THE FALL AND RISE OF THE FOGG ART MUSEUM LECTURE HALL: A FORENSIC STUDY

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In 1973 a significant building in the history of acoustics was destroyed. Harvard University's first Fogg Art Museum, which housed the lecture room that prompted Wallace Clement Sabine's interest in architectural acoustics, was demolished. However, a link to this space was preserved so its acoustical characteristics can be explored again. As computer models and auralization become ubiquitous for projects, the use of the computer model for renovation as a yardstick for comparing various options is an attractive supposition. But, this can only be the case if the "original" model can be considered "accurate." In this study, an attempt is made to create a *calibrated* model, based on historical measurements and post renovation measurements, turning back the clock to recreate and hence revisit this historical room. In addition to the measurement and simulation methods and obtained results, there was a substantial effort in finding the historical information to recreate the building. This historical information was in the form of architectural documents, scientific papers, articles in the press, as well as interviews and photos. All these pieces provide insight into this monumental site, raised from the rubble of history. This article presents much of the historical background of this study concerning the Lecture Room, while the majority of the technical aspects have been previously presented in recent conferences.[1,2]

Fogg Art Museum—History

From careful study of Sabine's work in the Fogg lecture room three conclusions can be drawn—the remarkable combination of circumstances that created the right situation for Sabine's discoveries, the brilliance of his achievement that can be appreciated by careful reading of his *Collected Papers on Acoustics*, and the likelihood that further information on his early research still awaits discovery.

It is seldom that a building gains significance for all the wrong reasons. The original Fogg Art Museum at Harvard University, opened in 1894 as a memorial to William Hayes Fogg, had all the natural advantages—location, a wealth of fine art and endowments, and an eminent scholar as its star; but its place in history may ultimately be as the vehicle for the founding of a new science.

According to a recent historical account, the bequest for the building came as a not entirely welcome surprise to Harvard. Charles Eliot Norton, who was the senior lecturer in fine arts, and founder of the first course in art history in the United States, is reported to have looked for ways to use the bequest other than a new building bearing the donor's name. The prominent architect Richard Morris Hunt who was awarded the commission evidently received little guidance from the university and had limited access to Norton during its design.[3]

After the new building design was made public it received strong criticism ranging from its architectural style to the inadequacies of the art galleries. It was described as an ill-placed and architecturally alien intrusion upon Harvard Yard.

Upon its completion the occupants soon learned that the semi-circular, domed lecture room was acoustically unsatisfactory. Norton found to his chagrin that in addition to its other shortcomings he could not speak over the strong reflections of his own voice returning from the semi-circular rear wall of the room. He criticized the entire building in a strongly-worded Resolution to the Board of Overseers and demanded that it be corrected forthwith "…*It is the duty of the graduates to remove this impediment.*"[4]

Some of the finer details were reported in contemporary newspaper accounts:

"The acoustic properties are so poor that Professor Norton could not make himself heard half-way across the room. It is now hung with muslin to stop the echo and nobody knows what will finally be done to put the room in fit condition.[5]"

"When the building was opened, Prof. Norton denounced it quite severely on several occasions and it soon came to be the standing joke around college. …The painting of 'Norton's Pride' in huge red letters on the building last winter is one evidence of the way in which the students regard the matter. …This morning, however, brought forth a lot of specific objections from Prof. Norton…The bad acoustic properties of the building then came in for a share in the affair. It is well-known that the remarks of a lecturer are badly distorted by the time they reach the rear of the room—and this objection was well-founded."[6]

Norton was the cousin of Harvard's president, Charles Eliot, which undoubtedly gave him added influence, but it is likely that the continuing embarassment to the university created by his frequent strenuous objections prompted the decision to look for an immediate remedy. President Eliot asked the twenty-seven year old Sabine, who had just received his assistant professorship, to address the acoustics with (in Sabine's words): *"…the end in view of correcting the lecture-room which had been found impractical and abandoned as unusable."* [7]

Sabine's analysis of the lecture room is best described in his 1898 presentation[8] and in the numerous letters published in W. D. Orcutt's 1933 biography of Sabine.[9] Samples of his hand-written notes from his tests in the lecture room have also been published.[10] Sabine's work provides the foundation for the science of room acoustics.

In addition to the difficulties of teaching by day and acoustic testing between 2:00 a.m. and 6:00 a.m., when the Harvard Square streetcars were not running, Sabine was under pressure from President Eliot to provide a solution for the lecture room, his initial task:

"Your explanation of November 3rd about your expenditures in making the investigation which Mr. Hooper and I asked you to make is very far from being satisfactory. You have made sufficient progress to be able to prescribe for the Fogg Lecture Hall, and you are going to make that prescription." [9]

Eventually Sabine prescribed acoustic treatment for the Lecture Room, stating that the room was *"…not excellent, but entirely serviceable…without serious complaint."* [11] Why his opinion was not shared by others is not clear, but in 1911-12 the lecture room was reduced from over 400 seats to around 200. In the words of the museum director: *"We hope for a… roof that does not leak (and) a medium-sized lecture hall instead of a large one in which you cannot hear."* [12]

No records have been found on the lecture room from the 1911-12 remodeling to 1927 when the new Fogg Art Museum was opened and the old building became an annex to the school of architecture. However, the drawings for the remodeling showed a new inner semi-circular wall following the column line with no sound absorbing material. This inadvertently restored the rear wall echo that Sabine had previously removed.

In 1935, the year that the Faculty of Design was established, the building was renamed Hunt Hall in honor of its architect. Around this time a layer of hair felt covered by a perforated asbestos board was installed on the lower two-thirds of the inner wall. Little additional information prior to 1965, when the room was first carpeted, could be elicited either from available documents or former occupants.

In 1972 the museum was returned to the Fine Arts faculty and some inexpensive changes were made to the lecture room. On the recommendation of Professor Robert Newman, a flat canopy was added over the raised lecturer's platform and an eight foot high band of highly absorptive material was added around the semi-circular inner wall. In 1973 a student report described the acoustical changes in the following manner: Before remodeling, focused reflections from walls and ceiling created locations at which *"…the sound was reinforced making hearing very easy (assuming the speaker did not move). Conversely there were dead spots where hearing was often extremely difficult."* After the remodeling, the student report concluded that *"Having attended two classes a week since these corrections were made, I can say that the hearing conditions … have been drastically improved. A speaker anywhere to the front of the room can be heard clearly throughout the hall."* [13]

The building was demolished in 1973 to make way for a student dormitory. So, for at least its final year, speech intelligibility in the room seemed to be relatively acceptable.

Acquisition of information

Acoustic reconstruction of an historical building, especially one that is no longer standing, begins with the accumulation of documentation concerning not only the geometry but also the construction materials. The documents found describing this room span 75 years, covering the series of renovations. Documents include original publications by Sabine himself, various architectural drawings, photographs, and several acoustical measurements.

Sabine's papers

In Sabine's important work, "Reverberation," the Fogg Art Museum was introduced.[11] His drawing is reproduced here in Fig. 1. In addition to the drawing, a number of acoustical and construction details are given, summarized in Table 1. Subsequent to the fundamental research efforts in the room, establishing the relationship between absorption and reverberation time (first in terms of theatre seating cushions, then in terms of open window area) the room was modified from its original design through the addition of an absorbing material. According to Sabine, *"…hair-felt one inch in thickness was glued to the walls in the rectangular spaces between the windows and on the recessed lunettes in the ceiling. Over this was stretched asbestos cloth, also of moderately high absorbing power…The asbestos was placed in contact with the felt, and held against it by an office-wire grating. The use of this construction was immediately successful, and it has remained untouched, the lecture room being used constantly, not merely for classes, but for public lectures and musical concerts."* [9]

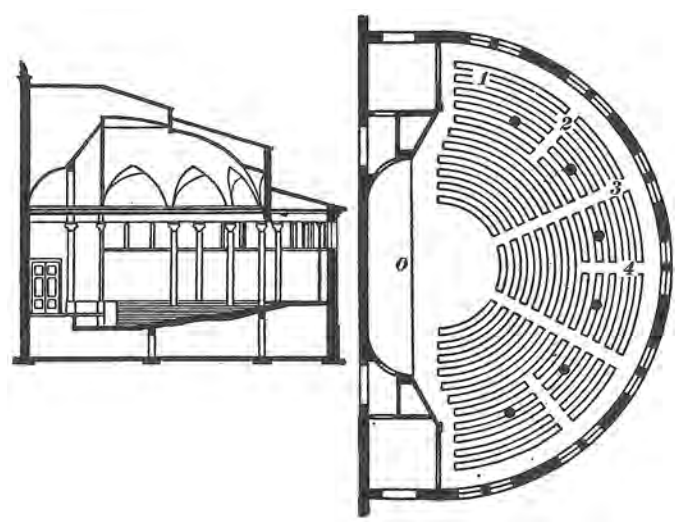

Fig. 1. Lecture-room, Fogg Art Museum.[11]

Table 1. Sabine's construction and acoustical data.[11]

Volume					2740 m^3		
Reverberation Time (512 Hz)					5.61 sec		
Total abs. (open window area): room empty					75.5 m^2		
Walls, plaster on tile (α at 512 Hz)					0.025		
Dome, plaster on lath (α at 512 Hz)					0.033		
α *vs.* freq: 1-inch thick hair felt and Sanders Theatre seat cushion.							
Organ Note	C1	C2	C3	C4	C5	C6	C7
~Freq (Hz)	31	63	125	250	500	1k	2k
Felt (1 inch)	0.12	0.14	0.23	0.54	0.64	0.56	0.52
Cushion	0.24	0.28	0.39	0.54	0.59	0.53	0.46

The absorption coefficients for 1-inch felt and Sabine's seat cushions are found in two other papers, "Musical Pitch" and "Architectural Acoustics" respectively (see Table 1).[11] These publications provided the only reference for the original acoustical state of the room. While there are a great deal of data concerning experiments with cushions, no data were found regarding the post-treatment conditions.

Architectural drawings

It was not learned until after the start of demolition that the University had no drawings of the museum prior to 1900. This discovery prompted a search, probably still incomplete, lasting three years for sources of information, including the Harvard libraries and other institutions in Boston, New York, and Philadelphia.

The first discovery of value was a single blueprint found in 1973 in the Cambridge building department comprising a plan and section showing the proposed addition of the semicircular wall separating the domed part from the lower surrounding space. Since no copier was available and material could not be taken out for copying, a pencil tracing of the blueprint became the source of plans and sections that were subsequently published.[14] While generally consistent with Sabine's drawings, later investigation has confirmed some inconsistencies compared to other drawings discovered later in *Architectural Review*, August 1894 (see Fig. 2 and the discussion in the section on the "Conflict between drawings").[15]

Following an initial presentation in 1973, copies of the paper were sent to many people whose names had surfaced in discussions with former faculty and staff familiar with the original Fogg Art Museum, requesting any information that could be added.[16] It is gratifying to re-read the correspondence from librarians, retired faculty, researchers and others who were very generous with time and recollections. One person suggested a check of records at the new Fogg, where a staff member not only found a photograph of the original room but also introduced a retired professor whose student class notes from Sabine's course in architectural acoustics are now in Harvard's Pusey Library. This photo, shown in Fig. 3, was used for the proceedings' cover of the Sabine Centennial Symposium.[17] Some information acquired after the 1973 presentation was presented at a meeting in 1976.[18]

The re-examination of correspondence and notes prompted by the current study elicits distinct regret about the many questions that, in hindsight, could have been asked of several elderly correspondents from 1973 to 1976. Another regret is that, had the dearth of information been apparent, more photographs could have been taken and interior dimensions could have been verified. However, this loss may in some ways be offset by the vastly improved communications afforded by computer resources. Samples of Sabine's original sound absorbing material should also have been saved from the rear wall and from one of the lunettes, or arched recesses, in the dome. It is hoped that continued study of the records will shed still further

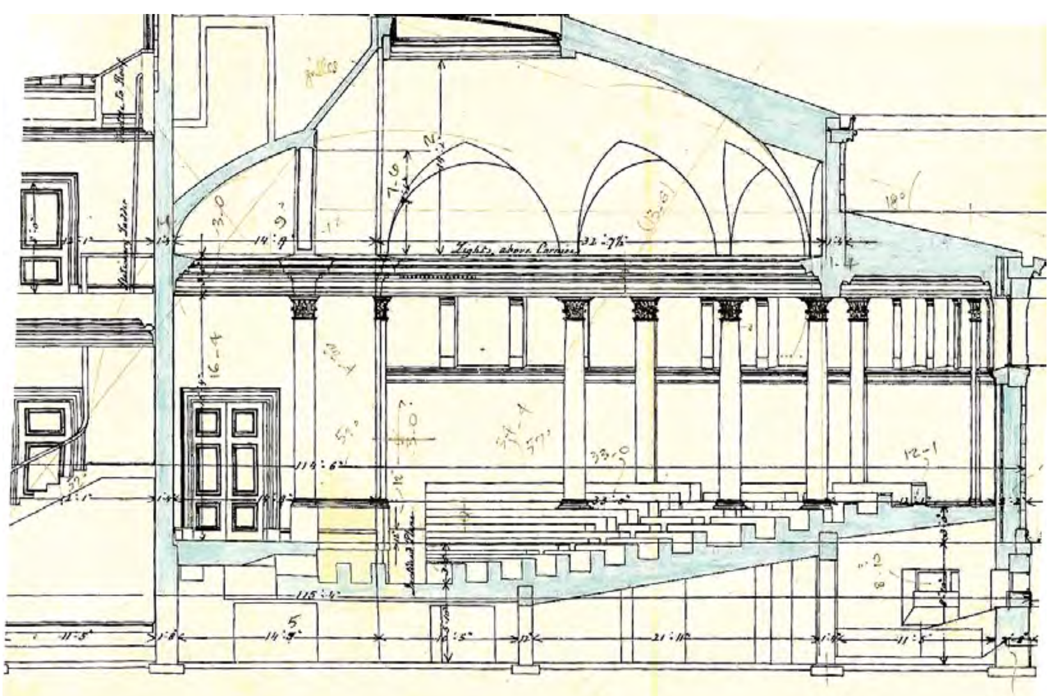

Fig. 2. Architectural section, colorized to better visualize the building structure[15]*.*

Fig. 3. Interior photo of lecture-room after 1898. Courtesy of Fogg Art Museum, Harvard University.

light on the Fogg Art Museum.

To summarize, the lecture room can be characterized as having gone through two architectural modifications since its completion in 1895: in 1912 (volume reduction, flat floor) and 1972 (addition of canopy). In addition, there were three purely acoustic modifications: 1898 (Sabine's acoustic treatment, partly removed in 1912), c.1930 (acoustic panels added on lower portion of rear wall) and c.1965 (floor carpeted). It is likely that successive paintings of the fabric covering in the lunettes gradually reduced their absorptive characteristics. Drawings of the various renovation stages can be found in *Architectural Acoustics*.[14]

Acoustical measurements

What has become a historical study of the Fogg Art Museum was not foreseen at the outset. A newspaper article on the planned demolition of the building simply prompted an interest in making some final acoustical measurements before the building ceased to exist. However, a subsequent *New York Times* article by the distinguished architectural critic Ada Louise Huxtable, deploring the loss of one more historical building, indicated the importance of reporting the measurements.

Demolition was scheduled for 16 June 1973, the end of the academic year, so measurements had to occur in the interval between the end of classes and that date. With the support of several University departments, acoustical measurements were made on two occasions. On 5 June, with the room in its final configuration, tape recordings were made of sound decay, impulse response, and sound distribution using noise bursts (1/3rd octave) and balloon bursts. Then the canopy was substantially demolished and on 15 June the measurements were repeated.

However, since the summer administrative staff had not been made aware of this study, permission to make the second set of measurements had to be renegotiated that evening at the campus gates, so they came perilously close to not taking place at all.

Creation of acoustical models

Using the collection of architectural, photographic, and acoustical details the task of constructing an acoustical model for study and subsequent auralization was possible. As the room had undergone various architectural and acoustic modifications, the goal was to have valid models for the various phases. The process adopted was to create a sequence of models, each linked to the previous one, covering the major changes. The primary goal was to arrive at the 1895 and 1898 conditions, those on which Sabine actually worked. In total, three conditions have been considered here: 1895 (pre-Sabine), 1898 (post-Sabine) and 1972, in which the 1912 remodeling, the c.1930 acoustic treatment, and the c.1965 carpet are included. The 1972 canopy has not been included.

Among the general assumptions necessary to make the transition from ink drawings to computer model, the lack of a lateral section and reflected ceiling plan made creation of the dome and skylight areas difficult and posed many questions. In addition, the majority of photos taken during the 1973 measuring session do not show the ceiling or higher elevations or were taken with the large canopy in place, masking the dome and arches. For this part of the model, the 1898 photo (Fig. 3) was the only real source of information. A great number of assumptions have been based on careful analysis of this photo.

Conflict between drawings

Several discrepancies were found when comparing the various section drawings (see Fig. 1 and Fig. 2). First, regarding the curvature of the dome and arch above the platform; in Sabine's drawings these curved surfaces are circular. In contrast, Fig. 2 shows a composite curve. While the authors have great respect for Sabine's acoustical work, they have more faith in the architectural study in terms of determining the actual geometry of the room. Inspection of Fig. 3 supports the non-circular form.

The second major discrepancy was the determination of the height of the room. In using Fig. 2, it was found that the noted height was inconsistent with the other dimensions of the room, being 9% smaller. As Sabine's drawing did not include dimensions, a calibration between the drawings would be necessary. Comparisons of other dimensions on the drawing showed the single inconsistent dimension was the height. This was shown as referenced to an external measure on the outside of the building. A final comparison was performed using photographs taken during the 1973 measurement sessions. These supported the hypothesis that the height was erroneously labeled and it was decided to discount this single noted dimension. These decisions result in the final model being based on a combination of dimensions from drawings of various sources.

Geometrical model 1972

A base model was created which contained architectural elements constant between the eras: the platform wall and arc and the dome. Most of the model was parameterized using circle and ellipse equations approximated from the architectural drawings. The dome section also has rotational symmetry, so there was need for only one "pie slice" to be modeled, than simply duplicated. The model is shown in Fig. 4. Source, *A1*, and receiver positions, *01* and *02*, for the measurement session are also shown (see previous section on "Acoustical measurements").

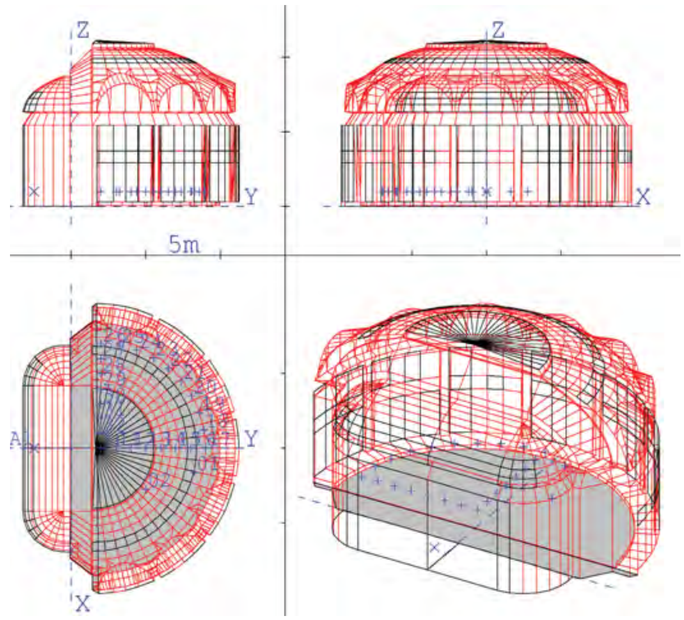

Fig. 4. Acoustical model, 1972.

Geometrical model 1895

The earlier era model was created by replacing the flat floor and rear wall (installed in the 1912 renovation) by the original architecture. The model is shown in Fig. 5, including a surface representing the original seating.

During model construction, one of the main resources for verification of the architecture was the singular photo shown in Fig. 3. Comparisons were possible through renderings of the model, where the approximate camera position was recreated (see example in Fig. 6). While the camera properties are not perfectly recreated, one can make certain judgments on the model. The red shaded surfaces, back of the lunettes and between the windows, are those on which Sabine installed acoustic treatment. Certain aspects appear to be slightly in error, though are not considered crucial, such as the tip intersection of the lunettes and dome. A final comparison of interest is with regard to the room volume. The model has an interior volume of 2632 m^3. This is approximately 4% smaller than Sabine's estimate (see Table 1).

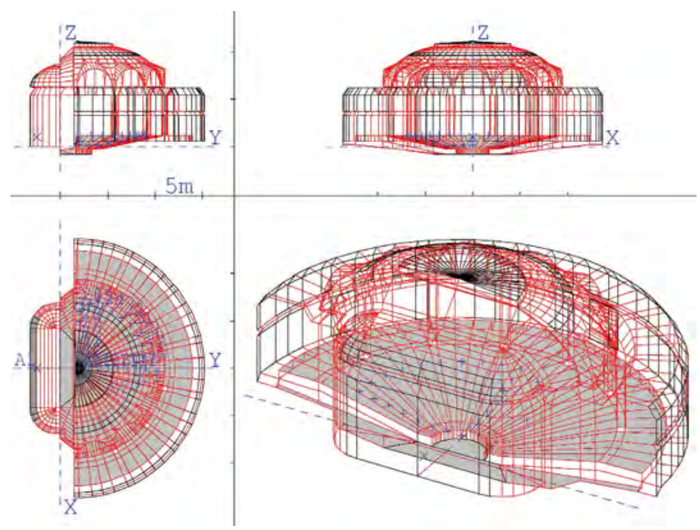

Fig. 5. Acoustical model, 1895.

Acoustical model calibration

Aside from the collection of architectural and anecdotal details on the lecture-room, this study includes actual acoustical measures in the room (albeit after several renovations). The approach for this study was to work backwards, from the 1972 room with the corresponding measured data back through the renovations to arrive at the earlier states. Agreement between the model predictions and measurements should provide some confidence in the reconstruction.

Replicating the measurement positions of 1973, the reverberation time (RT) was compared with the model. The measured data exhibited a dip in RT at 500 Hz. Some minor adjustments were made to absorption coefficients (particularly for the ventilation grilles near the skylight) and the diffusion coefficients (to account for the debris of the canopy on the floor during the measurements). The final state of the model using ray tracing techniques (T15 and T30) and traditional Sabine Reverberation Time calculation are compared to the measured data (typically T15 due to low S/N ratios), with results shown in Fig 7. The T15 calculation matches extremely well, with small variations at lower frequencies for T30. Sabine's diffuse field prediction equation is slightly less consistent with the measurement results.

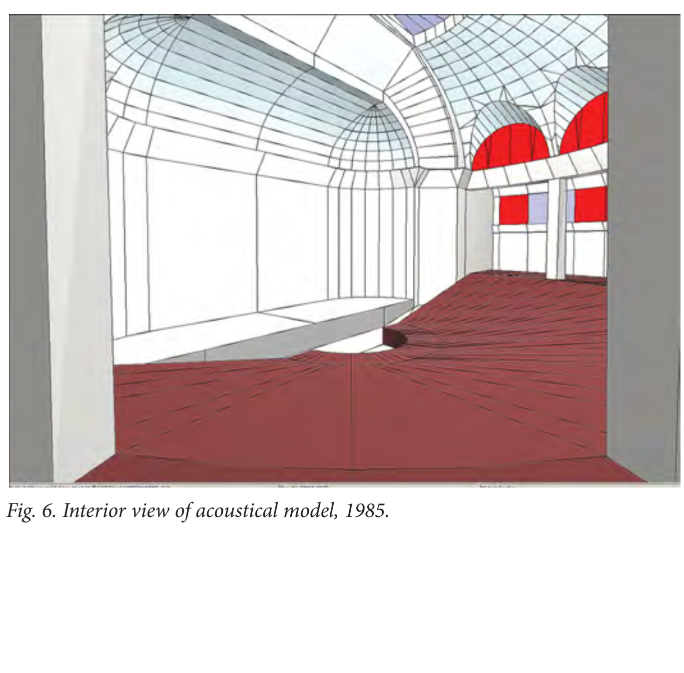
Fig. 6. Interior view of acoustical model, 1985.

Comparison 1895 and 1898

Using the model characteristics established through the calibration procedure (refinement of the acoustical properties of materials), it was now possible to undo the series of renovations occurring over the time span 1910–1973. Using the pre-renovation models, numerous acoustical parameters can be predicted, as well as the generation of impulse responses for auralization. While the latter is the goal, it is difficult to include them in a printed article. For that reason, several of the acoustical parameter results are presented.

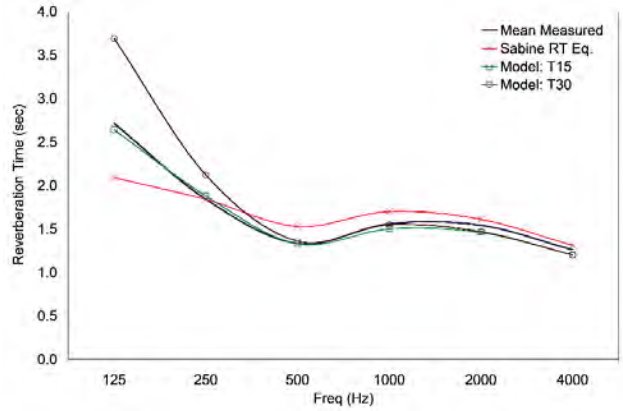

Fig. 7. Reverberation Time comparison for 1972.

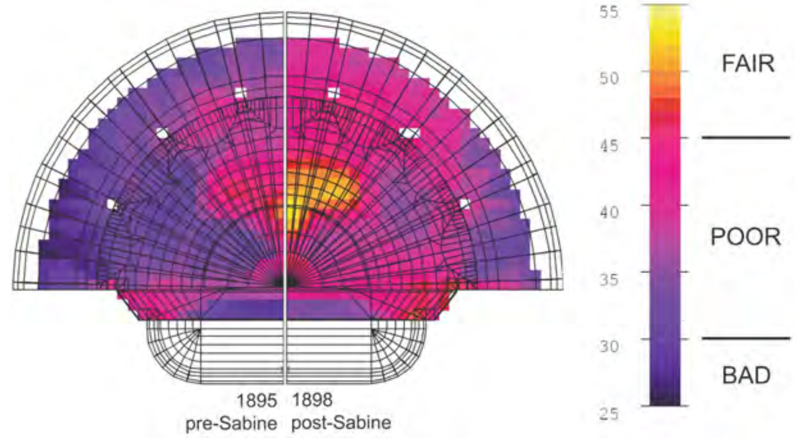

Fig. 8. STI Comparison: 1895 and 1898.

Comparison with Sabine's data

The fundamental room acoustic parameter is Sabine's reverberation time. Predicted RT values for the models are given in Table 2. These can be compared to Sabine's pure-tone measurement of 5.61 sec at 512 Hz for the 1895 state, representing a difference of only 4%, which is within the tolerance for perceptual and measurement errors.[19] There is also a clear reduction in reverberation time following Sabine's treatment. But, one must note that it does not approach the low values obtained during his scientific study using cushions where he obtained 2.03 sec with all seats covered, and a notable 1.14 sec with 1500 cushions placed throughout the room.[7]

Intelligibility measures

A parameter of great interest in the context of this room and its use is that of intelligibility. This was cited as the major fault of the room, and the reason for Sabine's involvement. A comparison of the intelligibility before and after Sabine's intervention is presented in Fig. 8. The lack of homogeneity as mentioned by the accounts is clear. While Sabine's treatment seems to have improved the intelligibility near the center of the room (particularly at the rear), there still remained a section of seating (dome radial angle region 20°-40°) with a consistently *BAD/POOR* intelligibility rating. In general, the room would still be classified as having *POOR* intelligibility.

Summary

This study presents the documentary work, as well as the acoustical modeling method, adopted in an attempt to acoustically reconstruct the Fogg Art Museum Lecture room. Using measured data and related published data by Sabine, a calibrated prediction and simulation model has been created. Comparisons of acoustical parameters and impulse responses indicate a valid model. Initial analysis of intelligibility through predictions appears to corroborate the anecdotal evidence for the poor acoustic functioning of the hall and its strong lack of homogeneity.

As the goal of this study has been to acoustically explore this historic building, through simulation and auralization, the authors have chosen to make the model files available for educational and academic use. The authors thank Harvard University, Boston Public Library, and Leo Beranek for continued support and Bengt-Inge Dalenbäck of CATT for making the model accessible to the general public (available at www.catt.se/FoggArtMusum.htm). All computer models and simulations were performed using CATT-Acoustic v.8.0c.[20] The authors also thank Kurt Graffy and Larry Tedford for their assistance and particularly for introducing the authors with the purpose of realizing this study. Sabine's *Collected Papers on Acoustics* is available from the Acoustical Society of America and from Peninsula Publishing, Los Altos, California.**AT**

Table 2. Predicted reverberation time: 1895 & 1898.

		125	250	500	1k	2k	4k
T15	*1895*	3.85	4.49	5.40	5.93	4.77	2.95
	1898	3.5	3.26	3.49	3.76	3.34	2.32

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