3pAAb3. Design and implementation of a tuned low-frequency absorber in a residential music listening/practice room

Aaron Farbo* and Christopher A. Storch

*Corresponding author's address: Cavanaugh Tocci Associates, 327F Boston Post Road, Sudbury, Massachusetts 01520, afarbo@cavtocci.com

The historic Bradley Mansion in Boston's Back Bay neighborhood was recently completely renovated and subdivided into multiple luxury-level condominium units built to suit to the new homeowners requirements. The historic preservation requirements imposed on the project presented challenges for designing and implementing sufficient acoustic absorption and sound isolation for the design of a new music listening and piano practice room in the lowest level residence. A custom-designed low-frequency absorber was developed to fit within an existing architectural niche at one end of the elliptical music room, and additional absorptive treatment was added to the walls to blend in with the existing finishes. Sound isolation to the neighboring condominium above the music room was improved via floor/ceiling modifications - a task made more challenging by the need to retain the terracotta structure and other historic details. Construction details and measurement results will be discussed in this case study presentation.
INTRODUCTION

Historic preservation requirements can present difficult challenges in many aspects of a project, including room acoustics and sound isolation. This was demonstrated during a recent project at the historic Bradley Mansion in Boston’s Back Bay neighborhood. The building was completely renovated and subdivided into multiple luxury-level condominium units built to suit each new homeowner’s requirements. This case study will discuss construction details for room acoustic treatments and sound isolation recommendations associated with one particular space. Measured results for reverberation time and noise isolation, both before and after the renovation, will also be presented.

HISTORY OF THE BRADLEY MANSION

The Bradley Mansion consists of three townhouses on the upper end of Boston’s Back Bay neighborhood and was built at the turn of the 20th Century. This set of residences represents Back Bay architecture at the absolute pinnacle of its achievement in terms of construction, finishes and architectural design. The eastern building was designed in an elegant, Georgian Revival style by Little and Browne, best known for their revival of the Colonial style of architecture. The middle building was designed by the prominent firm of Peabody & Stearns for the Minot family. Its carved limestone façade and Renaissance Revival detailing present a formal entry a step above any other in Boston. The western most building, designed by Little and Browne for the Bradley family features an extremely tall piano nobile, or formal floor, and handsome carved limestone detailing. These extremely fine façades convey a grand scale - similar to that of prestigious 5th Avenue or Newport homes of the same era.

For the renovation, the lowest level homeowner decided to turn an existing elliptical shaped room into a conservatory, complete with a grand piano and high-end audio system. Due to the constraints of the historic preservation, large scale changes to the wall shaping and architectural finishes were not allowed, and the homeowner was made aware of the acoustical challenges that would entail. The acoustical design for the space emphasized reverberation control and mitigation of the acoustical focusing using sound-absorbing treatment that would integrate into the existing aesthetic. A disused niche at one end of the room was also converted into a low-frequency absorber.

The condominium purchaser above the music room was especially concerned about sound isolation to their unit. The historic preservation requirements placed limitations on the sound isolation improvements that could be made in the plaster ceiling below, and the terracotta structure could not be significantly altered. Floor/ceiling improvements were recommended and detailed by Acentech, Inc. to help preserve existing finishes.

ROOM ACOUSTICS

One of the goals of this project was to provide a suitable environment for music listening - primarily reverberation control and the mitigation of acoustical focusing. As shown in the drawings and photographs, (Figures 2 and 3), the room is elliptical in plan with a fireplace at one end and a desk built into a nook at the other
end. The existing finishes include an ornately detailed plaster ceiling, hardwood flooring, and decorative wood paneling on the walls.

The elliptical shape of the room creates two foci which were very aurally apparent during acoustic measurements. Due to the historic preservation for the project we were unable to recommend any diffusion products which would have mitigated this focusing of sound, so we instead concentrated on reducing the reverberation to appropriate levels.

The measured reverberation time of the existing room is shown on Figure 4. The average mid-frequency (500 Hz to 2,000 Hz) reverberation time was approximately 1.3 seconds.

**FIGURE 2.** (a) Music room floor plan. (b) View of existing fireplace

**FIGURE 3.** (a) View of built in desk. (b) View of existing plaster ceiling.
In order to control reverberation in the new music room, acoustic treatment options were reviewed. To control reverberation at 250Hz and higher, traditional stretched-fabric wall treatments were integrated into the existing decorative wood paneling. Approximately 180 ft² were added to the walls, which can be seen covered in yellow fabric in Figure 7. A custom carpet was also designed for the room which would add to the total acoustical absorption in this frequency range.

To supplement the sound absorption in the lower frequencies, it was decided that a tuned low-frequency absorber, or “bass trap”, would be incorporated into the disused architectural niche at one end of the room. The bass trap was designed to fit into the existing dimensions of this niche as shown in Figure 3. Based on the size constraints of the cavity, a Helmholtz resonator perforated panel absorber was selected for the bass trap design.

A perforated panel absorber is a resonating absorber which is “tuned” to absorb a specific frequency. Typically it is some form of enclosed volume or box where one side has holes in it where air can move in and out. Each hole acts as the neck of a Helmholtz resonator, and the share of the cavity “belonging” to that hole is comparable to the cavity of the Helmholtz resonator. The frequency of resonance of perforated panel absorbers backed by a subdivided air space is given approximately by:

$$f_0 = 200 \frac{p}{\sqrt{(d)(t)}}$$  \hspace{1cm} (1)

Where:
- $f_0$ = frequency, Hz.
- $p$ = perforation percentage
  = hole area divided by panel area x 100
- $t$ = effective hole length, inches, with correction factor applied
  = (panel thickness) + (0.8) (hole diameter)
- $d$ = depth of air space, inches

To increase the absorptive frequency range of the bass trap, the cavity was split into two equal volumes, as shown on Figure 5. A piece of wood serves to separate the bass trap into two volumes while also stiffening the face
plate panel. Two volumes allow the bass trap to be tuned to separate frequencies. The upper volume was tuned to approximately 125 Hz while the lower volume was tuned to approximately 60 Hz. This resulted in 784 perforations (1/2-inch diameter holes) in the upper panel and 196 in the lower panel. In order to broaden the frequency response of the bass trap, glass fiber insulation was added to the cavity (1).

The bass trap material design consisted of a ½-inch thick perforated plywood face plate mounted on wood framing with 9-inch thick glass fiber insulation filling the cavity, as shown in Figure 6.

![FIGURE 5. 3D Computer Model Showing Bass Trap Design Concept](image1)

![FIGURE 6. Sketches Showing Bass Trap Design Concept](image2)

**Renovated Room Reverberation Time Result**

The renovated music room finishes include many of the original architectural details, including the ornate plaster ceiling, (now gilt with leaf), all the decorative wood trim on the walls, and the original fireplace. New finishes include carpet on the floor, detailed stained glass windows, and a magnificent chandelier. The piano installed in the
space was the homeowner’s existing Steinway Model D grand piano, a 9-foot long instrument typically seen on concert stages. An instrument of this size would easily overload the 7,100 ft³ of room volume with acoustic energy had the sound-absorbing treatments not been added. Pictures of the completed room with the piano can be seen in Figure 7.

After installation of the bass trap and additional acoustical treatment, the average mid-frequency (500 Hz to 2,000 Hz) reverberation times dropped to 0.6 seconds as shown in Figure 8. The combination of the custom bass trap and additional acoustical wall treatment were able to reduce the reverberation time in the mid to high frequency bands to an appropriate range for this type of space. The acoustical control provided by these finishes also helps to control excessive loudness that can be produced by a piano of this size. Readers will notice that there was not a significant reduction in the reverberation times in the 63 Hz octave band. The authors surmise the reasons may be due to the small size of the bass trap relative to the size of the room, its location toward the floor, limitations of the measurement methodology, or the fact that the bass trap was concealed behind a velour curtain as shown in Figure 7.

FIGURE 7. Photos Showing the Renovated Music Room
SOUND ISOLATION

A second acoustical concern during this project was that of sound isolation to the condominium unit directly above. The owner of the unit above expressed concern over hearing music from the space below and wanted to improve the isolation if possible. Above the music room is a large formal dining room called the Gold Room with many intricate historical details that would remain after the renovation. The original structure between the spaces is terracotta and would need to be retained.

The existing sound isolation was tested prior to renovations and was measured as NIC 51, limited in the low to mid frequencies as shown on Figure 9a. The first step in improving the floor/ceiling sound isolation was attempted from the music room below, because the flooring above was decorative parquetry and was wished to be preserved. The only route for available improvement without disturbing historical details was to add insulation above the outer ring of the plaster ceiling. Blown in insulation was installed in the interstitial spaces above the plaster ceiling, but only improved the sound isolation by one point to NIC 52.

Since the attempt to improve sound isolation from below produced minimal results, it was decided by the upstairs owner to replace the floor. Acentech, Inc. was hired by the upper unit owner, and they developed a detail for a floating floor system as shown in the sketch in Figure 10. The detail shows removing the existing wood floor down to the terracotta structure. An elastomeric flooring compound was applied on top of the existing terracotta structure prior to installing the isolation flooring to make an airtight seal. A Kinetics “RIM” system would then be installed with two layers of plywood and the finished hardwood flooring on top. Kinetics perimeter isolation board was installed to help improve isolation along the exterior walls, where sound leakage was noted during initial noise isolation testing. After installation of the Kinetics RIM system the sound isolation improved from NIC 52 to NIC 62 with 5-10 dB improvements in the low frequencies, as shown on Figure 9b. The background sound level during the post-renovation sound isolation measurements resulted in uncertainties in the data from 1000 Hz and higher. However, the range of uncertain data would not change the NIC results.
FIGURE 9. (a) Measured Sound Isolation Pre-Renovation (b) Measured Sound Isolation Post-Renovation

FIGURE 10. Sketch of Floating Floor Sound Isolation System Installed in Gold Room
CONCLUSION

Renovation of the historic Bradley Mansion in Boston’s Back Bay neighborhood presented some interesting acoustical challenges imposed by historic preservation requirements. The reverberation time in the music room was reduced to an appropriate range for music playing and listening, and sound isolation was improved to the condominium unit above.

ACKNOWLEDGMENTS

The authors would like to thank Jonah Sachs of Acentech, Inc. for his cooperation and sharing of data. We would also like to thank Andrew Sidford Architects and M. Holland & Sons, Inc. for sharing drawings and photos.

REFERENCES