Low-Cost Acoustically Sound Classroom (LCASC)

Authors: Uttam Kumar Tamboli[1*], Himanshu Rajak[1], Anmol Gupta[1], Devanshee Rajput[1], Archi Sharma[1]

Corresponding Author: Uttam Kumar Tamboli

[1]Batch 2018-2022, Bachelor of Technology (B. Tech), Civil Branch, LCIT College, Bilaspur, Chhattisgarh,

Chhattisgarh State Technical University (CSVTU). Bhilai

Corresponding Address: Ward No. 12, Ruchika Vihar Colony, Hardikala Road, Sirgitti, Bilaspur Chhattisgarh, Pin code: 495004

Abstract

Apart from the self-reluctance, indiscipline, and carelessness of students, the most prominent reason for their loss of focus in the classroom is the acoustical conditions of the classroom. Poor Acoustics of the classroom results in poor studying experience for students and poor teaching experience for the teachers which results in an overall decrease in the efficiency of classroom studies. Excessive noise and reverberation interfere with speech intelligibility, resulting in reduced understanding and therefore reduced learning. The best way to solve acoustics problems is to prevent them beforehand, not correct them after the construction as the renovation of poorly designed classrooms is much more expensive. So, it is evident that changing the acoustics of a classroom is possible but expensive by commercial means and only affordable by elite schools and colleges. Moreover, they are made from Styrofoam, polyurethane, and other synthetic materials which are non-biodegradable, harmful to the environment, and cause health issues in the long run. So, to provide a solution that can be applied in all the constructed classrooms, our team has come up with the solution of LCASC which has waste materials with natural sound absorbing properties as their primary raw materials along with other materials that are generally thrown away without a second thought. Our best out-of-waste solution is more eco-friendly and more affordable than the commercial solution making it highly adaptable for a wide range of schools and colleges to make their classrooms acoustically sound and make their students better in listening, understanding, learning, and growing.

Keywords: Waste materials; Acoustic classroom; Low cost; Waste to best; Eco-friendly acoustics, affordable acoustics

1.1. Introductionz

Noise control is one of the major requirements for improving the living and studying environment in a classroom, as unwanted noise always affects our concentration and peace of mind.
Poor Acoustics of the classroom results in poor studying experience for students and poor teaching experience for the teachers which results in an overall decrease in the efficiency of classroom studies.

1.2. Severity of the problem of acoustics problem in the classroom.

The following are certain aspects to explain the severity of poor acoustics in classrooms:

1) **It's Not Only About Us:**
As per the records of the Academic Year 2019-2020 produced by UDISE Plus, there are 15.1 lakh schools and 1389 universities as per the report generated by UGC for the year 2021.
2) **Good Listening Is the First Step of Studying:**
Poor audibility to the course content leads to a loss of focus of students and interest in studying.
3) **Big Problem for Back Benchers:**
The teacher's voice remains clear for the first one or two rows but starts to distort on traveling further.
Moreover, the echo effects of classrooms make the condition worse and it becomes barely possible for the students to listen clearly.
4) **Problem for Students = Headache for Teachers:**
When the teachers are not heard and understood clearly, their quality of teaching reduces thereby decreasing their morale in giving the best possible output.
5) **Existing Solution Is Not Widely Adaptable:**
The best way to solve acoustics problems is to prevent them beforehand, not correct them after the construction as the renovation of poorly designed classrooms is much more expensive. So, it is evident that changing the acoustics of a classroom is possible but expensive by traditional means.[1]

The solution to this problem is improving the acoustics of every classroom by performing soundproofing & other professional acoustic measures.
However, the commercially available soundproofing works are expensive and not affordable for all schools and colleges except the elite ones.
Also, the commercially available soundproofing works consist of soundproofing materials that are made of synthetic materials like polymers, polyester, Styrofoam, etc. which in the long run are not biodegradable, harmful to the environment and can also cause health issues to people.
Hence, there exists a solution for the problem but it is not widely adaptable.

1.3. Project Objectives

1) To make classrooms acoustically sound.
2) To improve the overall learning experience of students and the teaching experience of teachers.
3) To bring up a low-cost, affordable, and highly adaptable soundproofing setup for classrooms.
4) To bring up a solution that can easily and effectively be installed in all classrooms irrespective of the class size.
5) To encourage people for adopting eco-friendly alternatives in making their place of being acoustically soundproof.

1.4. Literature Review

1) Excessive noise and reverberation interfere with speech intelligibility, resulting in reduced understanding and therefore reduced learning.
2) The students who have English as a second language are not placed in separate classrooms with enhanced acoustics, but rather are mainstreamed with other students. Their learning is especially dependent on good acoustics as they are unable to "predict from context." With their limited vocabulary and experience, if they miss a few words from a teacher's lecture, they are less able to "fill in" the missing thoughts. Given these considerations, a wide range of students benefits from improved classroom acoustics.
3) If a teacher's voice is continuously echoing off the back wall of a classroom, each echo will interfere with the next word, making the lecture difficult to understand.
4) The best way to solve acoustics problems is to prevent them beforehand, not correct them after the construction as the renovation of poorly designed classrooms is much more expensive. So, it is evident that changing the acoustics of a classroom is possible but expensive by traditional means.
5) An important acoustical measurement called Reverberation Time (RT or RT (60)) is used to determine how quickly sound decays in a room. Reverberation time depends on the physical volume and surface materials of a room.
6) Large spaces, such as cathedrals and gymnasiums, usually have longer reverberation times and sound "lively" or sometimes "boomy." Small rooms, such as bedrooms and recording studios, are usually less reverberant and sound "dry" or "dead." From this, we can say that as our classroom is bigger than the usual classroom size, longer reverberation time and boomy or lively sounds exist in our classroom.
7) Ideally, classrooms should have RTs in the range of 0.4-0.6 seconds, but many existing classrooms have RTs of one second or more.

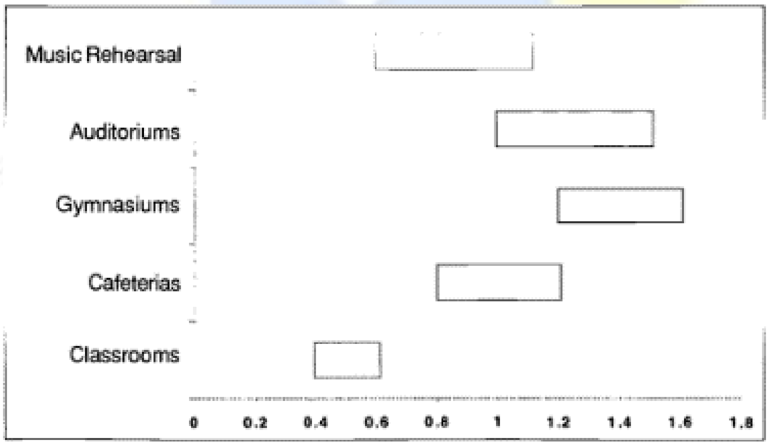

Fig 1 Graph showing standard values of Reverberation Time

(Source: Seep, B. et al. (2000) Classroom Acoustics: A Resource for Creating Environments with Desirable Listening Conditions, Acoustical Society of America, Melville, New York. Acoustical Society of America, Suite 1N01, 2 Huntington Quadrangle, Melville, NY 11747; Tel: 516-576-2360; Fax: 516-576-2377; e-mail: asa@aip.org; Web site: http://asa.aip.org. Available at: https://acousticalsociety.org/wp-content/uploads/2022/01/Classroom-Acoustics.pdf (Accessed: December 17, 2022).

RT can be estimated easily for both built and unbuilt classrooms with the use of the Sabine equation. The variables are the physical volume (ft') of the room, the areas (ft') of different surface materials, and the absorption coefficients of those materials at certain frequencies. The absorption coefficient is a measure of how much of the energy of a sound wave a material will absorb.

8) There are two ways to reduce the RT of a room: either the volume must be decreased or the sound absorption must be increased. Though decreasing the volume is not always an option. Hence the second measure of increasing sound absorption is considered.
9) Increasing the absorption in a room is accomplished by adding more "soft" materials, such as fabric-faced glass fiber wall panels, carpet, or acoustical ceiling tiles. Absorptive materials work best when spread throughout the room and not concentrated on just one wall or the floor or ceiling.
10) In a complete analysis, this calculation should be performed for each octave band, as the RT can vary widely at different frequencies. However, for a quick estimate, the RT of a classroom can be calculated for just a one-octave band representative of speech frequencies, such as 1000 Hz. If this RT is acceptable, then the RT throughout the speech range will likely be acceptable.
11) Noise interferes with oral communication, a factor that competes with the teacher's voice, which compromises the intelligibility of speech ability of both the students and the teachers. These professionals need to increase the volume of their voices to be understood and, at the same time, the efforts of students to understand the spoken message are much higher.
12) Coir fiber is a natural organic resource that is the seed-hair fiber obtained from the outer shell (endocarp) or husk of the coconut.
13) Sawdust is a plentiful by-product of timber operations and lumber production. Reuse of sawdust has to date been satisfactory primarily due to the very high-water absorption rate of the material.
14) Material thickness has the greatest influence on the material's sound-absorbing qualities. The absorption coefficient also varies with the frequency and angle of incidence of the sound. Generally, higher frequencies are more easily absorbed than low frequencies. Materials that are good absorbers allow sound to pass through them relatively easily.

1.5. Materials Required in LCASC Setup

The LCASC setup primarily has three elements:
1) Filler Materials – Sawdust, Neem Leaves, & Coconut Husk (Coir Fibres)
2) Container for Filler Materials – Used Tetra Packs
3) Stackable or Mountable Structure to carry the setup.

1.5.1. Filler Materials – Coconut husk, Saw dust & Neem leaves

1) Coconut husk:
Coir, or coconut fiber, is a natural fiber extracted from the outer husk of coconut and used in products such as floor mats, doormats, brushes, and mattresses.
It has many benefits: it is renewable, non-abrasive, Cheaper, Abundant, and causes fewer potential health risks.
Several research firms tested this and found that Coir showed great sound absorption capabilities and would significantly reduce noise levels. Moreover, it dampens the echo as well.
2) Sawdust:
The innate cellulosic quality of sawdust makes it an effective natural sound absorber. Its maximum air gaps provide a synergistic effect that isolates sound. Sawdust is also readily available where cutting, grinding, and drilling of wood takes place.
3) Neem (Azadirachta indica) Leaves:
Neem leaves have antiviral, anti-fungal, and anti-bacterial properties which help to reduce respiratory diseases and other severe health hazards that result from sawdust freely flying around. Including Neem leaves in the 'container' will assure good prevention against termite infestation, as the leaves are traditionally recognized as natural insecticides.

Fig 2 (a) Coconut Husk (b) Saw Dust (c) Neem Leaves

1.5.2. Container for Filler Materials - Used Tetra Packs

Tetra Packs:
Tetra Pack is majorly made up of 75% paperboard, 4% aluminum, and 21% polymers, thus categorizing these cartons as paper-based packaging.
The aluminum present in it helps in creating a barrier for oxygen, moisture, and light.

However, despite being recyclable and reusable, it is discarded in massive amounts and ends up in landfills in most cases. So, keeping this in mind, we decided to use these tetra packs of porous nature as containers for our filler materials. This way we can manage the bulk amount of waste for a good cause and prevent it from going into the landfill.
Each Tetra Pak will be filled with a combination of coconut fibers, sawdust, and Neem (Azadirachta indica) leaves.

Fig 3 Tetra Packs

1.5.3. Stackable Structure

For fixing the entire arrangement of tetra packs on the walls, plywood frames with horizontal stripes will be used which will act as a base for attaching the filled tetra packs. The rectangular frames will be prepared as per the dimension of the tetra packs to be used ensuring gapless stacking of tetra packs in the frame.
The reason for making this stackable structure is to ensure the portability of our setup. A thin cloth sheet can also be used to cover the structure for giving it an aesthetically appealing look.

Fig 4 Stackable structure made of a wooden frame using plywood.

1.6. Need of Study – What makes our project unique?

There are a couple of works already been done in developing a low-cost soundproofing acoustic material, however, the following are the novel actions and initiatives that make our project unique:

1) We have used coconut husk, sawdust, and neem leaves all together as the filler material for absorbing sound inside the tetra pack containers.
2) We have designed a stackable structure on the wall instead of sticking the packs on the wall to avoid damage to the walls.
3) Our structure can be easily mounted and unmounted from the walls when needed.
4) In our LCASC Setup, we have kept the size of the stackable frame customizable so that it can be made as per the required acoustic area to be covered and the width of the door of the room.

1.7. Measurements & Layout of Our Study Universe

Fig 5 Measurements & Layout of our Study Universe (Our Classroom)

1.8. Measuring Acoustics of Our Classroom by Calculating Reverberation Time:

Reverberation time is one of the prominent parameters for determining the acoustics of a room and how quickly sound decays in a room. The formula used for its calculation is Sabine Formula.

RT60 = 0.049 V/a
Where: RT60 = Reverberation Time
V = volume of the space (feet cubed)
a = Sabine's (total room absorption that is present at a given frequency)
a = Σ S α
Σ = Sabine's (total room absorption that exists at a given frequency)
S = surface area of material (feet squared)
α = sound absorption coefficient that exists at a given frequency or the NRC
Ideally, classrooms should have RTs in the range of 0.4-0.6 seconds, but many existing classrooms have RTs of one second or more.

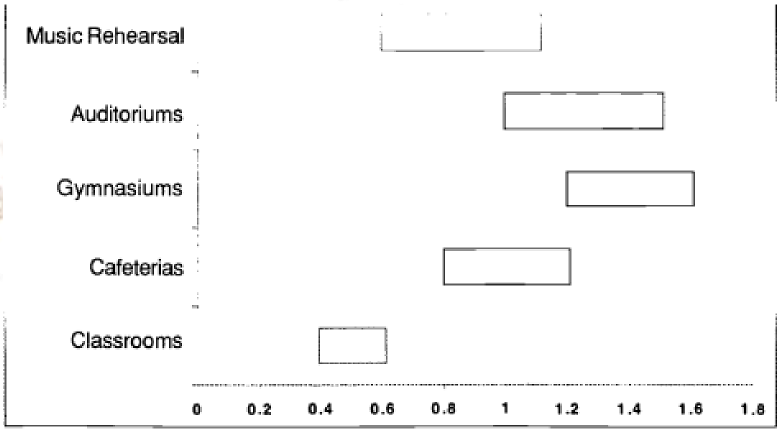

Fig-6 Graph showing Standard values of Reverberation Time.

(Source: Seep, B. et al. (2000) Classroom Acoustics: A Resource for Creating Environments with Desirable Listening Conditions, Acoustical Society of America, Melville, New York. Acoustical Society of America, Suite 1N01, 2 Huntington Quadrangle, Melville, NY 11747; Tel: 516-576-2360; Fax: 516-576-2377; e-mail: asa@aip.org; Web site: http://asa.aip.org. Available at: https://acousticalsociety.org/wp-content/uploads/2022/01/Classroom-Acoustics.pdf (Accessed: December 17, 2022))

Note:
The average fundamental frequency for a male voice is 125Hz; for a female voice it's 200Hz; and for a child's voice, 300Hz.
We are considering 1000 Hz or 1 kHz of 1/3rd octave frequency for our calculation.
Also, we have done the calculation of reverberation time for two cases:

a) When the Classroom is completely occupied.
b) When the Classroom is Empty.

The value of the total sound absorption (a) for our classroom is calculated in the table below.

S. No.	Material	Sound Absorption Coefficient (For 1000hz)	Total Areas of Materials (In sq. ft.)	Sound Absorption by Materials
1)	Students + teacher	0.45	33 X 2 X 2 = **132**	**59.4**
2)	Ventilator Grills	0.60	4.9 X 1.8 = **8.82**	**5.292**
3)	Wooden Doors	0.08	3.9 X 6.73= **26.25**	**2.1**
4)	Glazed tile	0.01	32.2 X 24 = **772.8**	**7.728**
5)	Smooth Concrete Painted (including beam)	0.02	6 X 1.8 X 10.1 + 2 X 1.8 X (24-1) + (32.2 X 24 X 23 X 1.8) = **881.88**	**17.638**
6)	Smooth Brick Wall with flush pointing, and painted	0.02	2 X 32.2 X 10.1 + 2 X 24 X 10.1 – 40.88 - 8.82 – 26.25 – 881.88 = **177.41**	**3.548**
7)	Plaster on the solid wall + ceiling	0.08	2 X 32.2 X 10.1 + 2 X 24 X 10.1 + 32.2 X 24 – 40.88 - 8.82 – 26.25 = **1832.09**	**146.567**
8)	6mm glass of windows	0.03	2 x 5.11 X 4 = **40.88**	**1.2264**
9)	Lightweight curtains	0.52	**= 40.88**	**21.257**
10)	Unoccupied plastic chair (for students + teacher)	0.20	33 X 1.5 X 1.5= **74.25**	**14.85**
11)	Classroom Board (Chalk Board)	0.01	1 X 7.11 X 3.11= **22.11**	**0.2211**
12)	Adult Office Furniture per desk	0.45	33 X 2.11 X 1.5= **104.445**	**47.000**

	Total Sound Absorption Value (a) (Completely Occupied Class)	**326.8275**
	Total Sound Absorption Value (a) (Empty Class)	**267.428**

Table 1 Determination of total sound absorption value (a) for reverberation time.

The volume of Classroom (V): 32.2 feet X 24 feet X 10.1 feet = 7805.28 cubic feet
Case -1: For Completely Occupied Class:
RT60 = 0.049 V/a (For FPS System) = (0.049 X 7805.28) / 326.8275 = **1.17 seconds**
Case -2: For Empty Class:
RT60 = 0.049 V/a (For FPS System) = (0.049 X 7805.28) / 267.428 = **1.430 seconds**
Now as per the standard values, the reverberation time of classrooms should be in between 0.4 to 0.6 seconds. So, with this, the acoustics of our classroom is not within the standard range.

1.9. Cost Estimation for acoustics work with the commercially available solution:

S. NO.	**Particulars**	**Area (In sq. ft.)**	**Acoustic Area (In sq. ft.)**	**Acoustic Foam (Rate: 80Rs/sq. ft)**	**Acoustic Panel (Rate: Panel 50 Rs/sq. ft. Cornice Rs 200 running sq. feet)**	**Acoustic Fabric Rate: 55 Rs/sq. ft.**
1)	Window Wall Area	113.75	**(1)-(2)-(3)-(4) =52.44**	52.44 X 80 = **Rs 4195**	Panel Cost 50 X 52.44 = **Rs 2622**	55 X 52.44 = Rs **2884.2**
2)	Window area	23.67			Cornice Cost: Rs 24 X 200 = **Rs 4800**	
3)	Window Wall Column area	29.60			= **Rs 7422**	
4)	Window wall Area of skirting	8.04				
5)	Blackboard wall Area	324.35	**(5)-(6)-(7)-(8) = 252.52**	252.52 X 80= **Rs 20, 201.6**	Panel Cost = 50 X 252.52 = **Rs 12626**	252.52 X 55= **Rs 13888.6**
6)	Blackboard area	31.01			Cornice Cost: Rs 32.2 X 200 = Rs **6440**	
7)	Blackboard wall Area of skirting	8.04			= **Rs 19066**	
8)	Blackboard wall Column area	2 x 16.39				
9)	Door wall Area	244.04	**(9)-(10)-(11)-(12)-(13) = 171.06**	171.06 X 80 = **Rs 13684.8**	Panel Cost 50 X 171.06 = **Rs 8553**	171.06 X 55= **Rs 9408.3**
10)	Door wall Ventilation area	8.87			Cornice Cost: Rs 24 X 200 = **Rs 4800**	
11)	Door area	26.47			**= Rs 13353**	
12)	Door wall Area of skirting	8.04				
13)	Door wall Column area	29.60				
14)	Back wall Area	324.35	**(14)-(15)-(16) = 283.53**	283.53 X 80 = **Rs 22682.4**	283.53 X 50 = **Rs 14176.5**	283.53 X 55= **Rs 15594.15**
15)	Back wall Area of skirting	8.04			Cornice Cost: Rs 32.2 X 200 = Rs **6440**	
16)	Back wall Column area	2x16.39			**= Rs 20616.5**	
	Total Acoustic Area		**759.55**			
(a)	Material Cost			**Rs 60763.8**	**Rs 60442.5**	**Rs 41775.25**
(b)	Labour Cost (30% of Material Cost)			**Rs 18229.14**	**Rs 18132.75**	**Rs 12532.57**
	TOTAL COST (a + b)			**Rs 78992.94**	**Rs 78575.25**	**Rs 54307.82**

Table 2 Cost Estimation using the commercially available solution for making our classroom acoustically sound.

1.10. Cost Estimation for acoustics work of LCASC Setup

Dimensions of Tetra Pack considered:
Length: 0.295 ft, Height: 0.639 ft, Thickness (Breadth): 0.1804 ft
Surface Area: 0.1885 sq. ft, Volume: 0.0340 cu. Ft
Weight of Filled Tetra Pack: 0.098 kg

Fig 7 Sample of preparation of filled tetra pack.

S. NO.	Particulars	Area (In sq. ft)	Acoustic Area (In sq. ft)	No. of Tetra Packs Used	Weight of Tetra Packs
1)	Window Wall Area	113.75	**(1)-(2)-(3)-(4) = 52.44**	52.44 /0.1885 = 288.80	28.30 Kg
2)	Window area	23.67			
3)	Window Wall Column area	29.60			
4)	Window wall Area of skirting	8.04			
5)	Blackboard wall Area	324.35	**(5)-(6)-(7)-(8) =252.52**	252.52 /0.1885 = 1339.628	131.28 Kg
6)	Blackboard area	31.01			
7)	Blackboard wall Area of skirting	8.04			
8)	Blackboard wall Column area	2x16.39			
9)	Door wall Area	244.04	**(9)-(10)-(11)-(12)-(13) = 171.06**	171.06/0.1885 = 907.480	88.93 Kg
10)	Door wall Ventilation area	8.87			
11)	Door area	26.47			
12)	Door wall Area of skirting	8.04			
13)	Door wall Column area	29.60			
14)	Back wall Area	324.35	**(14)-(15)-(16) = 283.53**	283.53/0.1885 = 1504.137	147.405 Kg
15)	Back wall Area of skirting	8.04			
16)	Back wall Column area	2x16.39			
Total Acoustic Area			759.55		
Number of Tetra Packs To be Used				**4040.038**	**395.915 Kg**
10% Extra to Cope Up with Defective Tetra Packs				**404**	**39.592 Kg**
Total Number of Tetra Packs to Be Used				= 4445 Tetra Packs	
Weight of all Tetra Packs					**435.61 Kg**
Considering 20% Saw Dust, 40% Coconut Husk & 40% Neem Leaves of the Total Weight of the Filler Mix					
Required Weight of Saw Dust			**87.122 Kg**		
Required Weight of Coconut Husk			**174.244 Kg**		

Required Weight of Saw Dust	**174.244 Kg**

Table 3 Estimation of raw materials for LCASC Setup

S. No.	**Particulars**		**Cost & Mode of Collection**	
1)	Raw Materials used:			
a)	Neem Leaves	Natural Resource	Low or No Cost	Can be collected voluntarily
b)	Coconut Husk	Natural Resource	Low or No Cost	Can be collected voluntarily
c)	Sawdust	Waste Material	Low or No Cost	Can be obtained from woodwork areas.
d)	Tetra Packs	Waste Materials	Low or No Cost	Can be collected with the help of door-to-door campaigns or collection drives
2)	Plywood (For making frames)	Commercially Available in 4 X 8 sq. ft sheets of Rs 65 each	Rs 65	3 (4 X 8sheets) X 65Rs = Rs 6240. Labour Charge = 30% of 6240 = Rs 1872 Total Cost: Rs 8112
3)	Transportation Charges		Rs 1000	
4)	Labour Charges for Preparing the Raw Materials for usage.		Rs 2000	
5)	Labour Charges for assembling the structure in the classroom		Rs 5000	
6)	Miscellaneous Expenses (Adhesives, nails, cloth sheets, etc.)		Rs 2000	
7)	**Total Cost**		**Rs 18112**	

Table 4 Cost Estimation of LCASC Setup for making our classroom acoustically sound.

Note: The above cost is the maximum amount that will be needed for the implementation of the LCASC Setup. If we use used but good quality clothes, nails, and other virgin resources instead of purchasing new ones, then the total expenses will be significantly lesser than stated above.

Following is a graph to show the economic difference in commercially available solutions and LCASC Setup:

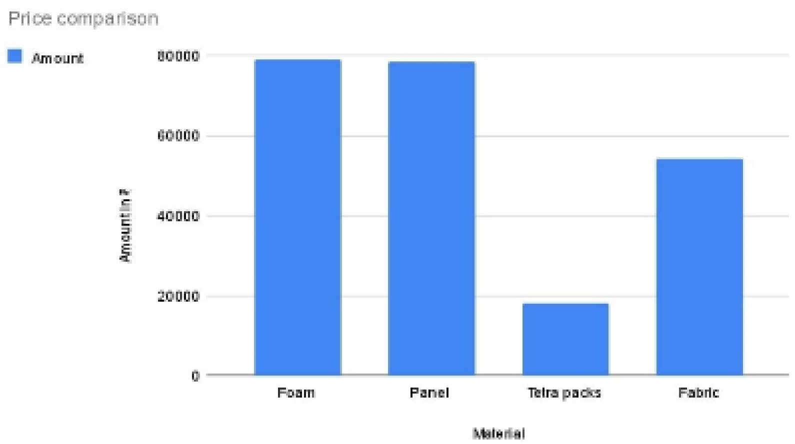

Fig 8 Graph Showing Economic Difference in Commercially Available Solution & LCASC Setup
(Software Used: MS Word)

1.11. Miniature Model of LCASC Setup

As the implementation of LCASC Setup on real grounds will require time, resources, and lots of hard work, we decided to make a working miniature model of our classroom with our LCASC Setup installed inside it to understand the following:
1)The behavior of materials used in our setup.
2)Practical challenges in making and installing our setup.
3)The actual acoustics improvement potential of our setup.
4)To obtain data-oriented observations and results for analyzing and predicting the performance of our setup on actual grounds.
We decided to make a miniature model with the front face open. This way we can showcase the internal orientation of the elements of our classroom and the way our acoustic setup will be established.
Moreover, it will help do experiments in the model with and without our acoustic setup to obtain comparative results.
Lastly, we decided to make the miniature model out of cement concrete or cement mortar, because we wanted to replicate our classroom even from the aspect of the used building material.

Also, the observations that will be obtained from the conducted experiments will be concerning cement concrete or cement mortar which are actual building materials.

1.11.1 Miniature Model Size Finalizing & Material Estimation for Model Making

By scaling down the actual size of our classroom and facilitating the required inner workable space after the build-up, we finalized the following dimensions of our miniature model:
Length = 2 feet 6-inch, Width = 1 feet 8-inch, Height = 1 feet 4 inch
Initially, we decided to make the model from the concrete mix for which the following is the estimation work that we did:

S. No.	Structural elements	Dimensions & Quantities	Volume
	Slab	(20 X 30 X 1) X 2	1200 inch3
	Long Wall	(30 X 60 X 1) X 2	3600 inch3
	Short Wall	(20X 16X 1) X 2	640 inch3
Open Areas for Deduction			
	Door	(3 X 5 X 1) X 1	15 inch3
	Window	(4 X 3 X 1) X 2	24 inch3
	Ventilation	(4 X 1 X 1) X 1	4 inch3
	Total Volume After Deduction		5397 inch3 = 0.0884 m3

Table 5 Material Estimation for Model Making
Amount of Cement required = 1 bag = 50 kg
Amount of Sand required = 50 kg
Amount of Aggregate required = 90 Kg
Total Weight = 190 kg

Weight according to different materials
1)Cement Concrete = 193.26 Kg
2)Reinforced Cement Concrete (RCC) = 201.31 Kg
3)Cement Mortar = 167.49 Kg
4)Fly Ash = 111.12 Kg
5)Plywood (8mm) = 14 Kg
(Sheet Area required = 3.25 m2)
With the above data we can conclude the following:
Making a model out of Cement Concrete, Reinforced Cement Concrete (RCC), Cement Mortar, or using Fly Ash by direct casting will make the model too heavy and it will be difficult to move or work with.
Making a model out of plywood is easy and can be made in less time but it will be costly overall. Moreover, the primary aim of making a model out of practically used building material and getting observations from it will be defeated as well.
Hence, we decided to make sample slabs in the laboratory and decide with their weight to opt either for cement concrete mix or cement concrete mix with the addition of fly ash.

1.11.2 Material Estimation for LCASC Setup Miniature Model

As per the wall dimensions, the number of walls and the area to be covered with our acoustic setup, we estimated the number of tetra packs required.
Hence Number of Tetra Packs required to cover the acoustic area of the miniature model = 200
Now, as per our previous estimation of filled tetra packs, we considered the weight of filled tetra packs = 98 grams.
Therefore, the total weight of filler mix = 200 x 98 grams = 19600 grams = 19.6 Kg.
Proportion considered for the mix = 20% Saw Dust, 40% Coconut Husk & 40% Neem Leaves of the Total Weight of the Filler Mix Hence,
Weight of Saw dust required = 3.92 Kg
Weight of Neem leaves required = 7.84 Kg
Weight of Coconut Husk required = 7.84 kg
Note: The amount of Tetra Packs used may vary. For estimation, we considered tetra packs of the same size. However, we are using waste tetra packs in our model so getting all 200 tetra packs of the same size is not possible. Moreover, their usage is more important than being identical.
Also, there are empty spaces to be left for open areas which will also affect the number of tetra packs used and their orientation of usage.

1.11.3 Raw Material Collection & Preparation for Miniature Model Making

Fig 9 Collection of Raw Materials

The raw materials required for our LCASC Setup are Used Tetra Packs, Neem Leaves, Saw Dust & Coconut Husk. As our required raw materials are either naturally available or are waste materials, hence we decided to arrange them with our voluntary efforts.
For the collection of Tetra Packs, we reached out to Miss. Geeta Rao, Head of the College Canteen and asked for her help in gathering used tetra packs.
She agreed and collected the waste tetra packs generated in the college canteen and handed them over to us.
We got 247 tetra packs in good shape which we could use in making our LCASC Setup. Other than Tetra Packs, we collected the sawdust from Carpenter's workhouse, collected coconut husk from General stores along with the coconuts used in our homes for religious purposes, and collected neem leaves from Neem trees of our locality.

Fig 10 Preparation of Raw Materials

After the collection of the raw materials, we prepared the raw materials for using them in our LCASC Setup. As the Tetra Packs contain beverages, hence they produce a bad odor after usage.
Moreover, the liquid also attracts ants and other insects which makes the tetra packs unusable without proper sterilization.
Hence, we washed and dried the used Tetra Packs so that all germs and odor will be removed and they can become ready to be used as the container of the filler material.
On removal of Coconut husk from the coconut, their fibers get intertwined in a complex manner. Hence for getting access to individual fibers, we straightened the fibers so that they can be filled inside the tetra packs easily.
We then sundried the coconut husk to remove even the small traces of moisture in them. We also sun-dried the sawdust to remove even the tiniest traces of moisture present in them.
For preparing the neem leaves for our setup, we removed the leaves from the stem and then sun-dried them to make them ready for using it in preparing the filler mix and making it ready to provide anti-bacterial and anti-fungal measures to our setup.
Then we prepared the filler mix by mixing sawdust, neem leaves, and coconut husk and filling them in the filler container i.e., Tetra packs. This way all our raw materials became ready to be used in making the LCASC Setup.

1.11.4 Miniature Model Casting

Fig 11 Slab Casting with Fly ash, sand, and cement

After obtaining good results while casting slabs with cement, sand, and fly ash in terms of durability, weight, and self-stability, we proceeded forward with the casting of slabs individually as walls, floor, and roof and then join them to make the model.
Note: The addition of zero aggregate will increase the durability and strength even more. Hence incorporated in the final slabs.

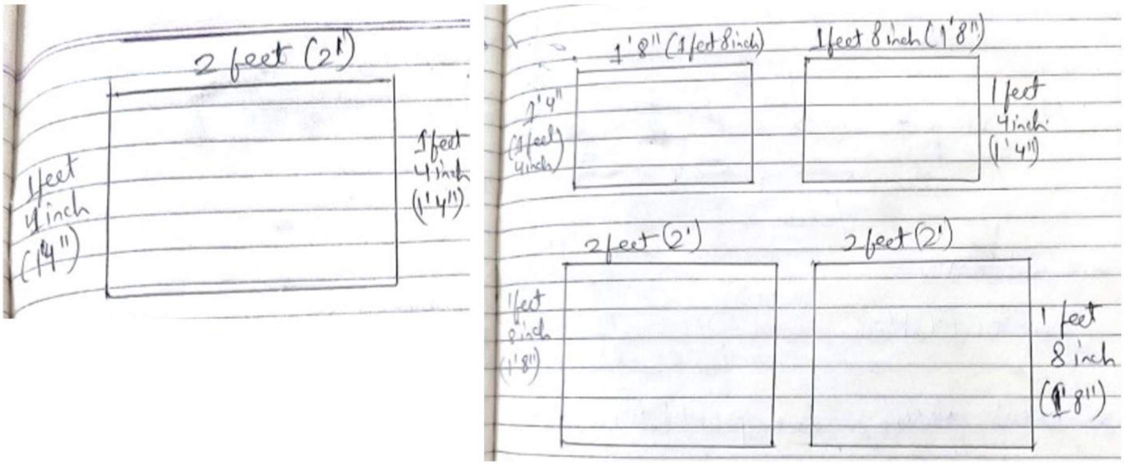

Fig 12 Slabs of Required Dimensions

The above layout shows the dimensions of the slabs to be made.

To make slabs of uniform shape, even surface, smooth finish, and sharp edges, we decided to use a firm base with a plastic cover so that the slabs can be removed easily after casting without any deformations.

For form works, we decided to use cardboard strips wrapped with tape and joined together as frames of desired dimensions. The usage of multiple layers of cardboard strips in making the form works made them strong and the tape wrapping gave them a smooth, even & waterproof surface in which casting can be done easily and can be removed without causing any deformation to the slabs.

After making of form works, we did the quantification of the number of materials required for making the concrete mix for slab casting.

Following are the number of materials required for each slab:

Walls	Cement	Ash	Zero Aggregate	Sand
Back Wall	1.5 Kg	2 Kg	2 Kg	1 Kg
Left Wall	1.2 Kg	1.5 Kg	2 Kg	1 Kg
Right Wall	1.2 Kg	1.5 Kg	2 Kg	1 Kg
Floor	1.5 Kg	2 Kg	2 Kg	1.5 Kg
Roof	1.5 Kg	2 Kg	2 Kg	1.5 Kg

Table 6 Quantification of Raw Materials for Concrete Mix

After quantification, we prepared the concrete mix for the slab casting with thorough dry and wet mixing.

As the casted slabs will be used for making a classroom hence, we planned to leave hollow spaces for windows, doors, and ventilation using solid removable blocks.

We also used wire mesh in the slab casting like the first and second attempts of slab casting. Also, we cut the wire mesh into proper dimensions excluding the hollow space for windows, doors, and ventilation. After this, we did the casting slabs with proper care and compaction. With a curing of 14 days, our slab became ready for model fixing and furnishing.

Fig 13 Preparing base for slab casting & Making strips for Form Works

Fig 14 Making Form Works

Fig 15 Quantification of Raw Materials

Fig 16 Preparing Concrete mix, placing wire mesh and open space blocks.

Fig 17 Slab Casting

Fig 18 Casting slabs with proper compaction and surface finish

Fig 19 Slabs ready for casting and curing.

1.11.5 Miniature Model Fixing and Furnishing

Fig 20 Model Fixing

After slab casting and proper curing, we then started fixing slabs in making the desired structure of the classroom. We did the markings on the corners of the slab and made holes using a drill machine.
Then we began joining the slabs for walls using L-shaped clamps and screws.

After that, we joined the three-walled structure with the base and roof slabs thereby giving our structure the look of our classroom. After model fixing, we proceeded with the model furnishing works in which we applied white cement layers on all the surfaces to strengthen the joints and give them a smooth finish and better aesthetics. On drying, the white cement coating gave strength to the entire structure and an appealing appearance.

Fig 21 Model Furnishing

1.11.6 Stackable Structure Making with Stacked Tetra Packs

For making the stackable structure to hold our LCASC setup, we decided to use cardboard formworks as they were stiff, waterproof, strong, and stable to hold the stacked tetra packs arrangement. This way we used one material for two important purposes in making our miniature model.

We then prepared the stackable structures for the inner walls of our miniature model leaving dedicated spaces for windows, ventilation, and door as well. Then we fixed the tetra packs arrangement inside the stackable structure ensuring that no gaps are present in them.

At last, the stackable structure with filled tetra pack layers was aligned in the model with a replication of Classroom chairs and tables (made from tetra packs and waste cardboard strips) to finish the model of LCASC Setup.

Fig 22 Making Stackable Structure with filled Tetra Packs

Fig-23 Finished Model with Acoustics Setup

1.12. Sound Sample Testing

Note: LCASC: LCASC

WITHOUT LCASC SETUP

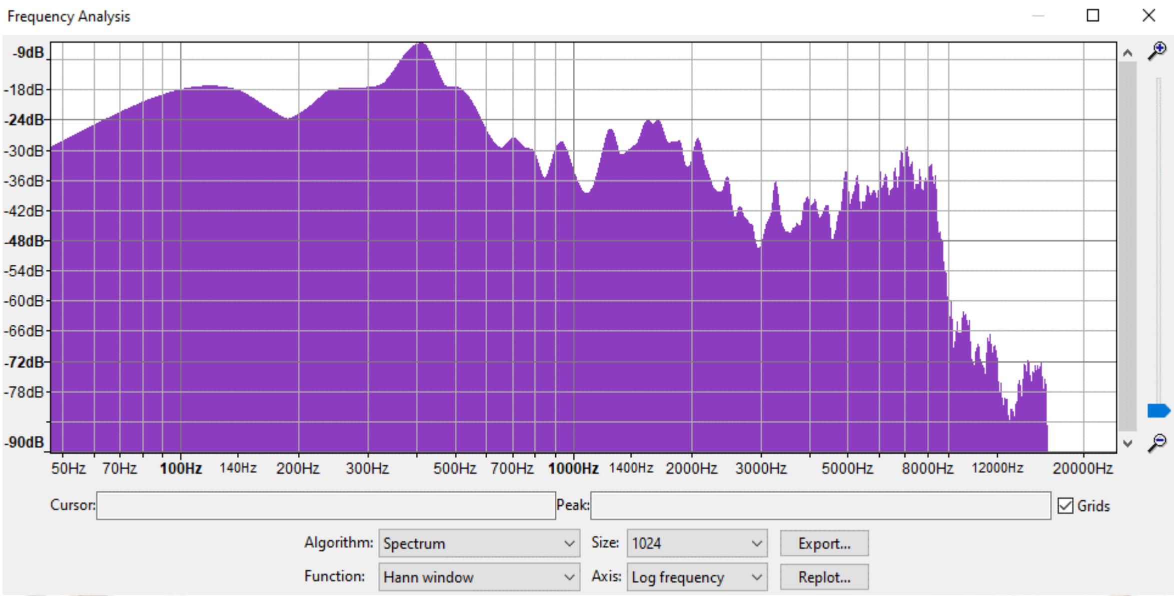

Fig 24 Sound Graph of Sample Testing without LCASC Setup

(Software Used: Audacity)

WITH LCASC SETUP

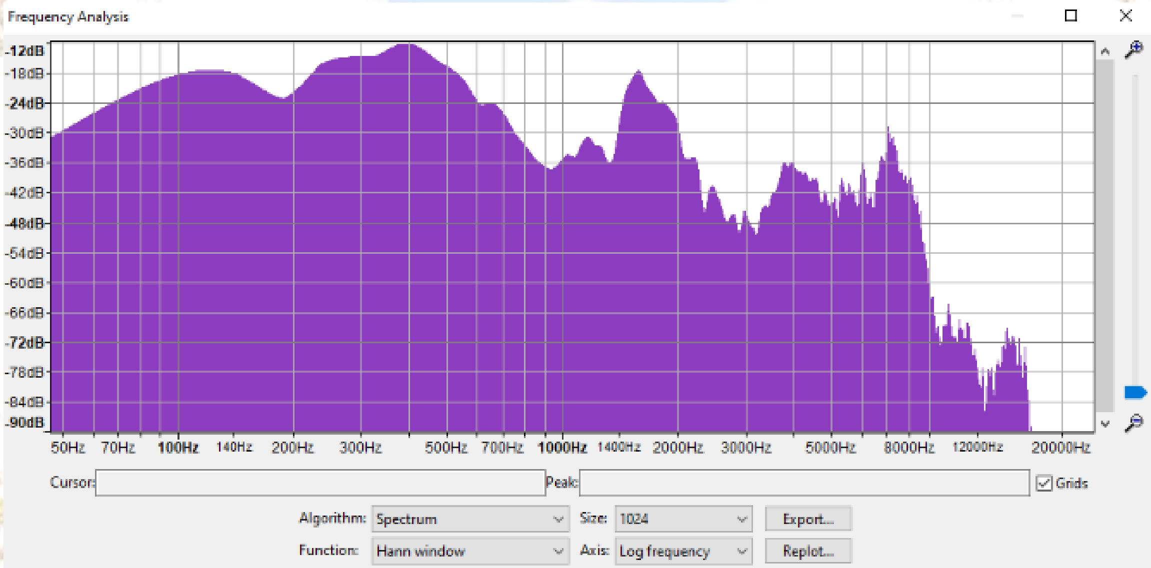

Fig 25 Sound Graph of Sample Testing with LCASC Setup

(Software Used: Audacity)

From the above two graphs, we can say that decibel increase took place distinctively at

1) At 400 Hz of 3 dB
2) 1000 Hz of 6 dB
3) At 1700 Hz of 6 dB

Other than that, the overall smoothness of the waves has increased and the clarity of the audio has become better as well. The Following QR Codes hold the sound test samples of both testing conditions.

Without LCASC	**With LCASC**

Fig 26 QR Codes of Test Sound Samples

(Online Resource Supplementary Information (SI)) (Software Used: Online QR Generator Tool)

With this, we can conclude that our LCASC setup is in working condition and it does improve the acoustics of our classroom.
During the actual implementation of our setup in an actual classroom, if standard acoustics measures like installing thick curtains, fall ceiling, and carpet laying on the ground are performed then the overall improvement in the acoustics of the classroom will be furthermore by certain degrees.
Comparative Study For the merits and demerits of both the solutions.

1.12.1. Advantages & Disadvantages of Commercially Available Solution:

Advantages:
1) Acoustic foam can reduce high-frequency sounds.
2) Acoustic foam can improve the quality of the sound produced in a room by absorbing the echoes which highly improves the quality of the speech and the sound inside that space.
3) Acoustic Foams have Easy Installation, Flexible Absorption and are highly efficient in sound absorption
4) Professional acoustics are light in weight.
5) They are aesthetically appealing
6) They can be easily replaced.

Disadvantages:
1) They are expensive and unaffordable for low-budget schools and colleges.
2) Acoustic Foams are highly sensitive to fire.
3) Acoustic tiles are not waterproof, although resistant to certain levels of humidity. The good thing is that they are easily replaced.
4) They are made up either of polyurethane, Styrofoam, or other synthetically made materials which are non-biodegradable and harmful to the environment.
5) Ineffective placement can severely hamper the efficiency of their performances.
6) In Acoustic Boards, it is difficult to conceal joints between units, soft structures are subject to damage, and paint and redecoration are harmful to absorption.
7) Labor charges are more for installing professional acoustics solutions.

1.12.2. Advantages & Disadvantages of LCASC Setup:

Advantages:
1) LCASC Setup is eco-friendly.
2) It is low-cost and easily adaptable.
3) The stackable structure of LCASC Setup is easy to mount and unmount on the wall.
4) Waste materials are our raw materials which facilitate us to use them for a good cause and prevent them from going into the landfill.
5) LCASC Setup is light in weight and can be applied easily.
6) As our filler material is natural hence it won't cause any health issues.
7) The Labour charge in LCASC Setup is significantly lesser than that of the commercially available solution.

Disadvantages:
1) Relatively lower efficiency than a professional solution but enough to make the classroom acoustically better.
2) More manual labor and voluntary work are required to assemble LCASC Setup than the commercially available materials.

1.13. Conclusion

After all the data analysis, data collection, measurements, calculations, and estimations, we can conclude the following:
1) The reverberation time of our classroom is more than the desired range and needs improvement to make our classroom acoustically sound.
2) The acoustics of our classroom can be improved by our LCASC Setup.
3) Our setup is more affordable than the commercially available solution.
4) Our setup is more eco-friendly than the commercially available solution.

Hence if LCASC Setup is brought into practice by all the schools and colleges then the learning experience of students and the teaching experience of teachers will improve which will improve the overall environment of classrooms and ultimately improve the studies of students in an eco-friendly manner.
Good Acoustics > Better Audio > Better Listening > Better Understanding > More Focus > Improvement in Studies.

1.14. References:

1.14.1. Literature Review References:

1) Seep, B. et al. (2000) Classroom Acoustics: A Resource for Creating Environments with Desirable Listening Conditions, Acoustical Society of America, Melville, New York. Acoustical Society of America, Suite 1N01, 2 Huntington Quadrangle, Melville, NY 11747; Tel: 516-576-2360; Fax: 516-576-2377; e-mail: asa@aip.org; Web site: http://asa.aip.org. Available at: https://acousticalsociety.org/wp-content/uploads/2022/01/Classroom-Acoustics.pdf (Accessed: December 17, 2022).
2) Rabelo, Alessandra Terra Vasconcelos et al. Effect of classroom acoustics on the speech intelligibility of students. CoDAS [online]. 2014, v. 26, n. 5 [Accessed 17 December 2022], pp. 360-366. Available from: <https://doi.org/10.1590/2317-1782/20142014026>. ISSN 2317-1782. https://doi.org/10.1590/2317-1782/20142014026.
3) Ayub, M. et al. (2009) ANALYSIS ON SOUND ABSORPTION OF NATURAL COIR FIBER USING DELANY-BAZLEY MODEL, Research Gate. Proceedings of the International Conference on Mechanical Engineering 2009 (ICME2009) 26- 28 December 2009, Dhaka, Bangladesh. Available at: https://www.researchgate.net/profile/Md-Ayub/publication/283359223_Analysis_on_sound_absorption_of_natural_coir_fiber_using_delany-bazley_model/links/5643135c08ae54697fb2bdfa/Analysis-on-sound-absorption-of-natural-coir-fiber-using-delany-bazley-model.pdf (Accessed: December 17, 2022).
4) Kang, C.-W., Oh, S.-W., Lee, T.-B., Kang, W., & Matsumura, J. (2012). Sound absorption capability and mechanical properties of a composite rice hull and sawdust board. Journal of Wood Science, 58(3), 273–278. https://doi.org/10.1007/s10086-011-1243-5.

1.14.2. Materials & Methodology References:

1) JCW Acoustic Supplies. (2019). Sound Absorption Coefficient Chart | JCW Acoustic Supplies. Acoustic-Supplies.com. https://www.acoustic-supplies.com/absorption-coefficient-chart/
2) Acoustic Fields. (n.d.). Retrieved December 17, 2022, from https://acousticfields.com/wp-content/uploads/2012/01/ACDA-10.pdf
3) Calculate Reverberation Time | Sabine Formula | eNoise Control. (n.d.). ENoiseControl. https://www.enoisecontrol.com/calculate-reverberation-time/
4) Guides, T.O.P.P.R. (2021) Reverberation: Definition, formula, derivation, and examples - TOPPR-guides, TOPPR Guides. TOPPR Guides. Available at: https://www.toppr.com/guides/physics/sound/reverberation/ (Accessed: December 17, 2022).
5) Sabine formula for reverberation time | Tech Glads. (2018, July 6). Tech GLADS.https://www.techglads.com/cse/sem1/sabine-formula-for-reverberation-time/
6) ABSORPTION COEFFICIENTS. (n.d.). https://www.acoustic.ua/st/web_absorption_data_eng.pdf
7) Annex Material data. (n.d.). https://cds.cern.ch/record/1251519/files/978-3-540-48830-9_BookBackMatter.pdf
8) Reverberation Time in Room Acoustics. (n.d.). Larson Davis. http://larsondavis.com/learn/building-acoustics/Reverberation-Time-in-Room-Acoustics
9) NTI Audio. (n.d.). Reverberation Time. Www.nti-Audio.com. https://www.nti-audio.com/en/applications/room-building-acoustics/reverberation-time
10) Company, M. K. E. T. (n.d.). Eco-friendly Sound proofing using coir matting. M.K.Export Trading Company. Retrieved December 17, 2022, from https://mketc.co.in/f/eco-friendly-sound-proofing-using-coir-matting
11) Hla, K.K., Aye, M.M. and Ngwe, M.H. (2011) Some Chemical Analyses and Determination of Antioxidant Property of Neem Leaf (Azadirachita indica A.Juss), Universities Research Journal 2011, Vol. 4, No. 3. The Government of The Republic of the Union of Myanmar Ministry of Education. Available at: https://www.doc-developpement-durable.org/file/Culture/Arbres-Fruitiers/FICHES_ARBRES/Nypa%20fruticans/Utilization%20of%20Mangrove%20Forest%20Plant%20Nipa%20Palm.pdf (Accessed: December 17, 2022).
12) T E R I. 2019 Used Beverage Carton Management Study for Indian Cities New Delhi: The Energy and Resources Institute. 134 pp. [Project Report No. 2018 CW 29(Part A)] (https://www.teriin.org/sites/default/files/2019-09/Used beverage carton %28UBC%29 management study for India.pdf)
13) How Classroom Design Can Reduce Noise. (2018, April 24). BFX Furniture. https://www.bfx.com.au/how-classroom-design-can-reduce-noise/
14) 7 Cost-effective ways to control school acoustics — Sound Zero. (2020, September 10). https://sound-zero.com/7-cost-effective-ways-to-control-school-acoustics/
15) A Complete Guide To Classroom Acoustics. (2019). Acoustical Surfaces. https://www.acousticalsurfaces.com/soundproofing_tips/html/crashcourse.htm
16) Soundproofing classrooms: The do's and don'ts — Sound Zero. (2021, January 26). https://sound-zero.com/soundproofing-classrooms-the-dos-and-donts/
17) Reducing carbon footprint: Tetra Pak ramps up recycling of used cartons. (2019, December 4). Business Today. https://www.businesstoday.in/latest/story/tetra-pak-recycles-54-cartons-aims-100-240397-2019-12-04

1.14.3. Result & Discussion References:

1) Sarthak Kaura. (2017, December 17). Acoustic & Materials. https://www.slideshare.net/sarthakaura/acoustic-materials-84289787
2) Acoustic ceiling tiles – what do you need to know about them? (2015, June 4). Deavita.net | Home Ideas, Design, Hairstyles, Makeup, Lifestyle, Health, and Beauty Tips. https://deavita.net/acoustic-ceiling-tiles-pros-cons.html
3) Soundproof Foam Pros and Cons – Alternative-energies.net. (n.d.). https://www.alternative-energies.net/soundproof-foam-pros-and-cons/