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Acoustical Design of an Auditoria

Pradeepa Chandramouli[1], Janani Selvam[2], Amiya Bhaumik[2]

Post doctoral Research Fellow, Lincoln University College, Malaysia
Lincoln University College, Malaysia
Email: pradeepa.pdf@lincoln.edu.my

In an auditorium, acoustic consideration is a factor to ameliorate good listening conditions as background noise, reverberation, clarity, and speech intelligibility are factors to be considered to attain good acoustic quality [1]. To achieve good acoustic sound, the acoustical design of the hall is studied either through measurement or certain simulation procedures. In this study, the acoustic simulation of a school auditoria is considered through ODEON [2] software and some of the acoustical indices have been examined in the context of better listening conditions. An impulse response of the space is simulated within the model for specific receiver positions, sound sources, characteristics, and architectural parameters of the space. Using a simulation model includes a perfect impulse sound source, full control background noise, and a well-defined onset time of the impulse response. The most effective use of computer modelling is to predict the response of the hall with a specific geometry.

1. Introduction

Acoustical design is essential for achieving sound clarity, aural comfort, and an optimal auditory experience in performance spaces such as auditoria. Effective acoustic planning enhances both speech intelligibility and musical quality by ensuring balanced sound distribution while minimizing reverberation and noise interference. Acoustical standards for auditoriums provide guidelines to achieve these optimal conditions by defining acceptable levels for reverberation time, sound transmission, and ambient noise levels.

Despite advances in acoustical engineering and the availability of these standards, numerous auditoria continue to exhibit issues, including uneven sound distribution, excessive reverberation, and poor sound clarity. These problems are often attributable to the misalignment between architectural form and acoustic performance, or inadequate adherence to acoustical guidelines during the design process. The increasing demand for multi-functional performance spaces necessitates the development of acoustical design strategies that integrate aesthetic, functional, and acoustic considerations while meeting established standards for sound quality.

The objective of this paper is to evaluate that acoustical design parameters of the auditorium has better agreement with the standard values

MCC auditorium, a part of Madras Christian school located at Chennai is originally constructed in the year 1950 named as Miller Hall, subsequently renamed in the name of Dr. Clement Felix who was the school head master. A renovation of the hall took place in the year 2016 for improving the acoustics of the hall. The plan and section of the auditorium are shown in Figure 1 & 2. The shape of the auditorium is shoe box type with dimensions of 39m x 15m, which can accommodate 850 people, refer Figure 3 (a & b). It is desirable to have good speech intelligibility as the hall is intended for many lecturers and other functions. It has been felt that higher absorption of walls, with moderate reflective ceiling will result in an appropriate acoustical solution. In this context, the acoustic simulation has been done through 3D model of the auditorium which has been done using Google sketch up. This sketch up model is exported to ODEON.

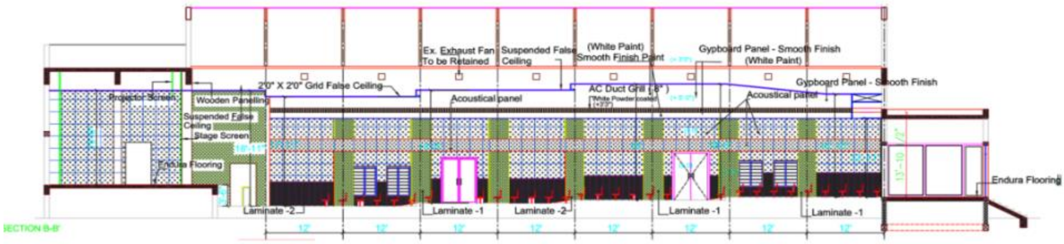

Fig 1. Plan

The accuracy of the values through simulation is dependent on the detail of the model exported. The various details of the hall are described in table (1).

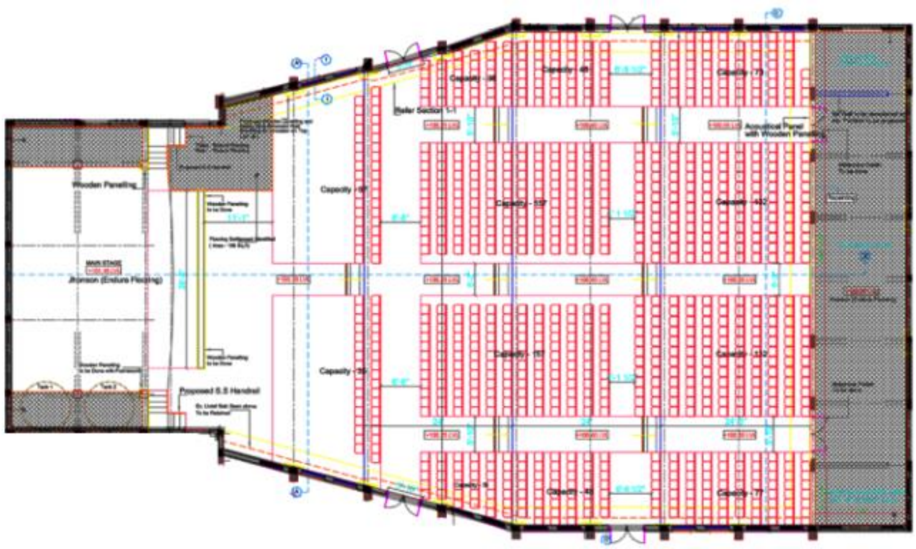

Fig 2. Section

Fig 3 (a) Interior View of the hall (b) Stage view

Table 1. Geometrical parameters of the hall

S.no.	Geometrical parameters	Dimensions
1	Average Length Lm	39.9 m
2	Average width W	15 m
3	Average height H, m	6.8 m
4	Depth of the stage D, m	8 m
5	Volume V m^3	4069 cub.m
6	Seating capacity S_a,m^2	850
7	Total Area ST, m^2	87 sq.m
8	Mean rake angle	4.5

2. Literature Review:

Barron [1] conducted extensive objective acoustic measurements in British concert halls, comparing subjective preferences with various objective measures. Preferences for intimacy and reverberance were discovered, and correlations demonstrated the importance of total sound level and early decay time. Bradley [2] discussed the evolution of newer auditorium acoustics measures other than reverberation time, emphasizing the importance of clarity and definition in addition to reverberation. Carl and Eyring [3] presented a reverberation time equation that accounts for variations in room shape, resulting in a more general formula than Sabine's. Their findings emphasized the importance of taking into account room geometry when predicting sound decay. Bradley [4] conducted detailed measurements of the acoustical conditions in multipurpose halls and renowned concert halls, revealing significant differences. The study sought to emphasize the significance of extensive measurements in accurately assessing auditorium acoustics.

Claus Lynge Christensen in 1999 [5], a room acoustical model capable of handling point, line, and surface sources was established, with a special ray-tracing algorithm for line and surface sources and Image Source Modelling for point sources. This method enabled the modelling of complex sound sources in workrooms, laying the groundwork for future advances in acoustic simulation. Rindel's work [6] advanced the field by emphasizing the benefits of hybrid models, which combine the best features of image source models and ray-tracing methods to shorten calculation times and improve results. The importance of accurately modelling sound scattering from surfaces was emphasized, indicating a need for more data on material scattering properties. Jens Holger Rindel's [7] comparison of measured room acoustical parameters with those obtained from computer simulations using the ODEON programme shed light on the accuracy of these models in non-rectangular spaces, such as concert halls, demonstrating the potential of these tools in real-world applications.

Graham Naylor's 1992 [8] prediction of room acoustical behavior highlighted the discrepancies that can result from geometrical simplifications, advocating for simpler room models to make more reliable predictions in certain situations. David and Bradley [9] and Carolina Reich and Marcon Passero [10] investigated specific applications of ODEON software in evaluating concert hall acoustics and classroom RTs, demonstrating the utility of simulation software in real-world settings. Jens Holger Rindel's 2010 [11] paper examined the strengths and weaknesses of various modelling techniques, emphasizing the differences that can arise due to differences in material absorption characteristics and the approximation of wave phenomena such as scattering and diffraction in simulations.

Previous researchers have already done scientific studies on acoustical materials, significant acoustical parameters, built form with respect to aural comfort. But there are very few studies carried on assessing the auditorium design parameters in agreement with varied acoustical parameters standard values.

3. Odeon Modelling

The modelling has been done in Auditorium mode. The following steps have been adopted. Three point sources (P1, P2, P3) have been simulated on the stage. They are at a distance of 2m from the front of the stage. The intra distance between the sources on the stage is 1.5m.[17]

The absorption distributed on the surfaces is chosen from library of materials provided with the ODEON programme, refer Figure (4) Receiver locations (R1, R2, and R3) have been specified to evaluate the acoustical parameters.

While evaluating the responses from point sources a hybrid calculation procedure is employed when the early reflections are evaluated using an image source method coupled with ray tracing. Subsequent reflections are completed using a special ray tracing process.

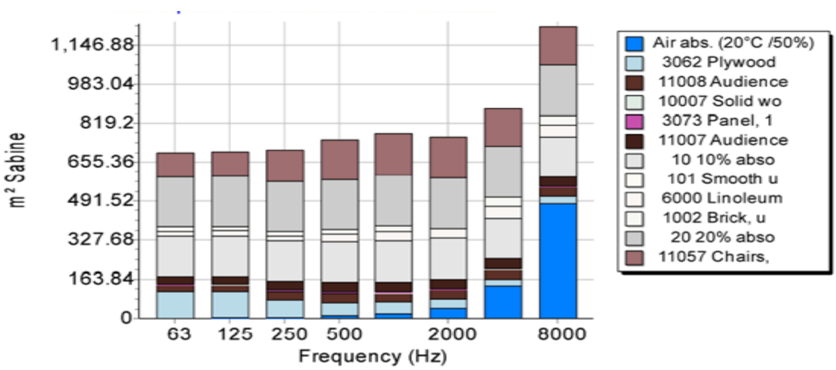

Fig 4. Materials used in the ODEON

An impulse response of the space is simulated within the model by positioning receiver and source positions, assigning absorption coefficient of the materials for the auditorium, The objective parameters are calculated based on the impulse response. The number of rays used in the model for simulation is 10,000 rays. An impulse response is simulated at each receiver position. Three sources defined as P1, P2, P3 with sound have output of 90dB, 100 dB and 90 dB[13]. Through an iterative process of gradual calibration for the absorption and diffusion coefficient, the reverberation time in octave bands is progressively adjusted so that the difference between the simulated and experimentally measured data is maintained within a 5% interval the JND (3,4) in the value of a parameter that can be perceived by the average listener Table (2).

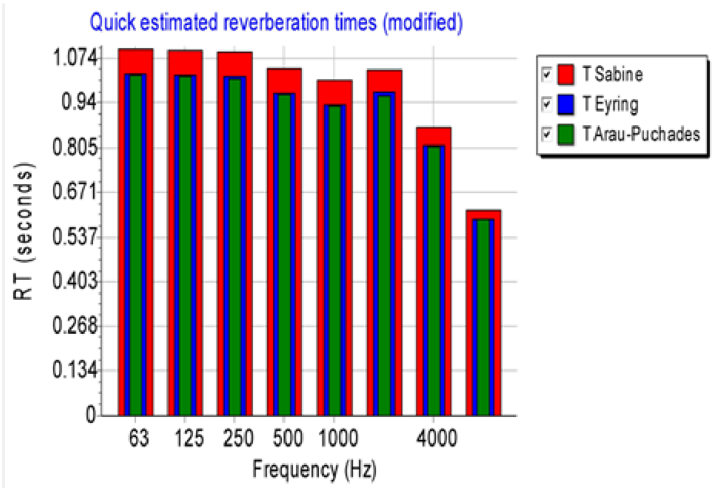

Fig 5. Reverberation Time

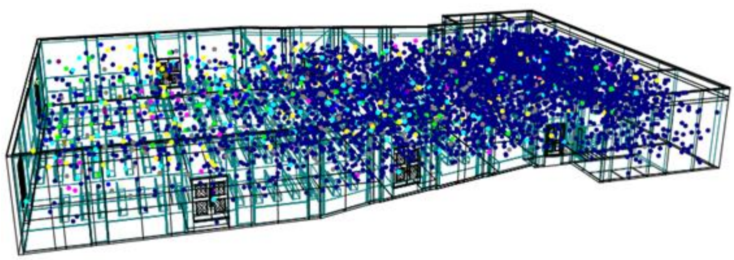

Fig 6.3D billiards

Based on assigning the material absorption coefficient, the quick estimate on reverberation time is done. (Sabine, Erying and Arau-Puchades), see Figure (5).

From this point, based on the RT values the series of calculations can be continued from the specified Impulse response length. The automated grid response with direct sound from the defined source can be calculated. Reflector coverage calculates the coverage provided by chosen reflecting surfaces. The 3D billiards display is a tool that can be used for investigating or demonstrating effects such as reflection, scattering, flutter echoes or coupling effects, refer Figure (6).

4. Results and Discussions

The following objective parameters have been obtained

(6, 7, 8):

4.1. Reverberation Time

Reverberation time (RT) is the time required for sound to decay 60dB, whereas early decay time (EDT) refers to the early part of the first 10dB of the sound decay. The field measurements showed that the finishing materials used resulted in fulfilled attaining optimum reverberation time. It is observed that the measured and simulated RT values have better agreement, see Table 2. This indicates that the decay is completely linear and the hall attains a satisfactory diffuse sound field.[15]

Table 2. Measured and Simulated RT

	RT Values						
	125	**250**	**500**	**1000**	**2000**	**4000**	**8000**
Measured	0.68	1.12	1.11	1.08	0.87	0.82	0.63
Simulated	1.00	1.06	1.00	0.96	0.98	0.85	0.61

4.2. Clarity

The equation for clarity is the Equation 1 of this research paper

$$C_{80} = 10lOG_{10}\left[\frac{\int_{t=0}^{t=80ms} p^2(t)dt}{\int_0^{\infty} p^2(t)dt - \int_{t=0}^{t=80ms} p^2(t)dt}\right] \text{ (dB) [20]}$$

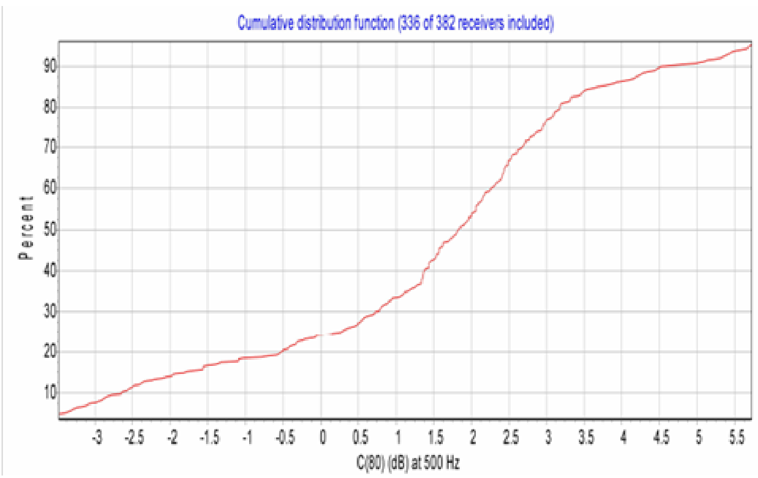

Fig 7. Graph showing Clarity

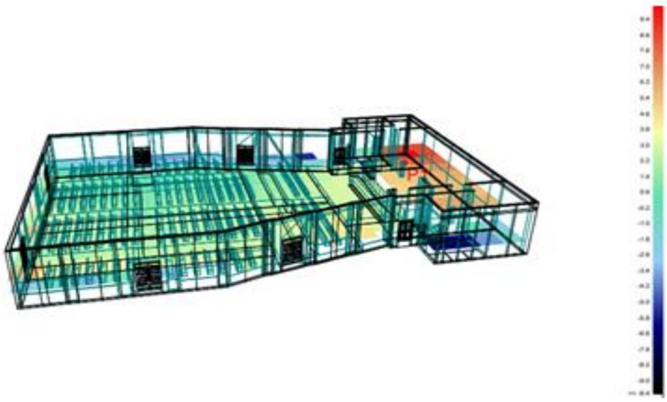

Fig8.Sound mapping showing clarity

For multipurpose halls the acceptable clarity: for front rows from >+8 and –2 to +3, and for back rows from +5 to +9. It is observed that the clarity value in the side seating is -2.2 and the middle seating it is +2.2 to +3.0, check Figure 7&8. Therefore, the results are satisfactory [5].

4.3. Definition

The equation for definition is the Equation 2 of the research paper.

$$D_{50}=\left[\int_0^{50ms} p^2_{0(t)}dt / \int_0^{\infty} p^2_{0\,(t)dt}\right] \quad [20]$$

Where te=50 or 80ms

In a satisfactory multipurpose auditorium, 65% of the words spoken should be clearly understood by the listeners, especially during lectures and seminars. The values show that approximately 60% of the words spoken in the hall are clearly understood, and the hall can be considered as acoustically intelligent, for D (50) is directly related with the speech intelligibility. [14]The results can be seen by the uniform distribution of definition levels in the hall, at each frequency in Figure(9).

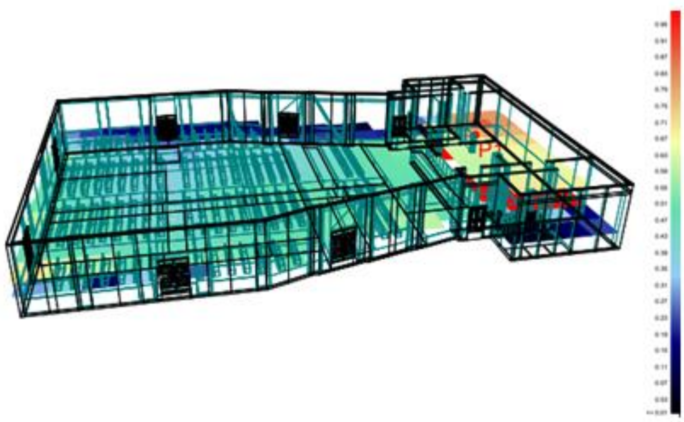

Fig 9. Sound mapping showing Definition

3.4. Lateral Fraction

From the graph, it is seen that listeners close to the sidewalls at the rear receive more lateral sound energy as compared to the listeners sitting on the central axis.

The lateral reflections at distant sidewalls from the stage is significantly lower as a result of longer direct sound path. The LF80 is related with the subjective parameter of envelopment, in the light of these results it can be told that the hall preserves “intimacy” and the feeling of “envelopment”[15]. The value at the receiver location is approximately 0.15 and the few areas in the audience space have nearly 0.23. It was observed that the left side of the door enclosure there is high eflections showing ‘red’ with value of 0.4 which can be solved by treating the door with absorptive, see Figure (10).

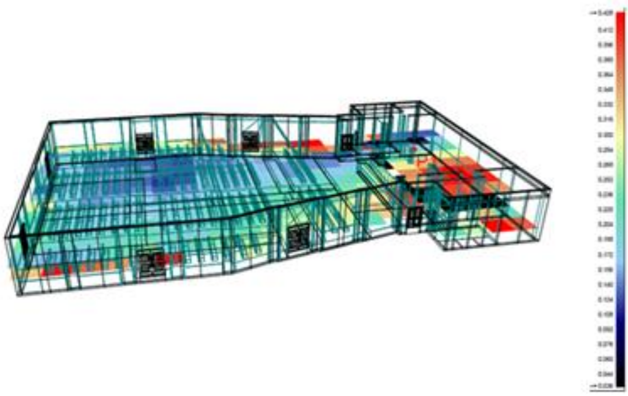

Fig10. Sound mapping showing LF

3.5. Sound Transmission Index

The even distribution of sound occurs as a result of STI 0.6-0.75 is good and > 0.75 is excellent (3)[16]. The estimated STI is 0.69 which is good, refer Figure (11 & 12.) [19]

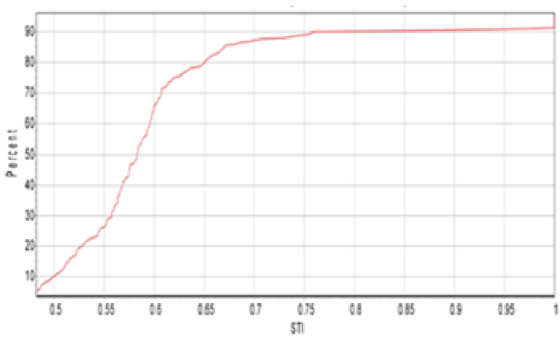

Fig 11. Graph showing STI

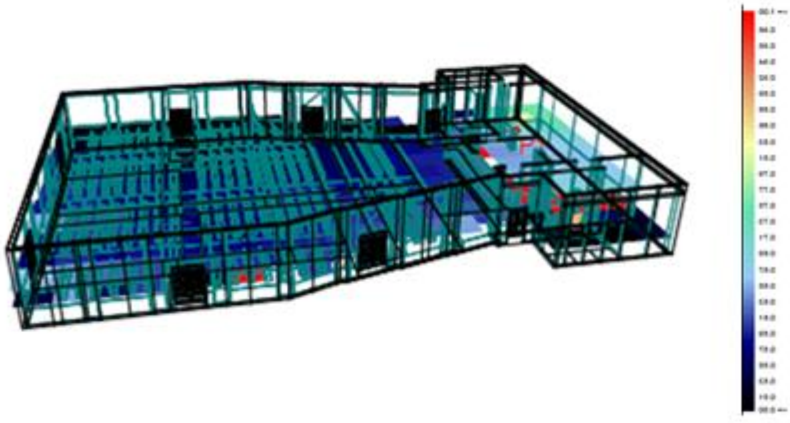

Fig 12. Sound mapping showing STI

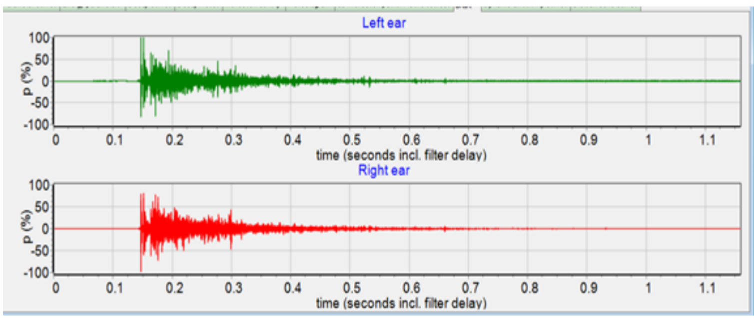

Fig 13. Reflectogram

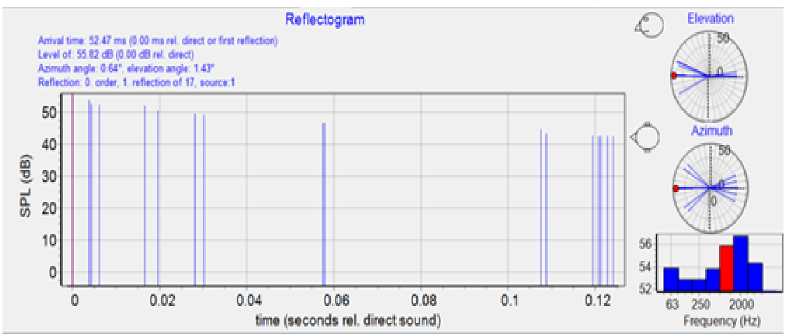

Fig 14. Binaural Impulse Response

3.6. Auralisation

The reflectogram displays the arrival of early reflections to a receive, see Figure (13 & 14). Each single reflection can be separated independently based on the early reflections. The arrival time and energy of the reflections can be determined on the reflectogram. In addition to that the direction and the surfaces involved in the reflection path are shown in reflectogram. In order to avoid the defects of echo, a particular reflection can be removed or modified. The

Binaural Impulse Response of the receiver at 13m away from the sound source, is observed that the direct sound arrives at the listener's ears reach approximately between 10 to 20ms.Simulation through auralisation indicates the arrival of direct sound at the listener ear.[18]

4. Conclusions

ODEON programming has been suitably used by selecting the nearest absorption characteristics of the materials employed in the halls. Evaluation of objective parameters such as clarity, strength, Lf, Definition, STI, AI is useful information apart from RT. The average number of reflections required through , Sound distribution study shows a fall of 3db from stage to the rear of the hall. Through Auralisation technique it has been found that the presence of reflectors in the hall enhances the listening conditions of the hall. The average value of clarity in the halls range from 2.5 to 9.5 dB. The average values of strength and definition are 4.4dB and 70% respectively. In this hall, the Lateral efficiency (LF) factor found to be good. The acoustical design parameters of this halls has better agreement with the standard values , due to the shape of the hall where is there is no bouncing of sound waves back and forth which creates the optimum reverberation with overall sound clarity.The acoustical simulation of the hall can be studies before the construction process so that unwanted acoustical defects can be avoided at an early stage.

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