverberation chambers are expanded relative to the inner volume, spanning its full height and length, and the reverberation chamber doors are located in both the “sending” and “receiving” ends of the space.

Adjustable acoustic control banners have been installed in the reverberation chambers and adjustable acoustic control curtains are being installed along the walls of the inner audience chamber. These will be used to control the reverberant characteristics as well, facilitating the use of the sound system by taming excessive loudness and “boominess,” and for adjusting the room for musical events requiring a less reverberant environment.

An adjustable height acoustic canopy in three sections is suspended above the performance platform to facilitate on-stage communication among musicians, to direct sound energy to seats in the center of the main floor, to act as a “plunger” or a relief valve for sound energy entering the reverberation chambers, and to adjust the scale of the platform to suit each particular performance.

3. Exterior Wall Design

The design goal for the interior background noise level in the Concert Hall was the threshold of human hearing for broadband noise (sometimes referred to as “N-1”). In noisy urban settings N-1 levels can only be achieved by using “box-in-box” double wythe masonry construction. However, the City of Lahti is relatively small, and City officials made the wise decision to locate Sibelius Hall along Lake Vesijärvi, which is remote from the downtown area and disturbed only by an occasional boat whistle. Therefore the ambient exterior background noise does not reach levels that would cause serious problems in meeting the N-1 levels.

The exterior wall system developed for Sibelius Hall consists of a glass curtain wall plus a 300mm thick sloped reverberation chamber wall, in essence, a wood box within a glass box. The sloped wall was pieced together using prefabricated sand-filled panels that were custom designed for this project. Each panel measures 9m L x 1.8m H and weighs approximately 5000kg. The surfaces of the panels are made of Kerto-Wood, a proprietary laminated veneer lumber (LVL) product, 51mm thick for the exterior-facing surface and 69mm thick for the interior-facing surface. The thicknesses of the surfaces are different to minimize the coincidence dip in the sound transmission loss performance. Further, the interior-facing surface doubles as the primary sound reflecting surface in the reverberation chamber. The added rigidity provided by the thicker plate, however small, is desirable for reflecting sound, preserving it within the Concert Hall volume.

The panels have interior studs approximately 600mm on center which form 180mm deep cavities into which sand is packed. The grain sizes of the sand particles were selected to vary between 0.5mm and 2.0mm and were packed into place on site in an attempt to avoid the voids within the wall structure which would be the result of the sand settling. Figures 1 and 2 show how these panels are assembled.

A layer of 15mm plywood was attached to the exterior-facing surface of the sand-filled wall system with a 100mm deep air space filled with mineral wool. This outer insulating layer was added to protect against the extreme variations in temperature and humidity expected in the interstitial space between the exterior glass curtain wall and the interior sand-filled reverberation chamber wall. This thin layer provides an increase in the sound transmission loss properties of the sand-filled wall system.

The sound transmission loss tests were performed by VTT Building Technology, and their results for the sand-filled wall system, without the glass curtain wall, appear in Figure 3 below. The resulting $R_w$ value of 63 dB is better than a 200mm thick concrete wall. The glass wall alone is expected to yield an additional $R_w$ of around 35dB. The glass wall is nearly 1m removed from the sand-filled wood wall system at all locations, so the sound reduction indices were assumed to have a combined result of the sum of the two $R_w$ values.
Fig. 1 Assembly of Sand-Filled Wooden Wall Panels

Fig. 2 Section Detail of Sand-Filled Wall Joint
4. Prefabricated Ceiling and Balcony Units

The balconies and ceiling in Sibelius Hall are also constructed of prefabricated Kerto-Wood elements.

The ceiling units are hung between the wood trusses which span across the Concert Hall, interconnecting with each other with a ship/lap joining detail. Each hollow ceiling unit has the dimensions 9m L x 1.8m W x 0.4m H. Again, for structural rigidity and acoustics reasons, the bottom surface of each ceiling unit, the surface which reflects sound, is constructed of 69mm thick Kerto-Wood. The finished ceiling is horizontal, flat, and painted black.

The balcony units generally follow the same construction detail as the prefabricated ceiling units except larger in scale. They are also supported from the massive wood trusses, resting on large steel brackets. The original design intent was for the 69mm thick Kerto-Wood undersides of the balconies to be exposed, performing the important role of reflecting sound downward and lateralizing the sound energy to listeners on the main floor and in the balconies. However, due to the need to fireproof the steel hanging brackets, and for architectural aesthetics, the undersides of the balconies were covered in very thin gypsum wall board over an air space. Hence, instead of being sound reflecting, the undersides of the balconies are probably sound absorbing at certain frequencies.

5. Reverberation Chamber Doors

When the reverberation chamber doors are closed, it is very important that they have the mass and stiffness necessary to reflect sound and preserve it within the inner audience chamber, acting as if they were fixed walls in a non-adjustable space. Additionally, when the reverberation chamber doors are partially or fully open, the doors are known to act as angled reflectors, directing sound into and out of the reverberation chambers at strategic locations. The material choice for the
reverberation chamber doors is acoustically important for these reasons. Kerto-Wood was used to construct the reverberation chamber doors because it was able to satisfy all of the necessary design criteria.

Because Kerto-Wood is a manufactured wood product, several options are available in the type of finish surface that can be obtained. Construction-grade Kerto-Wood was used for the core of the doors and finish-grade Kerto-Wood was used for the exterior surfaces. The layers were glued and screwed together and fitted into their steel frames on site. The 145mm-thick doors hang on hinges supported from a tubular steel structure running from the floor to the ceiling. The finished surfaces were stained and sealed with a urethane finish to give a relatively glossy, polished look.

VTT Building Technology tested the sound absorption characteristics of the construction-grade Kerto-Wood. The results are shown in Figure 4.

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Fig 4 Sound Absorption Coefficients for Various Materials

A series of grooves were designed into the surface of the reverberation chamber doors to scatter incident sound. They were created by using a router cutter at various depths and widths into the finish Kerto-Wood layer prior to being installed.

6. Listening Impressions, Results, and Conclusions

Public reception to Sibelius Hall has been positive. Newspapers and professionals have both commented that Sibelius Hall could well be the best hall in which to hear music in Scandinavia.

The reverberation time data that were taken at a test concert show that there are sufficiently long reverberation times for a wide range of classical music repertoire. However, the desired variation in reverberation times was not evident in the results at that point. Reasons for this are that the acoustic control curtains had not yet been installed in the interior of the audience chamber, severely limiting the usefulness of the room for events requiring the sound system. Further, the rubber gaskets which were designed to seal the reverberation chamber doors had not yet been installed, causing sound to leak into the reverberation chambers. It is theorized that the excessive sound leakage is responsible for the minimal variance in reverberation times shown in Figure 5.

The building in its unfinished state does not quite reach the background noise goal of N-1, but it is well below the PNC-15 level (see Figure 6). Several noise sources were identified within the Concert Hall, all of which were addressed. None of the intrusive noise was identified as coming from the exterior of the building, so it can be assured that the design of the sand-filled wall in combination with the glass curtain wall is a success. N-1 levels will most likely be achieved as construction is actually completed and remediation measures are taken.
Fig 5 Reverberation Times in concert Hall, March 2000

Fig 6 Background Noise Spectrum in Concert Hall

7. References


