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An analysis of acoustical effectiveness in the design of lecture hall spaces for teaching-learning: The case of Niger Delta University

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Abstract

The research tried to compare the acoustical effectiveness in the design of internal lecture hall spaces for teaching-learning of three lecture halls in Niger Delta University, Wilberforce Island, Nigeria. Data was physical measurements of the internal spaces as well as obtaining the absorption coefficient of the materials used in constructing the internal wall surfaces. Data was analyzed using parameters for good sightline and speech intelligibility. The findings revealed that only one of the lecture halls had good sightlines while the other two had poor sightlines for viewing because the students at the back row seats were obstructed from seeing the chalk or white board and the teacher by students in the front row seats. The results for speech intelligibility revealed that all the lecture halls had delayed Reverberation Time (RT) indicating that the speech from the lecturer may not be intelligible to all the students in every part of the hall spaces at low, medium and high frequencies because the RTs were below the required values of between 1.00 and 1.50 seconds. It was therefore recommended that lecture hall spaces should be designed for acoustical effectiveness in terms of good sightlines and speech intelligibility in other to enhance teaching and learning.

Keywords: Good Sightlines; Speech Intelligibility; Teaching-Learning; Reverberation Time; Acoustics, Absorption Coefficient; Frequency

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1. Introduction

In any educational set-up, the acoustical effectiveness of the internal lecture hall spaces for teaching-learning could be achieved if such spaces are designed to provide good sightlines and speech intelligibility. To provide good sightlines and speech intelligibility in a teaching-learning lecture hall space requires a good knowledge of the science of acoustics when designing those spaces. Acoustics is therefore, the science of sound which is concerned with the propagation of sound from its source to the expected recipients in form of speech, music, etc and made intelligible through the incorporation of appropriate design and construction of different building elements (Pumnia et al., 2005). The Merriam-Webster Dictionary (2017) defined acoustics as a science that deals with the production, control, transmission, reception, and effects of sound or the qualities that determine the ability of an enclosure (such as an auditorium) to reflect sound waves in such a way as to produce distinct hearing. When the teaching-learning environment is acoustically designed, the learning space becomes alive, speech intelligibility will be obtained and good sightline is assured (Amasuomo, 2014).

Good sightlines enable students in the remote parts of lecture halls to see the chalk or white board, and the teacher without any obstruction. Otherwise, the students at the remote back row seats will strain their necks to see the chalkboard or white board (Amasuomo, 2014; De-Chiara and Crossbie, 2001). It is therefore, important that lecture halls used for teaching-learning should be acoustically designed to provide good sightlines.

A perfect sightline between the audience and the stage is essential for visibility purposes and for a good direct sound supply to the audience (Biobyte, 2017). In this regard, Steele (2015) observed that the most fundamental principal of "places of assembly"; theatres, concert halls, arenas etc., is that the audience must see and hear. Experts in acoustics will tell you that if you can't see, you will think you can't hear, so sightlines are a critical element to a successful venue.

Audio Advice.com (2017) also emphasized that in designing theatres, sight lines are an extremely important element to consider so that the person sitting right in front of you will not block your view of the screen.

Acoustical effectiveness in the design of good sightlines could be fixed in two ways. Firstly, the screen could be kept really high off the floor. However, while that may eliminate people in the back rows from being blocked, it creates a new problem for people sitting on the front row with an extreme viewing angle. They are going to have to lean their head back the whole time. This method may be appropriate when the audience is engaged in a short period. Secondly, it is to have the rows of seats at different elevations. This will allow you to keep the screen positioned low enough to provide a great viewing angle for everyone. This can be accomplished through the use of risers but making sure your riser is high enough to provide enough clearance and that your screen is not too high up in other to solve your sightline problems (Audio Advice.com., 2017).

Speech intelligibility on the other hand is critical for proper development of school activities and communication between teachers and student (Rabelo et al., 2014). The term speech intelligibility indicates in per cent how many words are correctly comprehended by listeners in a room when an articulate speaker reads a text either directly or via a sound system, In terms of acoustics, speech intelligibility indicates how well speech or spoken word is perceived in a room either directly from a speaker to a number of listeners, or via a sound system with a microphone, amplifier and loud speaker (s) to a number of listeners (Troldtekt, 2017).

Adequate loudness and good distribution of sound depends on the room size, shape and absorptive properties of the boundaries of surface finishes; and the directionality of the sound in the room. When teaching-learning internal spaces are built following a careful acoustic design; during communication all the students will have full auditory access to the spoken message. Conversely, when the teaching-learning space do not follow parameters for good acoustics, intelligibility of speech will be affected and teaching-learning impaired because students in classroom may likely not understand the speech from the teacher (Technical Committee on Speech Communication of the Acoustical Society of America, 2002; Rabelo, Santos, Oliveira and Magalhães, 2014).

However, achieving acoustical effectiveness in the design of internal lecture hall spaces for teaching-learning requires selection of appropriate building materials for the construction of the internal lecture hall space. Careful selection of building materials for construction will ensure that every speech from the teacher is propagated and distributed to the hearing of every student in the hall. Thus, in most moderate-size auditoriums, it is not necessary to resort to electronic aid if the internal room surfaces are constructed with carefully selected building materials (Burberry, 1997; Crossbie and Watson, 2004; Boothroyd, 2017). The type of building materials to be selected will depend on their sound absorption coefficient. Some materials have high sound absorption coefficient and others have low sound absorption coefficient at low, medium and high frequencies.

Sound absorption is a measure of how much sound-absorbing material there is in a room. The sound-absorbing effect of different materials varies greatly. Some materials, usually porous or thin panel materials such as plasterboard, mineral and glass wool, textiles, carpets, cement-bond wood wool and certain wood floors as well as the people present in a room space have deep sound-absorbing effect and are termed sound absorbing materials. But, hard surfaces such as concrete, masonry, plaster, glass, etc absorb very little sound and are generally classified as sound-reflecting surfaces (Troldtekt, 2017; NTi Audio, 2017; Crossbie and Watson, 2004; Burberry, 1997). Therefore, every building material used in the construction of the internal acoustics environment is rated according to its sound absorption coefficient; and the sound absorbing effect of such material is dependent on the size of the sound absorption coefficient as well as the extent such material is used in the room space defined in square metres (Crossbie and Watson, 2004).

For any speech from a teacher in a lecture hall to be intelligible to all the listeners, the reverberation time required for that space should be known to enable acoustics designers to select appropriate building materials for the construction of the internal space. This involves the knowledge of the sound absorption coefficients of the various building materials to establish the appropriate reverberation time for a given room space.

Reverberation Time (RT) is therefore defined as the length of time required for sound to decay 60 decibels from its initial level (Quiet classroom, 2017). The International Organization for Standardization (2008) defined Reverberation Time as a measure of the degree of reverberation in a space, and is equal to the time required for a constant sound to decay into 60 dB after the sound source has ceased and is expressed in seconds (s). Essentially, RT refers to the amount of time it takes for sound energy to bounce around a room before being absorbed by the surface materials and air (BKL Consultants, 2017). It is the period of time taken for sound to level in a room space to die away or decay to inaudibility after the sound source has stopped (Bradley, 2002; MBI Products.com, 2001).

Large-volume spaces with lots of hard finishes such as concrete, stone and plasterboard will have longer RTs, while spaces with soft finishes such as carpeted floors, acoustically absorbing wall panels, curtains, acoustic ceiling tiles and furniture with open-weave fabric covers will have shorter RTs. However, apart from having acceptable Reverberation Times for speech intelligibility and these RTs at low, medium and high frequencies need to be balanced at all times. Thus, good acoustic design should be able to optimize reverberation time for every part of the internal space; a process that considers a range of factors including the room's function and size, as well as the characteristics of its surfaces (BKL Consultants, 2017).

From various studies, most classrooms do have the required reverberation time results. Therefore, failure to comply with the ideal values of reverberation time can undermine good speech intelligibility between students and teachers and can even interfere with the assimilation of the lesson content as well as having difficulty to distinguish sounds and understand speech (Yang and Hodgson, 2006). In such cases, the teacher will be competing against the lingering reflections of his or her own voice for the student's attention. The result is a chaotic jumble of sounds (Quiet classroom, 2017).

When the reverberation time is long or has high values, it becomes difficult to distinguish sounds and understand speech because the syllables will overlap and interfere with intelligibility. Therefore, long reverberation time is not appropriate for the teaching-learning classrooms, because the reflected sound in form reverberation will be longer than the ideal. This will interfere with the direct sound and will also be reduced (Technical Committee on Speech Communication of the Acoustical Society of America, 2002; Department of Education and Skills, 2003; Rabelo et al., 2014; Mc Squared System Design Group, 2017).

Conversely, when the reverberation time is short or late, the sound energy arrives at listener's ear too late after the original sound. This sound cannot be integrated with the direct sound or with early components of reverberation and thus interferes with the recognition of subsequent sounds (Boothroyd, 2017). Short RTs are therefore, features of too much low and high frequency absorption, indicating that these frequencies lack sufficient reverberation.

Acoustical effectiveness of internal lecture hall spaces has been a major challenge in teaching-learning. This is may be as result of the fact that most designers of lecture halls have never given adequate taught to the acoustical effectiveness of internal lecture hall spaces but rather they see the lecture hall space as a large room to accommodate a large number of students for the purpose of instruction (Amasuomo, 2014). The lack of designing lecture halls for acoustical effectiveness affects the effective teaching learning because it gives rise to lack of good sightlines and intelligibility of speech from the teacher to the students.

However, the problems of good sightlines and speech intelligibility occur when:

1- The floors of the lectures hall are not be stepped or raked adequately to provide the required sightlines for students to see the chalkboard and the teacher during instruction. This has make most students at the back-row seats become passive listeners since they only hear but not properly seeing unless they have to stretch their necks in other to see in between heads of rows in the front. That is every-other-row vision (Neufert and Neufert, 2012).

2- The materials used for the construction of the internal surfaces of lecture halls do not provide the required reverberation time that will enable the speech from the teacher to be properly distributed round the lecture halls. Thus, students at the back-row may not hear the teachers' speeches properly because the sound source may have decayed before getting to the back-row seats (Yang and Hodgson, 2006; Rabelo et al., 2014).

From the foregoing, the need to find out the acoustical effectiveness of internal lecture hall spaces for teaching-learning became pertinent because most lecture halls may not provide good sightlines and speech intelligibility for effective teaching learning. This study is therefore an attempt to compare acoustical effectiveness of the internal spaces of some lecture halls in other to establish whether the hall spaces will enhance effective teaching learning by using Niger Delta University for the study.

1.1. Objectives of the study

The research is a comparative study of acoustical effectiveness in the design of internal lecture hall spaces for teaching-learning in Niger Delta University, Wilberforce Island, Nigeria. The objective is to establish whether: the design of the lecture halls will provide students with acoustically effective internal space for:

1- The design of the lecture halls will provide students with acoustically effective internal space for good sightlines during teaching-learning.

2- The design of the lecture halls will provide students with acoustically effective internal space for speech intelligibility during teaching-learning.

1.2. Research questions

i. Will the design of the lecture halls provide students with acoustically effective internal space for space for good sightlines during teaching-learning?

ii. Will the design of the lecture halls provide students with acoustically effective internal space for speech intelligibility during teaching-learning?

2. Methodology

2.1. Choice of building

Three groups of lecture halls located at the Old Site of Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria were chosen for the study. They are the 2 No. Faculty of Engineering lecture theatres of the same design with sitting capacity for 300 students, floor area of 265 m^2 and volume of 1258 m^3 (Figure 1); 3

No. University Lecture Theatres buildings of the same design with sitting capacity for 345 students, floor area of 290 m^2 and volume of 1152 m^3 (Figure 2); and 3 No. University Lecture Halls buildings of the same design with sitting capacity for 260 student, floor area of 243m^2 and volume of 967 m^3 (Figure 3). These buildings are used for large classes for groups of students from various disciplines offering common courses.

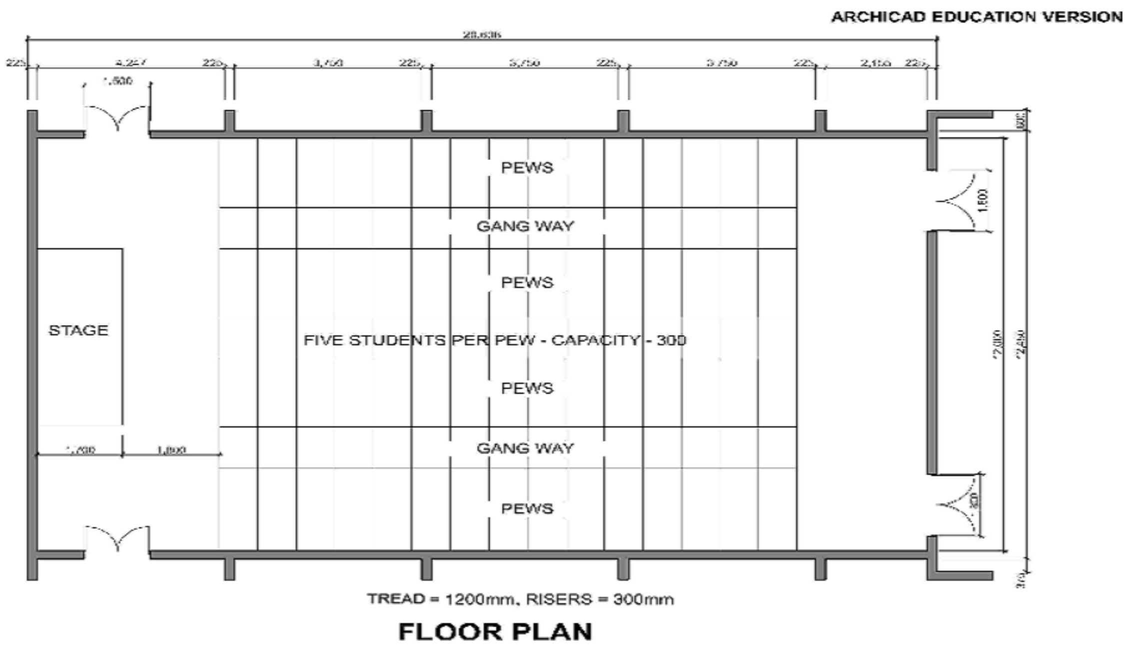

Figure 1. Faculty of engineering lecture theatres

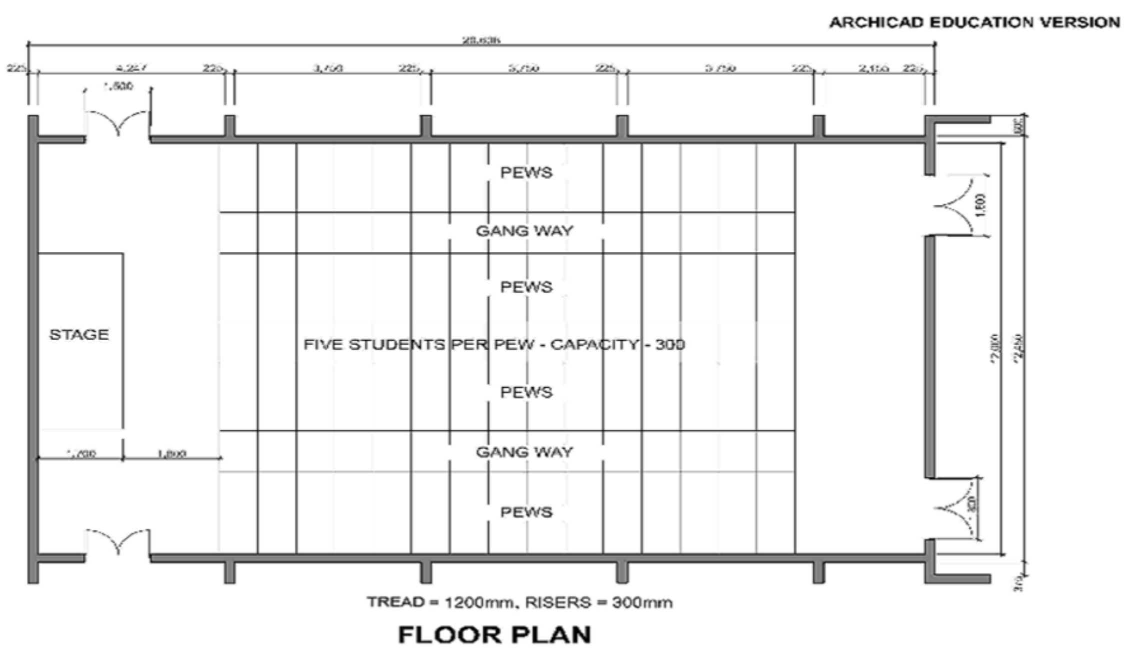

Figure 2. University lecture theatres

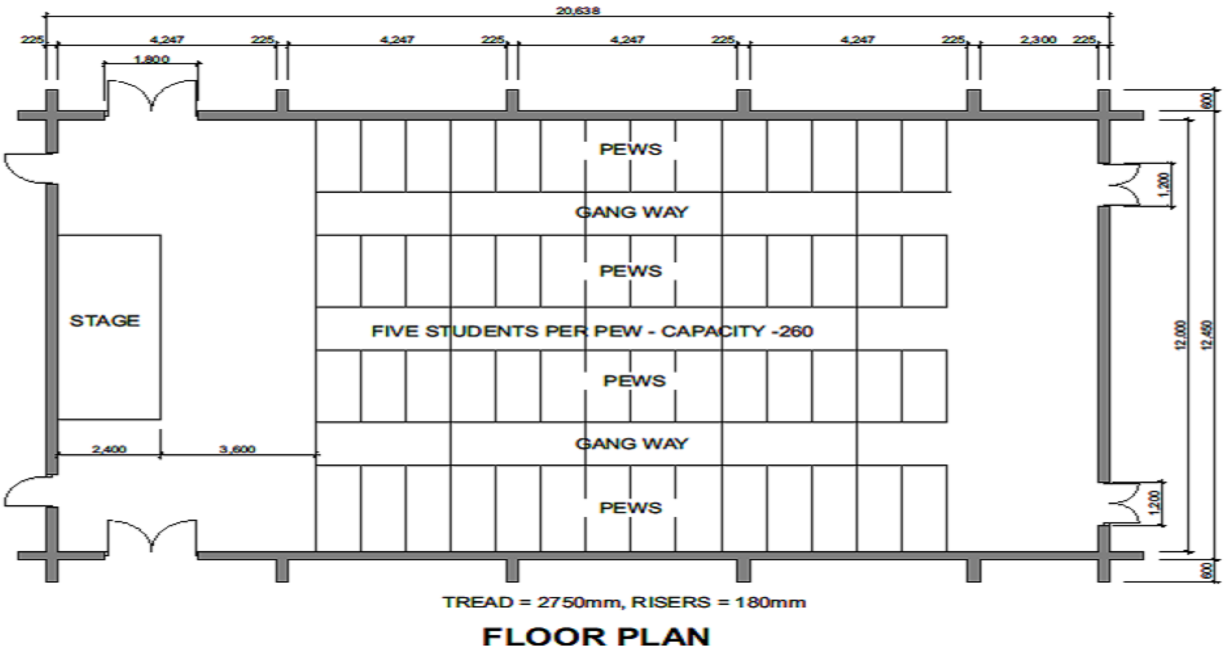

Figure 3. University lecture halls

2.2. Data collection

Data collection involved reproducing the plans of the various lecture halls showing the floor plans as well as door and window openings and the seating arrangements. In addition, data from the physical measurements are provided in Table 1.

Table 1. Physical Measurements of the teaching-learning lecture hall spaces

Surfaces	Finish	Faculty of Engineering lecture halls	University lecture theatres	University lecture halls
		Area (m^2)	**Area (m^2)**	**Area (m^2)**
Floor	Concrete (Terrazzo)	265	290	243
	Deducting 20 % of floor area	212	232	194
	Deducting 40 % of floor area	159	174	146
	Deducting 60 % of floor area	106	116	97
Walls	Rendered on sandcrete block and painted	321	258	197
Ceiling	Asbestos cement	----	290	243
	PVC (Plastics)	265	----	----
Windows	Glass (Small pane)	----	23	38
	Glass (Large pane)	72	----	----
Doors	Wooden	14	5	16
Seating capacity	Fully occupied	300	345	260
	2/3 occupied	200	230	173
Volume of lecture hall spaces		1258 m^3	1152 m^3	967 m^3
Treads of stepped floors		1200 mm	900 mm	2750 mm
Risers of stepped floors		300 mm	100 mm	200 mm
Floor-eye height of seated students				1150 mm
Floor-Chalkboard height				950 mm

Source: Author's field work, 2017

2.3. Data analysis

The data for the study was analyzed using the parameters enumerated below:

2.3.1. Parameters for good sightline

Table 2. Recommended dimensions for good sightlines

Parameters	Recommended dimensions
Floor-stage height	500- 750 mm
Floor-eye height	1120 – 1220 mm
Tread of seating tier (Row spacing)	800 – 1150 mm
Head clearance to allow average spectator see over head of average spectator in front (Every row vision)	130 mm
Riser (Difference in height between adjacent seating platforms)	60 – 125 mm minimum

Source: Neufert and Neufert, 2012

2.3.2. Parameters for speech intelligibility

iii. Deduct 20, 40 and 60 % at low, medium and high frequencies of the floor area to allow for shielding of the floor area by the audience (Neufert and Neufert, 2012).

iv. Compute the equivalent absorption area (A). This is the product of the internal surface areas in square metres multiplied by the related absorption coefficient at low, medium and high frequencies.

v. Calculate the Reverberation Times (RTs) of the lecture halls at full and two-third capacity to cater for large changes in (RTs) that may likely occur due to variation in the size of the audience (Neufert and Neufert, 2012).

vi. Compute the Reverberation time (T) of the room space using Sabine's equation thus: RT (Seconds) = 0.16 × V/A. Where V= Room volume (m^3); A = Total absorption area of internal surfaces (m^2); and 0.16 = Proportionality factor, a constant used to ensure that everything adds up (Burberry, 1997; Neufert and Neufert, 2012, troldtekt.com, 2017).

vii. A recommended Reverberation Time (RT) of between 1.00 and 1.50 seconds at low, medium and high frequencies will be used since the lecture halls are of medium size of between 750 and 7,500 m^3 and they are mainly used for speech (*Bradley, 2002;* NTi Audio, 2017; Burberry,1997; Neufert and Neufert, 2012).

3. Results

3.1. Research question 1: Will the design of the lecture halls provide students with acoustically effective internal space for good sightlines during teaching-learning?

3.1.1. Faculty of engineering lecture theatres

The results of the physical measurements of Faculty of Engineering Lecture Theatres in Table 3 revealed that all the assessed parameters were adequate for good sightlines.

Table 3. Measurements obtained from Faculty of engineering lecture theatres for good sightlines

Parameters	Existing dimensions (mm)	Recommended dimensions (mm)	Remarks
Floor-stage height	600	500- 750	Adequate
Floor-eye height	1150	1120 – 1220	Adequate
Tread of seating tier (Row spacing)	1200	800 – 1150	Adequate
Head clearance to allow average spectator see over head of average spectator in front (Every-row-vision)	100	100 -130	Adequate
Riser (Difference in height between adjacent seating platforms)	300	≤ 60 – 125	Adequate

In addition, the shaded portion in Figure 4 indicated that all the seated students had a clear view of the chalk board as well as the teacher. That is, there was head clearance to allow the average spectator behind see over the head of average spectator in front. Thus, the Faculty of Engineering Lecture Theatres provided acoustically effective internal space for good sightlines for teaching-learning.

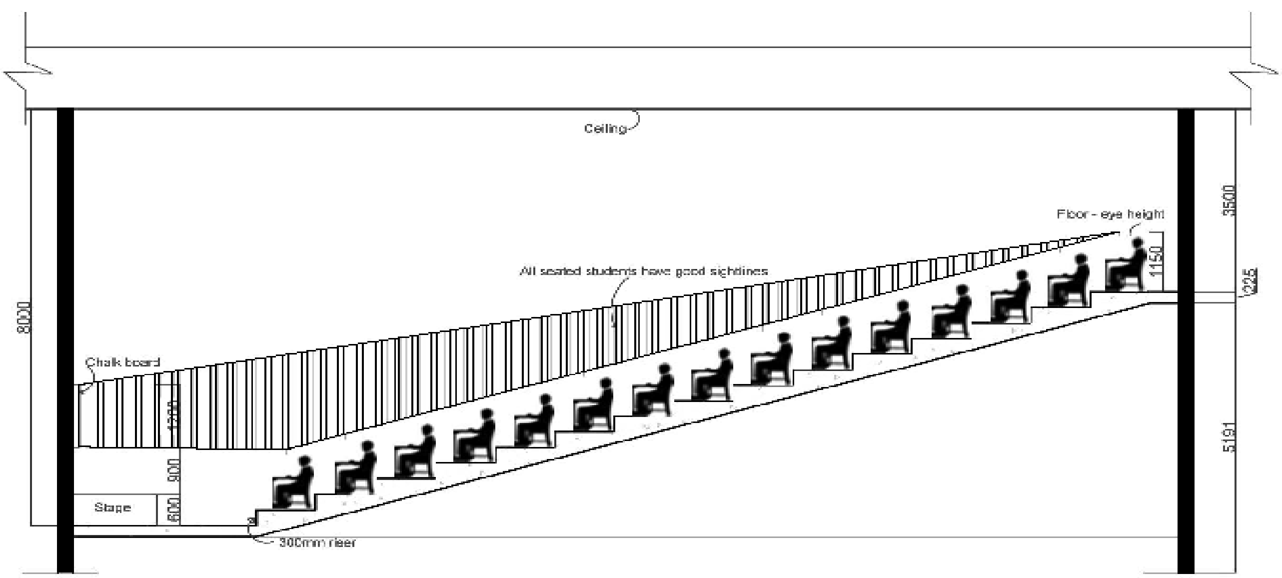

Figure 4. Faculty of engineering lecture theatres (*Diagram showing sightlines*)

3.1.2. University lecture theatres

In Table 4, the results of the physical measurements for the University Lecture Theatres revealed that the assessed parameters for good sightlines for were adequate.

Table 4. Measurements obtained from University lecture theatres for good sightlines

Parameters	Existing dimensions (mm)	Recommended dimensions (mm)	Remarks
Floor-stage height	500	500- 750	Adequate
Floor-eye height	1150	1120 – 1220	Adequate
Tread of seating tier (Row spacing)	900	800 – 1150	Adequate
Head clearance to allow average spectator see over head of average spectator in front (Every row vision)	100	100 -130	Adequate
Riser (Difference in height between adjacent seating platforms)	100	≤ 60 – 125	Adequate

All the seated students in the first fifteen rows in Figure 5 had a clear view of the chalk board and the teacher as shown in the shaded portion of the drawing. This was because, there was head clearance to allow average spectator behind see over the head of average spectator in front. However, the students seated in the last four rows will not see the chalkboard properly because the floor was not stepped. They can only see the chalkboard between heads of rows in front, that is, every-other-row vision. Thus, the University Lecture Theatres did not provide for all the seated students acoustically effective internal space for good sightlines during teaching-learning.

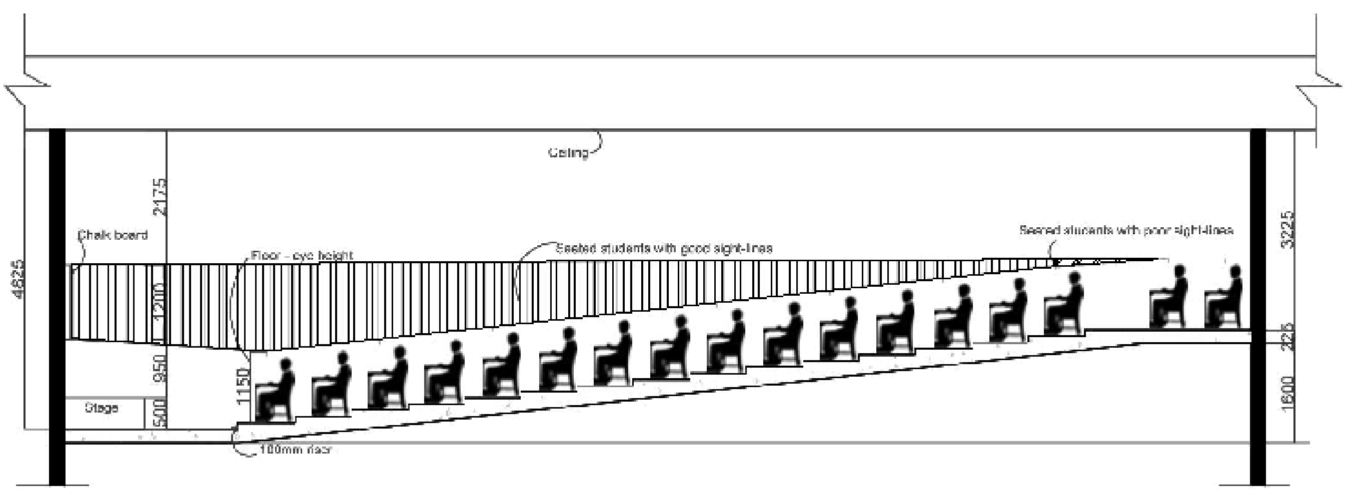

Figure 5. University lecture theatres (*Diagram showing sightlines*)

3.1.3. University lecture halls

The results of the physical measurements obtained for the University Lecture Halls in Figure 5, revealed that the assessed parameters for good sightlines for were also adequate.

Table 5. Measurements obtained from the University lecture halls for good sightlines

Parameters	**Existing dimensions (mm)**	**Recommended dimensions (mm)**	**Remarks**
Floor-stage height	600	500- 750	Adequate
Floor-eye height	1150	1120 – 1220	Adequate
Tread of seating tier (Row spacing)	2750	800 – 1150	Adequate
Head clearance to allow average spectator see over head of average spectator in front (Every row vision)	100	100 -130	Adequate
Riser (Difference in height between adjacent seating platforms)	200	≤ 60 – 125	Adequate

But from the diagram in Figure 6, not all the seated students had good sightlines to have a clear view of the chalkboard. This is because each row of tread has three pews and it was only students seated in the first pews of each tread can have a clear vision of the chalk board as shown in the shaded portions. That is, the two pews behind the first pew in each row of tread will not have good sightlines since there was no head clearance to allow an average spectator behind see over the head of average spectator in front. Thus, the students will see only between heads row in front, that is, every-other-row vision.

Thus, the University Lecture Halls did provide for all the seated students acoustically effective internal space for good sightlines during teaching-learning.

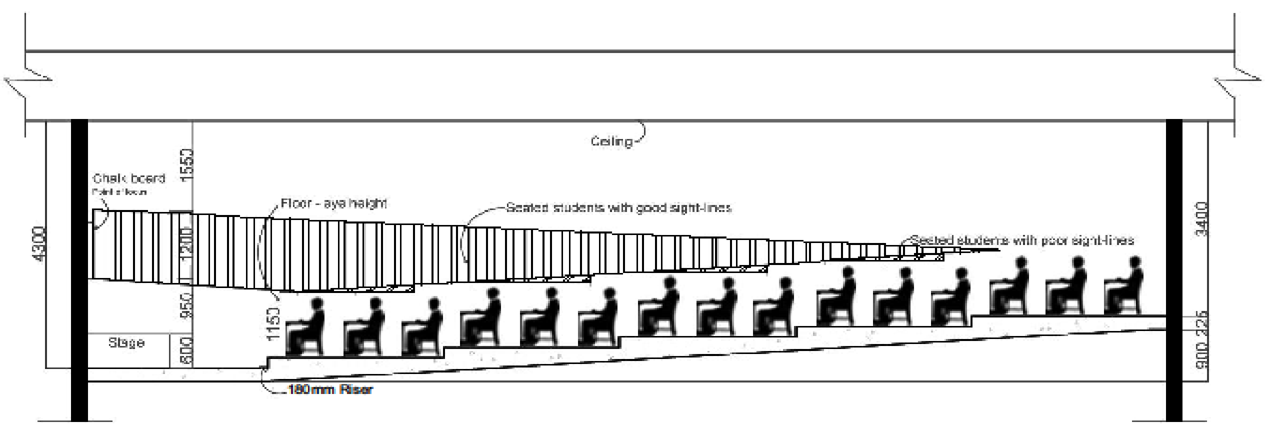

Figure 6. University lecture halls (*Diagram showing sightlines*)

3.2. Research question 2: Will the design of the lecture halls provide students with acoustically effective internal space for speech intelligibility during teaching-learning?

3.2.1. Faculty of engineering lecture theatres

The results of the Reverberation Time (RT) in Table 6 for the Faculty of Engineering Lecture Theatres at low, medium and high frequencies were 0.99, 0.87 and 0.72 seconds respectively for fully occupied hall with an average RT of 0.88 seconds. The average RT value was lower than recommended RT of between 1.00 to 1.50 seconds indicating short RT. The short RT was an indication of too much sound absorption in the lecture space due to materials used for the construction as well as the seated students whose hair and the clothes they wore also absorbs sound. Thus, at full capacity, the hall space was not acoustically effective for the sound energy from the source to be properly distributed in order for the speech from the lecturer be intelligible to the students in every part of the hall space.

Table 6. Computation of Reverberation Time (RT) for Faculty of Engineering lecture theatres

Surfaces	Finish	Area (m^2)	Low frequency 125 Hz		Medium frequency 500 Hz		High frequency 2000 Hz	
			Absorp. Coeff.	Absorp. unit	Absorp. Coeff.	Absorp. unit	Absorp. Coeff.	Absorp. unit
Floor	Concrete (Terrazzo)	265						
	Deducting 20 % of floor area for low frequency	212	0.01	2.12				
	Deducting 40 % of floor area for medium frequency	159			0.02	3.18		
	Deducting 60 % of floor area for high frequency	106					0.02	2.12
Walls	Rendered on sandcrete block and painted	321	0.1	32.10	0.06	19.26	0.09	28.89
Ceiling	PVC (Plastics)	265	0.02	5.30	0.03	7.95	0.03	7.95
Windows	Glass (Large pane)	71	0.18	12.78	0.04	2.84	0.02	1.42
Doors	Wooden	14	0.1	1.40	0.05	0.70	0.04	0.56
Air								0.007
Students seated on wooden pews	Fully occupied	300	0.5	150	0.66	198.00	0.80	240.00
	2/3 occupied	200	0.37	74.00	0.47	94.00	0.56	112.00
Total absorption units	Fully occupied			203.70		231.93		280.95
	2/3 occupied			127.70		127.93		152.95
Reverberation Time (Seconds)	Fully occupied			0.99		0.87		0.72
	2/3 occupied			1.58		1.57		1.32
Average reverberation time at fully occupied space (Seconds)								0.88
Average reverberation time at 2/3 occupied space (Seconds)								1.49

Source of absorption coefficients; JCW, 2014

The results of the RT at two-third capacity for low, medium and high frequencies were 1.58, 1.57 and 1.32 seconds respectively with an average RT of 1.49 seconds. The average RT value was within the recommended values of between 1.00 and 1.50 seconds. At 2/3 capacity, the hall space was acoustically effective because the level of sound absorption from seating students was reduced. With the average RT within the recommended value was an indication that the speech from the source was evenly distributed to every part of the hall space; and the speech is likely to be intelligible to the students.

3.2.2. University lecture theatres

The RT results for the University Lecture Theatres in Table 7 were 0.60, 0.36 and 0.38 seconds for fully occupied space; and 0.84, 0.46 and 0.54 seconds for two-third occupied space at low, medium and high frequencies respectively. These values were below the recommended RT values of 1.00 to 1.5 seconds. The average RTs for full capacity and 2/3 capacity of 0.44 and 0.61 at all frequencies were also below the recommended RT values. The internal lecture hall space therefore lacked acoustical effectiveness for speech intelligibility for teaching-learning because of the short RTs at all frequencies.

Table 7. Computation of Reverberation Time (RT) for University lecture theatres

Surfaces	**Finish**	**Area (m^2)**	**Low frequency 125 Hz**		**Medium frequency 500 Hz**		**High frequency 2000 Hz**	
			Absorp. Coeff.	**Absorp. unit**	**Absorp. Coeff.**	**Absorp. unit**	**Absorp. Coeff.**	**Absorp. unit**
Floor	Concrete (Terrazzo)	290						
	Deducting 20 % of floor area for low frequency	232	0.01	2.32				
	Deducting 40 % of floor area for medium frequency	174			0.02	3.48		
	Deducting 60 % of floor area for high frequency	116					0.02	2.32
Walls	Rendered on sandcrete block and painted	258	0.1	25.80	0.06	15.48	0.09	23.22
Ceiling	Asbestos cement	290	0.36	104.40	0.95	275.50	0.65	188.50
Windows	Glass (Small pane)	23	0.04	0.92	0.03	0.69	0.02	0.46
Doors	Wooden	5	0.1	0.50	0.05	0.25	0.04	0.20
Air								0.007
Students seated on wooden pews	Fully occupied	345	0.5	172.50	0.66	227.70	0.80	276.00
	2/3 occupied	230	0.37	85.10	0.47	108.10	0.56	128.80
Total absorption units	Fully occupied			306.44		523.10		488.44
	2/3 occupied			219.04		403.50		341.24
Reverberation Time (Seconds)	Fully occupied			0.60		0.35		0.38
	2/3 occupied			0.84		0.46		0.54
Average reverberation time at fully occupied space (Seconds)								0.44
Average reverberation time at 2/3 occupied space (Seconds)								0.61

Source of absorption coefficients; JCW, 2014

The implication of short RTs was that the building materials used for the construction of the internal hall spaces as well as the seated students had high absorption surfaces. There was early decay of sound energy from sound source to the students which was indication that making speech intelligibility from the teacher will be difficult for students the lecture hall space.

3.2.3. University lecture halls

The results of the RTs for University Lecture Halls in Table 8 for fully occupied space were 0.64, 0.37 and 0.40 seconds respectively at low, medium and high frequencies with an average RT of 0.47 seconds. Furthermore, the RTs for two-third occupied space were 0.59, 0.31 and 0.37 seconds respectively at low, medium and high frequencies with an average RT of 0.42 seconds. The average RTs for full capacity and 2/3 capacity at all frequencies were far below the recommended RT values of 1.0 to 1.5 seconds. The internal lecture hall space therefore lacked acoustical effectiveness for speech intelligibility for teaching-learning because of the short RTs at all frequencies.

Table 8. Computation of Reverberation Time (RT) for University lecture halls

Surfaces	**Finish**	**Area (m^2)**	**Low frequency 125 Hz**		**Medium frequency 500 Hz**		**High frequency 2000 Hz**	
			Absorp. Coeff.	**Absorp. unit**	**Absorp. Coeff.**	**Absorp. unit**	**Absorp. Coeff.**	**Absorp. unit**
Floor	Concrete (Terrazzo)	243						
	Deducting 20 % of floor area for low frequency	194	0.01	1.94				
	Deducting 40 % of floor area for medium frequency	146			0.02	2.92		
	Deducting 60 % of floor area for high frequency	97					0.02	1.94
Walls	Rendered on sandcrete block and painted	197	0.1	19.70	0.06	11.82	0.09	17.73
Ceiling	Asbestos cement	243	0.36	87.48	0.95	230.85	0.65	157.95
Windows	Glass (Small pane)	38	0.04	1.52	0.03	1.14	0.02	0.76
Doors	Wooden	16	0.1	1.60	0.05	0.80	0.04	0.64
Air								0.01
Students seated on wooden pews	Fully occupied	260	0.5	130.00	0.66	171.60	0.80	208.00
	2/3 occupied	173	0.37	64.01	0.47	81.31	0.56	96.88
Total absorption units	Fully occupied			242.24		419.13		387.03
	2/3 occupied			176.25		328.84		275.91
Reverberation Time (Seconds)	Fully occupied			0.64		0.37		0.40
	2/3 occupied			0.59		0.31		0.37
Average reverberation time at fully occupied space (Seconds)								0.47
Average reverberation time at 2/3 occupied space (Seconds)								0.42

Source of absorption coefficients; JCW, 2014

The implication of short RTs was that there were too much sound absorption surfaces in the hall space. Thus, the sound energy decayed or died too early and the speech from the teacher is likely not to be intelligible to the students in every part of the lecture hall space.

4. Discussion of findings

Research question 1 was to establish whether the design of the lecture halls will provide students with acoustically effective internal space for good sightlines during teaching-learning.

From the findings, it was the Faculty of Engineering Lecture Theatres that had good sightline because all the seated students in each tread of rows had a clear vision of the chalkboard without being obstructed by those students in the front row seated. However, the University Lecture Theatres and University Lecture halls had problems of good sightline because not every seated student had adequate clear vision of the chalkboard. Most students in the back row seats were obstructed from the seeing the chalkboard by the seated front row students.

It was therefore, important that lecture halls used for teaching-learning should be acoustically designed to provide good sightlines. In this regard, Amasuomo, (2014); De-Chiara and Crossbie (2001) reported that good sightlines enable students in the remote parts of lecture halls to see the chalk or white board, and the teacher without any obstruction. Otherwise, the students at the remote back row seats will strain their necks to see the chalkboard or white board. A perfect sightline between the audience and the stage is essential for visibility purposes and for a good direct sound supply to the audience (Biobyte, 2017). Steele (2015) also observed that the most fundamental principal of places of assembly; theatres, concert halls, arenas etc., is that the audience must see and hear. Experts in acoustics will tell you that if you can't see, you will think you can't hear; and so sightlines are a critical element to a successful venue.

Audio Advice.com. (2017) also emphasized that in designing theatres, sight lines are extremely important element to consider so that the person sitting right in front of you will not block your view of the screen. It is therefore very pertinent that internal lecture hall spaces should have acoustical effectiveness in the design in order to enhance teaching-learning.

Research question 2 tried to ascertain whether the design of the lecture halls will provide students with acoustically effective internal space for speech intelligibility during teaching-learning. The findings established that in the Faculty of Engineering Lecture Halls with an average Reverberation Time of 0.88 seconds at full capacity, the hall space did provide the required speech intelligibility from the teacher to the students because, the reverberation times for low, medium and high frequencies were short. But, at 2/3 capacity with an average Reverberation Time of 1.49 seconds for all the frequencies, the hall space provide the required speech intelligibility from the teacher to the students. In the case of University Lecture Theatres and Lecture Halls, the reverberation times at full and 2/3 capacity and at all frequencies were below the lower band of the expected RTs of between 1.00 and 1.50 seconds. Thus, the reverberation times were short and speech intelligibility during instruction was likely to be affected. The implication of the finding was that the internal lecture hall spaces were not designed for acoustical effectiveness and therefore, teaching learning will be equally affected.

Generally, the three lecture halls did not provide the required the RTs for speech intelligibility at all frequencies because the RTs were short. The import of short reverberation time for speech intelligibility is that there was too much low and high frequency absorption and these frequencies lack sufficient reverberation. In this regard, Boothroyd (2017) observed that when the reverberation time is short or late, the sound energy arrives at listener's ear too late after the original sound. This sound cannot be integrated with the direct sound or with early components of reverberation and thus interferes with the recognition of subsequent sounds. Short reverberation time occurs when the materials used for the construction of the internal surfaces exhibit high sound absorption coefficients. Absorbing materials reduce RT particularly with the presence of people in a room space when compared to the unoccupied room (NTi Audio, 2017).

5. Conclusion and recommendation

The finding of the study revealed that the Faculty of Engineering Lecture Theatres had good sightlines but delayed Reverberation Time at full capacity. This means that the internal spaces of the lecture halls for teaching learning were not designed for acoustical effectiveness in terms of speech intelligibility. The implication was that the speech from the lecturer will not be adequately distributed to every part of the hall space for every student to hear.

In the case of the University Lecture Theatres and Lecture Halls, there were no good sightlines and the Reverberation Times were also delayed. Basically, these two groups of lecture halls were not designed for acoustical effectiveness required for teaching learning.

From the foregoing, the lecture halls evaluated in this study did not comply with requirements of acoustical effectiveness in terms good sightlines and speech intelligibility. The speech from the lecturer may not be intelligible to all the students in the lecture halls because the Reverberation Times; that is the time it will take the sound energy from the lecturer to get to the students were delay since the RTs at low, medium and high frequencies were below the required RTs of between 1.00 and 1.50 seconds.

From the foregoing, greater emphasis should be given to acoustical effectiveness in the design of the internal spaces of lecture halls to enhance teaching and learning. Acoustically enhancing teaching and learning therefore involves good sightlines for students to see the chalkboard and the teacher through the stepping of the floors with appropriate risers and rows of treads. In addition, the internal spaces should be alive to enhance effective communication between the lecturer and the students through the use of carefully selected building materials in the construction of the internal surfaces of the halls. This will improve the Reverberation Times and hence speech intelligibility to every seated user of the lecture halls.

However, the study had some limitations. It only studied the lack of acoustical effectiveness in the design of the lecture halls for teaching-learning but did not provide for the selection of appropriate building materials to improve the Reverberation Times and enhanced propagation of intelligible speech to every seated audience in the lecture halls. The researchers therefore, suggest that a future study should provide for appropriate design of lecture halls and the selection building materials with their absorption coefficients for the construction of the internal spaces of lecture halls that will give the expected Reverberation Times for enhanced speech intelligible speech.

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