Acoustic performance in raw earth construction techniques used in Colombia

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Four techniques of raw earth construction buildings are largely used in Colombia housing development until the XX century, decreasing to other construction systems; nevertheless, several houses built on earth techniques are architectural heritage that currently is keeping the original earth construction. Earth as construction material is known for its fire-retardant properties, thermal inertia and low environmental impact material. Some authors have found that earth constructions have high performance of sound reduction in wall thickness of 20 to 110 centimeters and more, at the same time is possible obtain good sound absorption into the rooms with earth as fair-faced surface in walls.

In the historic neighborhood La Candelaria in Bogota there are many houses built of earth raw construction and nowadays mostly of those houses are architectural heritage used as museums or exhibition halls. On-site acoustic measurements carried out in rooms of two of these houses where evaluated reverberation time and transmission loss obtained high acoustic performance in these buildings. The presented work is part of an ongoing research project on acoustic characterization of raw earth construction techniques in Colombia.

Keywords: Acoustic performance, raw earth, adobe, tapial, Samano, Independencia, La Candelaria.

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1 Introduction

About 50% of heritage architectural buildings in Colombia have been built in earth construction techniques[1)]. Many of this building are from the Spanish colonial period which were dwellings. In the neighborhood La Candelaria in Bogota D.C some of that kind of heritage buildings have a museum use and offer comfortable spaces to contemplate the art, good speech rooms or workshop rooms. In the acoustic performance are quiet rooms which do not require any kind of conditioning even as film screening rooms not only to be built in earth techniques but by gardens and inner courtyard typically from the Spanish colonial period.

Inside rooms of heritage buildings is lesser perceptible the airborne noise to traffic noise or transmission sound from adjacent rooms. This observation carry to analyze the acoustic performance

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1) Ministerio de Cultura de Colombia

of this type of buildings select two houses in La Candelaria neighborhood in Bogota, La Casa Samano built in 1780 localized in Carrera 4 No. 10-18 and La Casa de La Independencia built in 1637 localized in Calle 10 No. 3-45. Both houses are part of museum of Bogota and belong of La Candelaria Corporation.

In each house was select one room to analyze the reverberation time and loss transmission in one wall to interior courtyard. This testing campaign is part of a research project focused in the characterization of the acoustic performance of the construction techniques on raw earth used in Colombia.

2 Raw earth construction, techniques more used in Colombia

- **Tapial or rammed earth** is a construction technique in walls through compaction of earth with a “pisón” between wood boards. The walls have thickness from 40 to 200cm.

- **Adobe** is a block made of mass of clay raw to improve the cohesion. The most common dimensions of the block are 30 x 15 x 7cm and traditionally 38 x 18 x 8cm [1].

- **Brick compact earth BTC**[2)] block of raw earth made of mixing of earth 82,75%, sand 6,20% and concrete 11,3% [2]. This technique was developed in Colombia after 50´s by means the machine Cinva Ram created for the industrialization of brick to improve the adobe blocks.

- **Bahareque** are wood elements vertical and horizontal than form a simple or double mesh with an inner space filling of earth and clay [3]. This is a very ancient technique developed since the human beginnings.

These techniques are used around the world in some countries of America, Africa, Europe, Asia and Oceania [4]. The rammed earth and the adobe technique were learned in Colombia from the Spanish colonization period.

3 Acoustic performance in raw earth walls

The amount of mass (superficial density Kg/m²) in raw rammed earth walls and big thicknesses represent a better improvement of sound reduction. A rammed earth wall of 250mm thickness can has 50dB[3)] sound reduction and 300mm thickness with dry density p = 2100Kg/m^3 achieves sound reduction index R=58.3dB [5], this values far exceed the minimum acoustic standards.

The Australian acoustic standard AS/NZS 1276-1979[4)] is one of a few regulation around the world which indicated values of performance earth walls, according measurements done of some researchers found that a rammed earth wall 300mm thickness achieve Sound Transmission Class STC 57dB[5)] and

[2)] in spanish language BTC “Bloque de tierra compactado”.
[3)] Bulletin 5 Earth-Wall Construction CSIRO testing. http://www.rammedearthconstructions.com.au/rammed-earth-info/ (source consulted in january 2016)
[4)] Australian Standard Methods for determination of sound transmission class and noise isolation class of building partitions. Replaced by AS/NZS 1276.1:1999
[5)] http://rammedearth.davis.net.au/Terra2000.php (source consulted in january 2016)

a rammed earth wall 250mm thickness achieve Sound Transmission Class STC 50dB[6], good results for any material.

In the research to achieve sound reduction values in rammed earth wall, recognizing superficial density (m) is possible establish an approximated value through the next formula of a British standard[7]

$$R_w = 21.65\log10m – 2.3 \quad (1)$$

In other research found compare the sound attenuation achieved in structures made of different materials: earth block 15% perforation (p = 1600Kg/m³), vertically perforated brick, plastered on both sides (p = 1200Kg/m³) and calcium silicate masonry unit (p = 1800kg/m3), 24cm thickness in all cases and a vertically perforated brick (p = 800kg/m³) last one with less sound attenuation. The sample to obtained better sound attenuation is the earth block perforated achieves between 10 to 20dB higher than the others [6].

3.1 Sound absorption in an earth wall

Some sources consulted about earth construction say that the wrinkled on earth walls could have good sound absorption, however was found that an earth brick can has sound absorption coefficient α = 0,0015 in the range frequency 500Hz and 1000Hz [7] according this results earth brick does not have a high sound absorption coefficient front other materials (concrete, brickwork, plaster board and fiber board) but is important have on mind that porosity in any material can improve the sound absorption, so will be useful studying and do testing in this field.

Values and results of sound reverberation in rooms built on earth are unknown. In the next figure 1 shows some reference values between activity and volume in rooms.

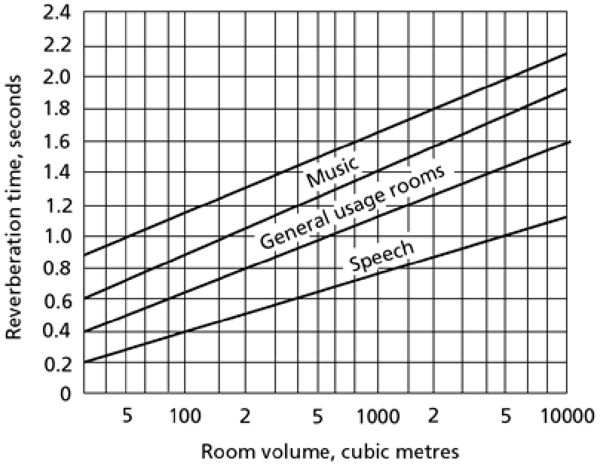


Figure 1- Reverberation Time recommended depending on activity and volume of the room. Source: Brüel & Kjaer http://www.bksv.com/Library/Dictionary.aspx?key=R

6) http://earthdwellings.com/2013/12/10/excellent-acoustic-properties-of-rammed-earth/ (source consulted in january 2016)

7) Formula mass law curve British Standard BS8233-2014 Guidance on sound insulation and noise reduction for buildings.

4 Room characterization

The houses where were carried out testing have been restored through the time and have suffered some modification in the original construction, the house Casa Samano only preserved the front part and the façade in earth walls while the house Casa de La Independencia preserved mostly the original enclosure in earth walls.

4.1 Room Nº 1 Casa Samano

The testing room is an exhibition hall rectangular 23,53 x 4,90mts 115,29m² is localized in the second floor of the house (see figure 2). The room has two heights 3,18mts and 4,43mts because the ceiling is an isosceles trapezoid 33,45m³, the room has 400,10 m³. In the west side it has 5 openings, four double doors 1,23mts width x 2,20 height and one window 1,15mts width x 1,30mts height, to the outward balconies on west façade, in the south side it has one opening 1,20mts width x 2,45mts height this is a double door to outward balcony on south façade (see figure 4). In the east side has 4 openings: a double door 1,70mts width x 2,20mts height, to a small adjacent room and the other openings, 3 double doors 1,23mts width x 2,20mts height, 1,45mts width x 2,20mts height and 1,38mts width x 2,20mts height, these doors communicate the balcony on principal courtyard.

The room is built in the raw earth techniques adobe and tapial 0,70mts thickness. The doors made of wood 4cm thickness and glass with shutters in the glass part, in the room there is wooden floor. The ceiling is wooden structure by round profiles 8cm diameter localized each 55 – 60cm approximately. Along the room there are three wooden porticos built afterwards as roof support (see figure 3).

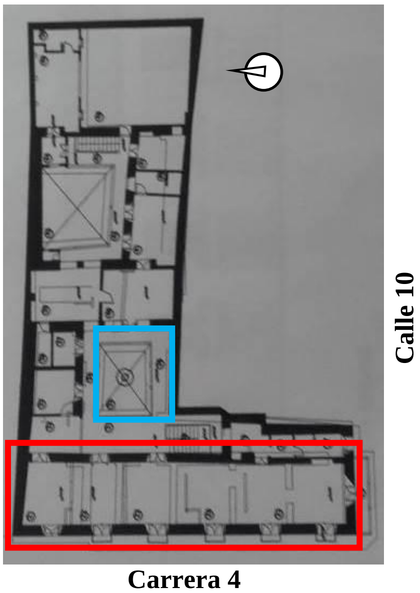


Figure 2- Second floor Casa Samano localization Room Nº 1 in red and main interior courtyard in blue. Source: Corporación La Candelaria.

Figure 3- Inside Room Nº 1 Casa Samano
Source: Own file Andrea Niampira Daza

Figure 4 – Façade outside the Room Nº 1 Casa Samano. Source: own file Andrea Niampira

4.2 Room Nº. 2 Casa de La Independencia

The testing room is used as classroom to workshop localized in the first floor of the house (see figure 5) it is mainly square 5,10 x 4,70mts in plant and 3,29 height, the ceiling is flat. The room surface is 23,97m2 and 78,86m³ volume. Inside there are 3 openings, one double door 1,66mts width x 2,27mts height localized on the east side of courtyard, in the west side of room there are two closed windows (see figure 6), both of 0,96mts width and different heights 1,70mts and 1,90mts.

Inside room only two walls (east and northwest) are made of adobe and tapial raw earth techniques 0,80 thickness, the adjacent walls are made of different materials, one is a double dry wall (north) and the other one is a masonry brick wall (south). The door 0,4cm thickness made of wood, the glass windows 3mm, the floor has tablets clay and the ceiling is made of timber and profiles wood 5cm x 5cm.

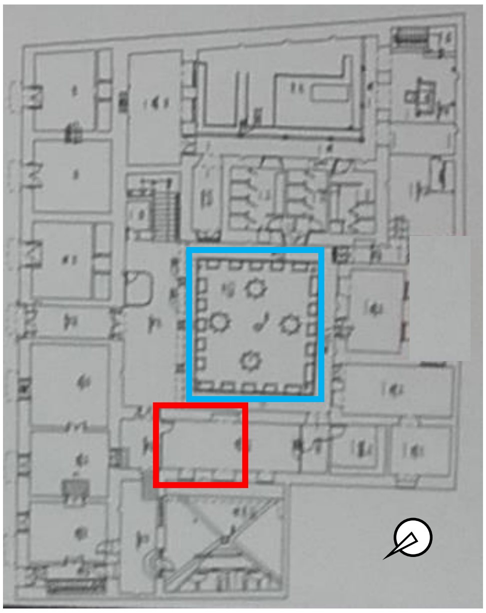


Figure 5 - First floor Casa de La Independencia Room Nº 2 localization in red and main interior courtyard in blue. Source: Corporación La Candelaria.

Figure 6- Inside Room Nº 2 Casa de La independencia. Source: Own file Andrea Niampira Daza.

Figure 7 – Main interior courtyard. Source: Own file Andrea Niampira Daza.

Figure 8 – Façade Casa La Independencia. Source: Own file Andrea Niampira Daza

5 Testing and results

Were carried out the acoustic measurement of reverberation time RT and transmission loss TL in Room No 1 and Room No 2, which have different shape, materials and volume. The testing were done in April 06 of 2016 according the acoustic standards [8] to measure façades and rooms on-site. In the table 1 measuring equipment use relate.

Table 1- Equipment used in testing of Room Nº 1 and Room Nº.2

EQUIPMENT	BRAND	REFERENCE	QUANTITY
Measuring Microphone	Behringer	ECM8000	2
Sound Meter Spectrum analyzer Class II software Svantek to download the results.	Svantek	943A	2
Pistonphone calibrator 94dB -114dB	Svantek	SV 30A	1
Speaker 12", 1000 watts power. Amplifier class D. Range frequencies from 43Hz to 20kHz. Maximum level 135dB.	Electro Voice	ETx-12P	1
Dodecahedron Omnidirectional sound source. Range from 50Hz to 16kHz. Source maximum 121dB during 2 minutes and 116dB during 15 minutes.	Svantek	Qsource	1
Interface Convert analogous and digital signal. 18 input and 8 output. Phantom power in channels. 24bits sampling frequency 96kHz.	Focusrite	Scarlett 18i8	1

5.1 Measured background sound Room Nº 1 and Room Nº2

To the background noise calculation of the Room No 1 Casa Samano were taken 3 measures in different positions having points on the side ends and in the center inside the room, the intervals of measuring were 5 minutes to have 15 minutes and calculate background noise equivalent (Leq). (see table 2). In the Room Nº 2 Casa de La Independencia were taken 2 positions with same configuration and intervals of 5 minutes (see table 3).

Table 2 – Background noise measured Room No 1

Equivalent level (Leq) Room Nº 1	
Position microphone	**(dBA)**
1	45,1
2	44,4
3	46,6
LeqT	**45,4**

Table 3 - Background noise measured Room No 2

Equivalent level (Leq) Room No 2	
Position microphone	**(dBA)**
1	44,1
2	42
LeqT	**43,1**

5.2 Reverberation time measuring Room Nº 1 Casa Samano

Was used the omnidirectional noise source 1,50m height from the floor and three positions of dodecahedron on the side ends and in the center of room, in every position of sound source were taken 4 points to measuring without repetition of positions and taking into account the critical distance of omnidirectional source. Was analyzed a T30 coefficient where the omnidirectional source should be 45dB above the background noise level and guarantee a reasonable difference to calculation the reverberation time. The critical distance was calculate according the room dimensions.

Length = 23,53m
width = 4,90m
Ceiling height nº1 = 3,18
Ceiling height nº2 = 4,43m
Volume 1 = 400,10
Volume 2 = 33,45

$$dmin = 2\sqrt{\frac{V}{c * T}} \quad (2)$$

where

dmin = Critical distance or minimum separation between microphone and sound source to avoid the influence of sound direct.
V = Room volume m³
c = Sound velocity m/s
T = Estimated reverberation time in seconds expected.

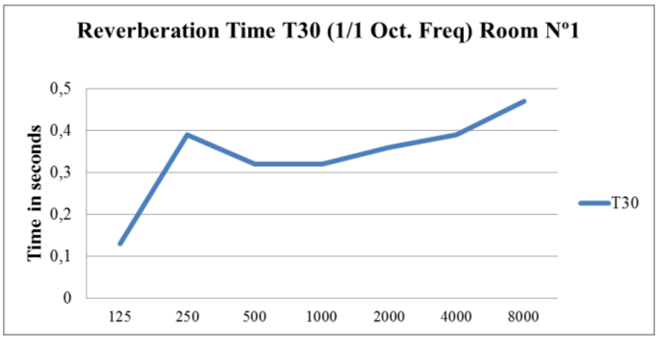
In Room Nº 1 the critical distance calculated = 1,76mts with a reverberation time =1,5 sec estimated and 344m/s sound velocity.

RT the measuring was carried out by EASERA software generating an omnidirectional sound source Sine Sweep frequency at a short interval. To analyze a source T30 was calibrated 96,6dB above the background noise level of 45dB. In the next tables (Table 4 and Table 5) is show the results obtained.

Table 4 – RT results Room Nº 1 Casa Samano

Reverberation time Room 1	
Frequency [Hz]	T30 (1/1 octave) sec
125	0,13
250	0,39
500	0,32
1000	0,32
2000	0,36
4000	0,39
8000	0,47

Table 5 – Graph results RT by frequencies Room No. 1 Casa Samano



The $T30_{mid}$ obtained for Room Nº 1 is 0,32 sec in range frequencies 500Hz and 1000Hz.

5.2.1 Transmission loss TL Room Nº 1 Casa Samano

Following the ISO standard for on-site measurements given the RT and sound absorber area. To calculate TL was used the speaker method as noise source located in the floor outside with an angle +/-45º guarantee the speaker noise exterior level above 6dB of the background noise level. The results shows below in Different Levels Normalization obtained a Sound Transmission Class STC 41dB.

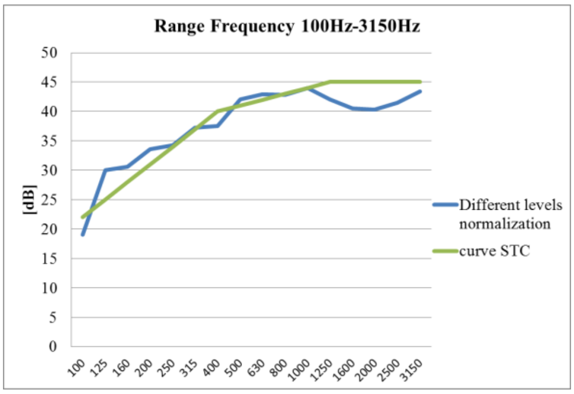
Table 6 – Different levels normalization result Room Nº 1

Frequency[Hz] (1/3 Oct.)	D2mn,T
100	0,1
125	11,1
160	11,7
200	14,7
250	15,3
315	18,3
400	18,6
500	23,1
630	24,0
800	23,9
1000	25,1
1250	23,1
1600	21,6
2000	21,4
2500	22,6
3150	24,5

Table 7 – Sound Transmission Class result Room Nº 1

Frequency [Hz] (1/3 Oct.)	curve STC
100	22
125	25
160	28
200	31
250	34
315	37
400	40
500	41
630	42
800	43
1000	44
1250	45
1600	45
2000	45
2500	45
3150	45

Table 8 – Graph results STC and D2mn,T curve Room Nº 1



5.3 Reverberation time measuring Room Nº 2 Casa La Independencia

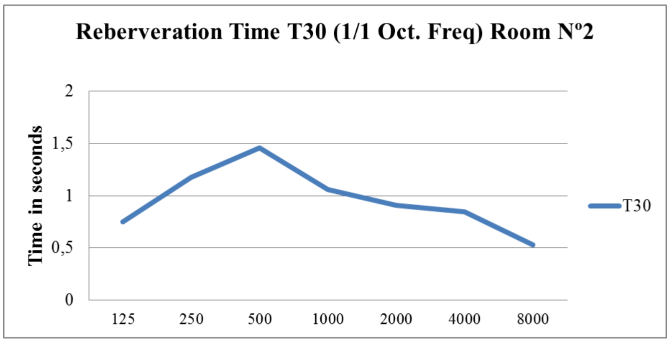
The procedure was similar to that carried out in Room Nº 1 but in this case were measured only two positions of the sound source, on the sides end and in the center. In each position were measured four points without repetition microphone positions and considering the critical distance of 1,38m according to the equation (1) and the room dimensions 5,10mts length, 4,70mts width, 3,44mts height.

To analyze T30 was calibrate 91,2dB above the background noise level of 43dB. In the next tables (see Table 9 and Table 10) is show the results obtained.

Table 9- RT results Room Nº 2 Casa de La Independencia

Reverberation time Room 2	
Frequency [Hz]	T30 (1/1 octave) seg
125	0,75
250	1,18
500	1,46
1000	1,06
2000	0,91
4000	0,85
8000	0,53

Table 10 - Graph results RT by frequencies Room Nº 2 Casa de La Independencia



The $T30_{mid}$ obtained for Room Nº 2 is 1,26 sec in range frequencies 500Hz and 1000Hz.

5.3.1 Transmission Loss TL Room Nº 2 Casa La Independencia

Following the ISO standard for on-site measurements given the RT and sound absorber area. To calculate TL was used the speaker method as noise source located in the floor outside with an angle +/-45º guarantee the speaker noise exterior level above 6dB of the background noise level. The results shows below in Different Levels Normalization (see Table 11) obtained a Sound Transmission Class STC 35dB. (see Table 12)

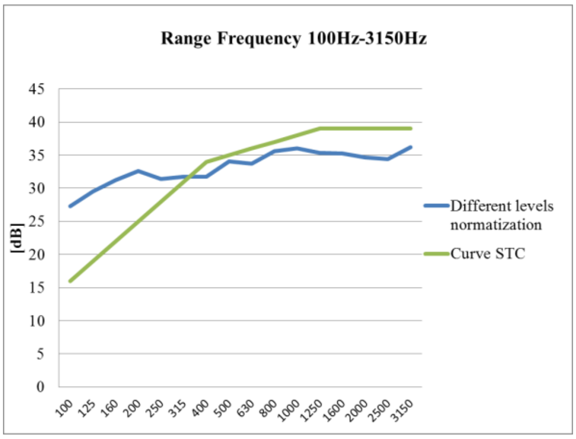
Table 11– Different levels normalization result Room Nº 2

Frequency[Hz] (1/3 Oct.)	D2mn,T
100	20,7
125	22,9
160	24,6
200	26
250	24,8
315	25,1
400	25,1
500	27,4
630	27,1
800	29
1000	29,4
1250	28,7
1600	28,6
2000	28
2500	27,8
3150	29,6

Table 12– Sound Transmission Class result Room Nº 2

Frequency[Hz] (1/3 Oct.)	Curve STC
100	16
125	19
160	22
200	25
250	28
315	31
400	34
500	35
630	36
800	37
1000	38
1250	39
1600	39
2000	39
2500	39
3150	39

Table 13 – Graph result STC and D2mn,T curve Room Nº



6 Conclusions

This is the first acoustic measurement campaign conducted in the research project of acoustic performance of four raw earth techniques used in Colombia. The rooms tested have different characteristics of shape, volume and materials so the results are not comparable among them however is possible analyze the result of sound absorption that can offer each room according the reverberation times obtained.

In Room Nº 1 Casa Samano was obtained RT_{mid} 0,32sec this value is a great result compared to the volume of the room 400,10m³, considering that the recommended minimum values for a conference room with a similar volume is around 0,6sec so the high absorption capacity in room most likely due to the shape, length, width, height of enclosure, the isosceles trapezoidal ceiling and materials in room, where wood and earth walls predominates observed.

In Room Nº 2 Casa de La Independencia was obtained RT_{mid} 1,26sec this value is higher than the optimum minimum 0,4sec for a similar volume 82,45m³, the highest values are in the middle range frequencies about 500Hz possibly due for the relationship in shape, length, width, height and the reflective surface materials present (large glass area in compare to the walls), floor clay tablets and two of the side walls in other material drywall and brick masonry.

According to the results is possible glimpse that the sound reverberation in a space depends primarily on the relationship between shape and the predominant material, in this aspect is necessary to continue working and testing the earth as fair-faced surface of walls.

In the transmission loss TL obtained is visible high performance STC in both walls however in Room Nº 1 is STC 41dB and Room Nº 2 is STC 35dB this difference may be due to the shape and materials in room because the thickness of walls in Room Nº 2 (0,80mts) are bigger than walls in Room Nº 1 (0,70mts) and the SCT value is better in Room No 1. Anyhow in both rooms measured was obtained good improvement of sound insulation rising from low frequencies range.

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