

## Acoustics of multipurpose halls in Croatia

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### ABSTRACT

In the modern-day era, halls are usually built to host a variety of events that can range from movie projections, congresses and meetings, theatre plays, sporting events, music performances in various genres, etc., all of it with or without sound reinforcement. Each type of event requires specific acoustical conditions in the hall, which makes the acoustics of a multipurpose hall a challenge to be dealt with mostly by making compromises. In smaller communities, there is often only one hall large enough to accommodate all the visitors interested in attending an event, usually a cultural center or a sports hall of a school. However, the trend of building multipurpose halls is present in cities as well, in order to use such spaces as much and as often as possible, to maintain their self-sustainability. To address the acoustics of multipurpose halls in Croatia and make an overview, this paper gives a comparison of basic acoustical parameters of 16 different halls. The parameters were either measured as a way of acoustical analysis, or simulated during the acoustic design process. The acoustics of these halls is analyzed with regard to their size, intended use, and the values of relevant acoustical parameters.

Keywords: Room acoustics, Multipurpose halls

### 1. INTRODUCTION

The design of public performance spaces rarely aims to serve a single purpose, i.e. these spaces are required to host many different types of events. Big cities can afford to build dedicated concert halls, conference centers, etc., but even they resort to building multipurpose halls or using existing ones for any number of events. Smaller communities do not have much of a choice, as there is often only one public space at their disposal. For example, a small town will want to use the sports hall of its elementary school, or a small concert hall of the local music school, or a movie theater for different kinds of program. Private investors, who build halls almost exclusively for commercial use, often demand to have an acoustically favorable space for different types of events.

The challenge in designing a multipurpose hall is reflected in identifying all possible uses, i.e. types of events the hall is to host, in adding weight to each individual use according to its frequency, importance, and other factors, and, finally, in deciding on a compromise that is required to obtain the most favorable acoustics for all considered cases. The design of single-purpose spaces allows the designer to aim for optimal acoustics of the space they are designing, whereas the designers of multipurpose halls will strive to achieve the least-objectionable acoustic conditions for all intended uses.

The main motivation for this paper are the challenges the authors have dealt with over the years in the area of multipurpose hall design. A similar paper (1) was written by the authors on the acoustics of churches in Croatia and its changes over time. The encouraging trend is the growing interest the architects show for the acoustics of the spaces they design, multipurpose halls included. This improvement has happened over the years, starting from the situation where visual appeal was highly appreciated, but acoustics was often completely ignored, resulting in a space with visually spectacular architectural design, but unusable in practice due to bad acoustics.

The data that contains the values of the most common acoustical parameters was either measured or simulated for all included spaces, or both, depending on the task laid out before the authors in each particular case. The said data was obtained by simulation in the acoustic design process, or measured in either the initial stage or the control stage of these projects. Reverberation time was chosen as the most relevant parameter for assessing the acoustical conditions in examined halls, especially because relevant standards and recommendations use reverberation time as the parameter of interest, and stipulate its optimal values for any given situation. Size (volume) and purpose(s) of the investigated

spaces are also taken into account. The seating or standing capacity of a given hall is also recognized as an important parameter, leading to the specific volume, i.e. volume per person.

## 2. THE DESCRIPTION OF THE INVESTIGATED HALLS

Due to a variety of uses that can be defined for each investigated hall, the halls were sorted together in the following way: firstly, they were divided based on their purpose. This division took into account the primary purpose of the halls, i.e. whether the dominant program content in their most common use is speech or music. The music group was further subdivided to classical music and modern music, and the speech group was subdivided to sports and other speech content. The secondary purpose of the halls is complementary to the primary one, i.e. if the primary purpose of a hall is to host music-based events, then its secondary purpose is to be able to host speech-based events as well, and vice versa. The following subsection give a short description of the investigated halls. If a facility has several halls, their descriptions are grouped together in the same subsection.

### 2.1 The concert hall of Albert Štriga Music School in Križevci

This concert hall is frequently used for teaching and concert performance. It is a part of the aforementioned music school located in the Croatian House building in Križevci, built in 1914. The hall was measured in its current state, with the intent of the school to implement some kind of acoustic treatment in the future. The hall is quite small and made mostly of hard materials. The exception are large windows and the ceiling that provide some absorption of low frequencies, and the upholstered seats that introduce some absorption at middle and high frequencies. As a space primarily used for teaching purposes, the hall requires acoustics treatment to shorten the reverberation, thus making the communication between teachers and pupils easier, and providing the clarity required to hear all fast notes clearly.



Figure 1 – Albert Štriga hall (left), and Croatian House hall (right) in its present state

### 2.2 The Croatian House hall in Split

The Croatian House hall in Split is meant to become the representative concert hall for the city of Split, with the primary purpose of hosting all kinds of chamber music ensembles. The building itself and the hall within was built in 1908 and has suffered a number of changes since then. Acoustic conditions in the hall were measured in 2014, in what was then the current state, i.e. the hall and the entire building were in a quite run-down state, and in need of restoration. The building is being restored, and it is expected to host the concert season in the year 2020/2021. The values of reverberation time presented here are the ones simulated for the purpose of thorough restoration. Due to the status of the building as a cultural and architectural monument, only discrete acoustic treatment was possible. Therefore, appropriate chairs were selected as a mean of treatment. The hall is a classic shoebox type. Besides its primary purpose as a concert hall, the hall is to host different kinds of speech-based events, such as celebrations, meetings, presentations, etc.

### 2.3 Blagoje Bersa concert hall of the Music Academy in Zagreb

This concert hall was opened in 2016 as a space that would be used primarily for all kinds of student projects and classical concert performances. However, initial demands on acoustic design were overwhelming; to ensure financial sustainability, the wish of the investors was that the hall be able to host just about any event and/or performance imaginable, serving as a movie theater, theater, opera house, concert hall, conference hall, etc. In 2018, an organ was installed in the hall. Although the initial acoustic design was aiming at a reverberation time of about 1.5 seconds, the final state of the

hall, as measured just before the grand opening, is characterized with a much shorter reverberation time. The hall itself has a changeable configuration that allows the size of the stage to be changed as needed, and even the orchestra pit to be opened for opera performances. These changes demand that a part of the audience area be sacrificed, so number of seats varies. The net volume of the hall also depends on its configuration.

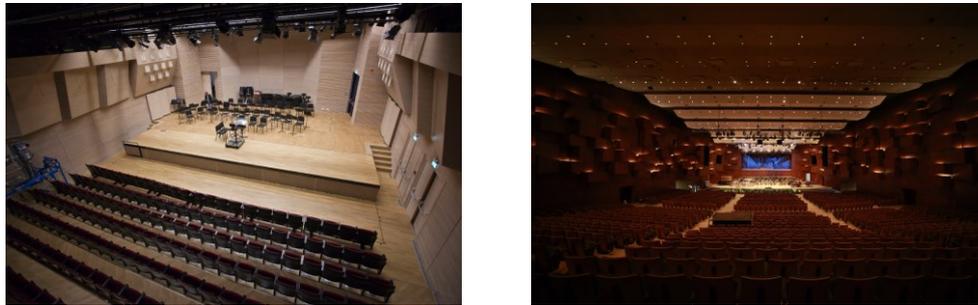


Figure 2 – Blagoje Bersa concert hall (left) (2), and Vatroslav Lisinski concert hall (right) (3)

## 2.4 Vatroslav Lisinski concert hall in Zagreb

Vatroslav Lisinski concert hall was opened in 1973 as the first concert hall in Zagreb designed exclusively to host symphonic music performances. To this day, it is still the most representative space for classical music performances, despite some drawbacks regarding its design. Extensive measurements of acoustical parameters were made, on request of the management of the hall. Apart from classical music, the hall hosts modern music performances, as well as all kinds of large meetings, conferences, and various ceremonies as speech-based events. Ballet and opera performances are sometimes organized as well.

## 2.5 Pogon - Zagreb Centre for Independent Culture and Youth

This facility strives to promote out-of-mainstream cultural and other events. The facility has three spaces that were encompassed in the acoustics design project made by the authors. Two of them, namely, the great and the small hall are in use, while the club as the third space requires renovation. The facility hosts a variety of events, from festivals and concerts, theater performances, to lectures, conferences, movie projections, workshops, etc.

The great hall is the largest of the three spaces, used mostly for popular music concerts.

The small hall is adequate for small events, such as workshops, rehearsals, presentations, etc.

The club space was also included in the acoustic project, as the intention is for it to be used mostly for club music performances.

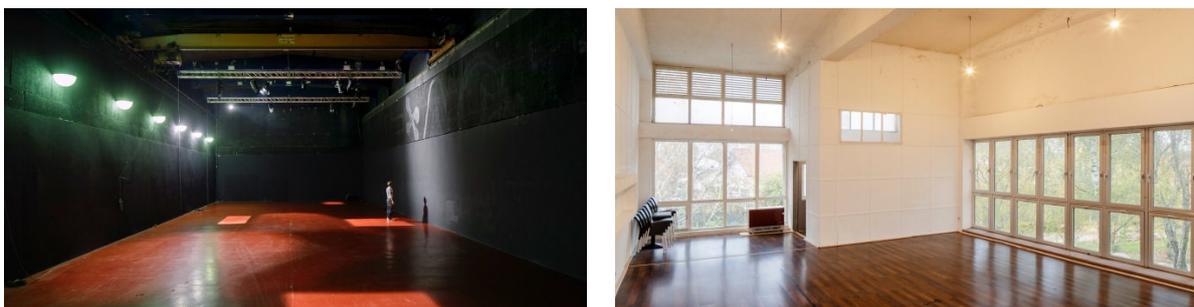


Figure 3 – The great hall (left) and the small hall (right) of Pogon (4)

## 2.6 Stara mehanika – Educational center for entrepreneurship and lifelong learning in Pula

This facility is still in the design stage. The intent is to create a representative facility in the town of Pula for hosting a variety of different events, from theater to modern music, but also entertainment event such as stand-up comedy, puppet shows, magicians, cabaret, as well as congresses, lectures, round tables, fashion shows, etc. Two spaces are to be built, namely, the great hall and the small hall.

The great hall is to become a facility to host large-scale indoor events, mainly concerts involving various modern types of music.

The small hall is designed primarily for small-scale events, from entertainment to various kinds of meetings, presentations, etc.

## 2.7 Bunker hall in Samobor

The Bunker hall was originally a warehouse within a military installation that was eventually abandoned and its facilities made available for public use. It was built almost exclusively out of reinforced concrete, and its initial reverberation time of 7 seconds was inappropriate for any kind of use. The desire of the town council was to have a hall that would be used primarily for concerts, hosting performers from different genres of modern music. The hall was acoustically treated, and the reverberation time, as shown below, has been significantly reduced.



Figure 4 – Bunker hall

## 2.8 The hall of the Diplomat hotel in Zagreb

The grand hall of the Diplomat hotel is to be used mainly for weddings and other types of celebrations where modern music performances are expected. Its secondary use is extended to conferences, meetings, presentations, etc. The hall consists of the main space, a side annex, and a gallery, which can be connected or function separately. The configuration shown here assumes that all three spaces are used together as a whole.

## 2.9 The Croatian House hall in Glina

This hall is to be renovated, and appropriate acoustic treatment has been proposed. Its primary purpose is to serve as a venue for different kinds of meetings, presentations, etc. Additionally, the hall is to be used for small ensemble performances, and any other events important to a small town such as Glina.

## 2.10 The movie theater hall in Samobor

The freshly renovated public hall in Samobor has always been used as a central place for all kinds of public happenings. It is most commonly used as a movie theater, but it also hosts various musical events that are of considerable importance to the town and its people. In light of that, the hall has been renovated and acoustic treatment has been applied. A control measurement of acoustical parameters has been made.



Figure 5 – Movie theater Samobor (left), and the hall in St. Thomas church (right)

### 2.11 The hall in St. Thomas church in Mostar

The hall of St. Thomas Church in Mostar, Bosnia and Herzegovina, is another example of a multipurpose hall designed primarily for speech-based events, but also as a performance space for all kinds of small-ensemble shows. The hall is in the design stage and is to be constructed.

### 2.12 The Ivan Benković sports hall in Dugo Selo

This sports hall is used primarily for teaching in physical education, and the occasional matches in different kinds of team sports. The floor is large enough to hold a full-size handball court. It can be divided into three equal-sized sections, each of them large enough to hold a full-size basketball court. Due to space restriction, the hall only has small, foldable bleachers. As the largest indoor space in the town of Dugo Selo, it is frequently used for all kinds of public gatherings. The reverberation time in its initial state was excessive, so some acoustic treatment was applied, thus reducing the reverberation. However, the reverberation time is still too long, and further steps are required. Both cases are presented in the paper.

### 2.13 The Ljudevit Modec sports hall in Križevci

This sports hall meets the same criteria as the one described in the previous section, regarding its size and the most common uses. The main difference is in the design of the roof, which is made of light sandwich material, as opposed to the roof of the Ivan Benković hall that is made of pre-fabricated concrete plates. Consequently, low-frequency absorption is quite high. The hall has both fixed stands and foldable bleachers that extend along the length of the hall on both sides. To house the audience area, the hall has been enlarged, and it is the largest space considered in this investigation.



Figure 6 – Ivan Benković sports hall (left), and Ljudevit Modec sports hall (right)

## 3. ACOUSTICAL PARAMETERS OF THE HALLS AND DISCUSSION

This section presents the most important parameters that characterize the investigated halls. The halls were grouped according to their primary purpose. Four groups were established: halls for classical music, halls for modern music, halls for speech, and sports halls. Location was given for each hall, along with its volume as a measure of size, the mid-frequency single-number reverberation time as defined in (5), the bass ratio as the measure of reverberation balance between low and middle frequencies, the seating or standing capacity. For brevity, the primary and secondary purpose of the halls was roughly divided into speech-based events and music-based ones, without further details.

The described data is shown in Table 1.

Table 1 – Relevant parameters of the investigated halls. The halls are sorted by their primary purpose, and then by size.

Hall	Town	Volume (m <sup>3</sup> )	$RT60_{500-1k}$ (s)	Bass Ratio	Capacity (persons)	Purpose	
						Primary	Secondary
1 Albert Štriga concert hall	Križevci	660	2.15	1.25	91		
2 Croatian House concert hall	Split	1650	1.63	1.09	250	Classical music	Speech
3 Blagoje Bersa concert hall	Zagreb	2350	0.91	0.92	246		

4	Vatroslav Lisinski concert hall	Zagreb	16000	1.78	0.83	1850		
5	Pogon - small hall	Zagreb	404	0.57	1.51	50		
6	Pogon - club	Zagreb	671	0.57	1.15	334		
7	Stara Mehanika - small hall	Pula	918	0.89	0.97	120		
8	Diplomat hotel - wedding hall	Zagreb	2040	0.72	1.48	221	Modern music	Speech
9	Bunker hall	Samobor	2600	1.12	1.37	1000		
10	Pogon - great hall	Zagreb	3339	1.27	0.84	1200		
11	Stara Mehanika - great hall	Pula	10500	1.18	1.03	600		
12	Ivan Benković sports hall – before treatment	Dugo Selo	13800	6.44	0.86	100		
13	Ivan Benković sports hall – after treatment	Dugo Selo	13800	4.57	0.90	100	Sports	Music
14	Ljudevit Modec sports hall	Križevci	18600	5.41	0.56	600		
15	Croatian House hall	Glina	1536	0.89	1.11	244		
16	Movie theater hall	Samobor	2095	0.81	1.21	225	Speech	Music
17	Hall of St. Thomas church	Mostar	2140	0.89	1.08	300		

Figure 7 shows the mid-frequency single-number reverberation time vs. room volume for all investigated halls. To assess the adequacy of each hall for its primary purpose, the recommendations from DIN 18041:2016 (6), usually used in defining the optimal acoustic conditions for a given space, are taken as guidelines. All the halls were eventually grouped in three groups: halls for unamplified music, halls for speech and amplified music, and sports halls. For clearer display of the data, the data for sports halls was not shown in the figure, as it greatly exceeds the recommended value of 2 seconds for sports halls larger than 10000 m<sup>3</sup>.

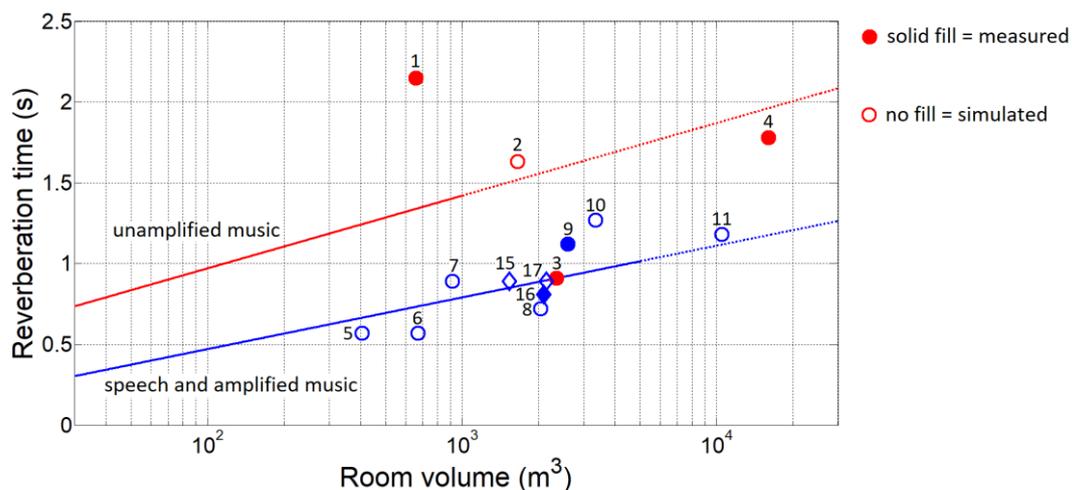


Figure 7 – Mid-frequency single number reverberation time vs. room volume for classical concert halls (red circles), modern music halls (blue circles), and speech halls (blue diamonds).

As shown in Figure 7, the reverberation time in the halls intended primarily for speech and amplified music does not deviate much from the values recommended by DIN 18041. The exception is hall 10, i.e. the great hall of Pogon, in which there were limitations as to what materials can be applied in the hall. As the result, a reverberation time higher than recommended was obtained. In all other cases, the designed reverberation time was achieved using common materials, and the designed values match quite closely to the recommended ones. The four concert halls, on the other hand, show considerable differences when it comes to meeting the DIN 18041 recommendations. Hall 1, i.e. the concert hall of Albert Štriga Music School is the smallest one, yet it has the longest reverberation time. The wish of the users is to shorten it by implementing acoustic treatment, as they report problems both in teaching, when good communication between the teacher and the student is crucial, and in preparing the students for performance. The main complaint is that the students love excessive reverberation

because it conceals certain mistakes in playing or singing, and they do not have to make an effort to play or sing loud, both of which only makes it more difficult for them when they play in a more acoustically controlled (damped) hall. Hall 3, i.e. Blagoje Bersa concert hall of the Music Academy in Zagreb has too short a reverberation time to be a true concert hall, due to certain technical issues that resulted in too much sound absorption introduced in the hall. While the players of wind and brass instruments seem to love such acoustics, the players of string instruments often complain about the hall being too “dead”. The hall serves quite nicely for all kinds of speech-based events, but also as a practice hall for orchestra rehearsals, as the short reverberation is quite unforgiving and reveals all mistakes made during playing or singing. Short reverberation also enables reasonably dry recordings to be made in the hall.

Figures 8 and 9 present the reverberation time as a function of frequency. The reverberation time was normalized to its mid-frequency single-number value so that similar halls can be directly compared, regarding their frequency-dependent behavior. Figure 8 shows the normalized reverberation time in concert halls and sports halls, whereas Figure 9 shows the same for small (<1000 m<sup>3</sup>) and large (> 1000 m<sup>3</sup>) halls for modern music, and for the halls for speech.

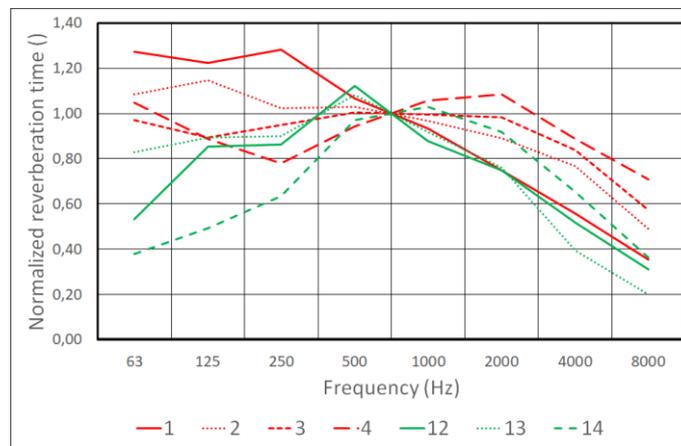


Figure 8 – Normalized reverberation time vs. frequency, shown for concert halls (red lines), and sports halls (green lines). The numbers in the legend correspond to the number of the hall as listed in Table 1

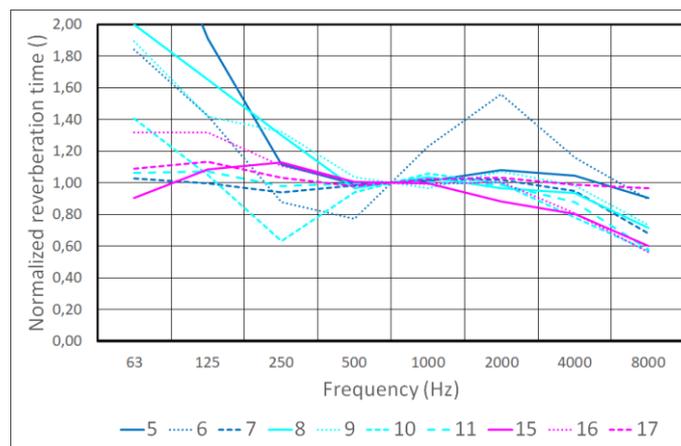


Figure 9 – Normalized reverberation time vs. frequency, shown for small modern music halls (blue lines), larger modern music halls (cyan lines), and halls for speech (magenta lines). The numbers in the legend correspond to the number of the hall as listed in Table 1

The data shown in Figure 8 reveals that the concert hall of Albert Štriga Music School suffers from serious imbalance between low- and high-frequency reverberation. Additional steps have to be taken in order to shorten the reverberation time at low and middle frequencies, thereby achieving the

required balance, and shortening the overall reverberation time. The Croatian House concert hall is in the implementation stage, and the data shows a well-balanced design that will yield a proper reverberation time and the required warmth for classical, mostly chamber music, while maintaining enough speech intelligibility for speech-based events. The remaining two concert halls, i.e. the Blagoje Bersa and the Vatroslav Lisinski concert hall, seem to suffer from the same problem, with their low-frequency reverberation not being long enough to provide the warmth that classical music requires.

The reverberation in both sports halls, as shown in Table 1 and Figure 8, is excessive, and reaches its highest values at middle frequencies. This finding is a very fortunate circumstance, as any additional absorption will have to be introduced in the form of mid-frequency absorbers. In already finished halls, this is far easier to achieve than to have to deal with excessive low-frequency reverberation. During the measurements conducted in these halls, it was found that direct speech communication across the hall was very difficult, but still possible in the Ljudevit Modec hall (hall 14), due to relatively short low-frequency reverberation. In Ivan Benković hall (two cases; hall 12 before treatment, and hall 13 after treatment), such communication was impossible before treatment, and barely manageable after it. Both findings suggest that further acoustic treatment measures have to be taken, if the halls are to meet the relevant criteria regarding their acoustics.

The data shown in Figure 9 reveals that the halls designed primarily for speech-based events (halls 15, 16, and 17) have a well-balanced reverberation throughout the entire frequency range, as intended, with the values of the bass ratio of around 1.1 to 1.2.

The halls designed primarily for modern music performance (halls 5 to 11) over electroacoustic systems, i.e. amplified music, should follow the same criterion applied for halls for speech-based events, as amplified music requires reasonably short and well-balanced reverberation. In some cases, it was not possible to meet these criteria in full due to technical and financial limitations on available space and choice of finishing materials. As a result, these halls have considerably long reverberation, especially in the 63 Hz octave band, which is usually not even considered, and it should be, given that the energy content of modern music material is considerable in this particular frequency band. In the next design step, further steps will need to be taken to correct this issue, if possible.

#### **4. CONCLUSIONS**

This paper collects the results of the efforts made by the authors to design and/or evaluate different halls in Croatia over the past ten years. Originally, many of them were intended to be used for a single type of events, but their use has been extended to a number of different programs over the years. The reasons for this range from technical to financial, and in many cases, it is a mere question of availability of a given space. Acoustic design of multipurpose spaces depends on the range of foreseeable purposes, and is rarely aimed at achieving optimal acoustics for one particular purpose. Instead, the design process heavily relies on compromise, resulting in “equally bad” acoustics for all intended types of program. The design process also suffers from further limitations imposed by architects, fire safety experts, and other experts involved in the overall design process. These limitations result in narrowing the range of materials to be used, and the range of surfaces on which these materials can be placed. As a part of further work, the intent of the authors is to promote cooperation between all interested parties in multipurpose hall design in as early stage as possible.

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