LIVING WALL AND ACOUSTIC COMFORT – A CASE STUDY

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Résumé

Le confort des occupants dans un environnement intérieur inclut non seulement les qualités thermiques de l'espace mais s'étend à d'autres attributs de performance spatiale. Par exemple, la performance acoustique des pièces intérieures est perçue comme ayant un effet direct sur les niveaux de productivité des occupants de l'espace. L'intégration d'un système de verdure tel qu'un mur vivant peut être une stratégie d'isolation acoustique possible. Le but de la recherche actuelle était d'obtenir des mesures acoustiques in situ à quatre endroits avec des murs vivants, et d'évaluer leur potentiel global d'isolation acoustique. De plus, l'étude comprenait une évaluation du potentiel d'intégration du mur vivant à la galerie Paul Cocker, au département des sciences de l'architecture de l'Université Ryerson. Les résultats ont démontrés que les chutes d'eau, les pompes et les systèmes de ventilation des modules de mur vivant généraient des niveaux de bruit élevés. Les résultats de l'étude de cas sont présentés dans cet article.

Mots clefs : Conception durable; acoustique intérieure; systèmes de verdure verticale; simulation acoustique.

Abstract

Occupant comfort in an indoor environment includes not only thermal qualities of the space but expands to other space performance attributes. For instance, acoustic performance of indoor rooms is seen to have a direct effect on the productivity levels of the occupants of the space. The integration of greenery system such as a living wall can be a possible sound absorption strategy. The aim of the current research was to obtain in situ acoustic measurements at four locations with living walls, and evaluate the overall potential of sound absorption of these living walls. In addition, the investigation included an assessment of the potential of integrating the living wall within the Paul Cocker Gallery, at Ryerson University's Department of Architectural Science. The results showed that the living wall modules generated high levels of running waterfall, and pump and fan system noise. The results of the case study are presented in this paper.

Keywords: Sustainable design; indoor acoustics; vertical greenery systems; acoustic simulation.

1 Introduction

Buildings are constructed essentially to provide an indoor environment entirely separated from the outdoor atmosphere, creating an enclosure that caters for the well-being of its occupants. Indoor enclosed spaces are a function of the construction assemblies and the enclosed volume within. The current 'green' and 'sustainable' industry incorporates factors that are an index to comfort of the occupants and users of the space. Therefore, the various aspects of building physics are integrated in the design of buildings that provide energy savings in their construction and occupation phases. Previous studies evaluating the effect of indoor environment in terms of human comfort and their work performance demonstrated a significant reduction in work performance of the occupant due to their discomfort within the space [1]. Comfort for occupants of the space extends beyond thermal qualities. Where other aspects come into consideration, the indoor air quality (IAQ) extends to encompass a broader range of attributes of a space, attaining an overall indoor environment quality (IEQ).

A significant index of the indoor environment quality for occupant comfort and productivity levels is the acoustic performance of the space [2]. The acoustics of a space is influenced by airborne and structure borne sounds, transmitted from outdoors and adjacent spaces. The requirement for noise control strategies is recognized in sustainable building design, in addition to the more common parameters of air quality and thermal control [3].

The necessity of attaining well-defined acoustic qualities pertains to the tasks carried out within the space, to avoid disruption of concentration of users or the undesired transmission of conversation. Additionally, noise levels above a certain threshold could lead to discomfort, and with longer exposures and higher noise levels, a possible partial or total hearing loss [2].

Current practices incorporate living walls within interior spaces for their indoor air quality properties. Studies have shown that these living walls can also be utilized for sound absorption, where they have the ability to absorb some of the noise within the space and reduce the overall sound levels [3].

Living walls are generally constructed as panels of geotextile felts with pre-cultivated plants, which are fixed to a vertical support or on the wall structure. A variation of this

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panel form integrates a module box with a substrate, structurally held onto the wall.

The focus of this paper, therefore, is to evaluate the effectiveness of the integration of living walls within interior spaces to improve the acoustic comfort for the occupants. In-situ measurements of four spaces with installed living walls were carried out to determine the acoustic conditions. Living walls were, then, integrated in a 350 cu.m Paul Cocker Gallery space located in the Department of Architectural Science building of Ryerson University in Toronto. Acoustic simulations were used to assess the potential of applying living walls as a passive sound absorption mechanism. Absorption coefficients of the living walls as well as that of the gallery envelope space were obtained from the literature. The results of the measurements and acoustics simulations are presented below.

2 Background

The necessity of noise absorption in interior spaces is linked with occupant comfort within the space. Noise levels, above a certain threshold, has been shown to reduce people's efficiency in carrying out tasks, as well as affect the sense of balance, raise blood pressure and reduce blood flow volume, as verified by laboratory studies [3].

Surfaces within an internal space would absorb, reflect or transmit sounds. Lower absorption coefficient values of the room surfaces results in higher sound pressure levels in the space, and longer reverberation time, affecting speech intelligibility and sound perception [4]. Hence, criteria have been set to create a guideline for architects and engineers to follow when designing spaces when acoustic performance is considered.

2.1 Acoustic comfort

In order to determine the acoustic comfort within interior spaces, the criteria and guidelines are considered according to the typology of the spaces and the tasks carried out in them. Design values to be achieved in different spaces, through the use of Noise Criterion, Room Criterion, and weighted sound pressure levels dBA and dBC are available in the literature [4]. The following acoustic metrics were used to evaluate the suitability of living walls.

Room criteria contours

The Room Criterion curve (RC) defines the background noise level within a space using a single number, determined from the measured octave-band sound pressure levels. RC curves provide the character of the sound in addition to the single number, defining the sound within a room as either rumbly or hissy, if they fall within the range shown on the RC graph [4]. In addition, RC Contours include low frequency bands (16 Hz and 31.5 Hz) so as to determine the impact of noise induced vibrations.

Reverberation time

Reverberation time of an enclosed space is the time that it takes the measured sound pressure level to decrease by 60 dB. It defines the level of acoustic absorption within the space [5]. The optimum reverberation time values, from Reference 6, at 500 Hz is shown in Figure 1, based on the volume and the use of the given space.

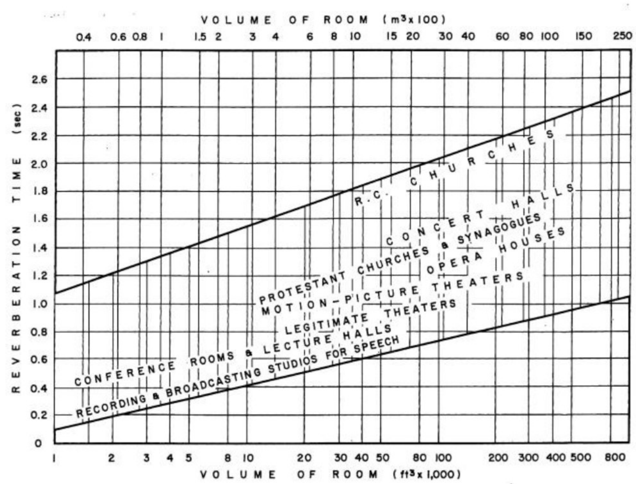

Figure 1: Range of acceptable reverberation time [6]

Clarity

Clarity and Reverberation time have an inversely proportional relationship, where increasing reverberation time would lead to a lower clarity value, and to obtain a higher clarity, the reverberation time has to be decreased.

Clarity (C80) is defined as the difference between the sound energy received at a listener in the first 80 milliseconds and the reverberant energy in dB [5].

An acceptable range of value for clarity is between –3 to +10 dB, where increasing the reverberant energy could lead to a decrease in clarity (more negative value) and thus decreasing the definition of sound and obtaining a "muddy" sound [5]. It is essential to maintain the design RT values to ensure that the sound reaching the listener has a well-defined clarity.

2.2 Living walls

Vegetation can reduce sound levels through the reflection, scattering and absorption by plant elements. Azkorra et al. have shown that the sound absorption of living walls is dependent on both the soil (substrate) and the vegetation itself [7]. The vegetation rooting and the presence of fibers leads to an acoustically very soft soil, due to the porosity created by the plant elements, hence, significantly influencing the absorption properties of the soil. With greater vegetation coverage, the absorption coefficient of the wall increases with increasing frequencies. Therefore, it can be determined that the substrate (soil) performs well in low frequency by absorbing the acoustic energy, and the plants perform better in high frequencies through scattering the sound [8, 9].

Azkorra et al. evaluated a modular based living wall system, where measurements were carried out in a reverberant chamber and the sound absorption and sound reduction index were calculated. The measured sound reduction index ranged from 9.7 dB to 17.1 dB across one-third octave frequencies centered at 100 Hz to 5 kHz. The sound absorption coefficient ranged between 0.35 and 0.51 across the frequency bands.

Experiments carried by Wong et al. conclude that the sound absorption coefficients of living walls under investigation are higher than those of other building materials, therefore, representing an enhanced noise attenuation mechanism [9].

Davis et al., tested living wall modules solely with substrate and densely planted with ferns and showed that the most prominent outcome found was the increase in sound absorption caused by ferns for frequencies higher than 400 Hz [3]. The weighted random incidence sound absorption coefficient of the modules densely planted with ferns equaled 1.0.

Perez et al. evaluated the effect of sound absorption of two in-situ vertical greenery systems, a Green Wall and a Green Façade [10]. The Green Wall was a pre-cultivated modular based system, while the Green Façade was made with a 2-mm wire mesh parallel to the cubicle façade wall, located 25 cm away by means of metallic supports anchored to the wall. Their results agreed with those obtained by Wong et al. [9] and Azkorra et al. [7]. The acoustic performance of the two Vertical Greenery Systems (VGS) demonstrated different frequency spectra, where the Green Façade exhibited a profile much more irregular than the Green Wall.

The results obtained from the work of Horoshenkov et al. show that the absorption coefficient of plants is controlled predominantly by the leaf area density and angle of leaf orientation [8]. However, absorption coefficient for the living wall was not determined.

Lacasta et al. found the absorption coefficient of in-situ green walls to be measured at approximately 0.65, using an experimental prototype [11]. The intensity of vegetation density in the wall used was at an intermediate stage, and the noise absorption values demonstrated can be observed as average values.

Kang et al. conducted a series of measurements in a reverberation chamber to examine random-incidence absorption coefficients and scattering coefficients of vegetation by considering soil depth, vegetation coverage and leaf size, and soil moisture content [12]. Outcome attained solidified findings of References 7, 8, and 9, concerning the absorption of acoustic energy by the soil and the scattering by the plant, in addition to the increase in coverage of the vegetation and its impact on the overall absorption coefficient of the living wall across the frequency range.

Fernandez-Bregon et al. assessed the effect on sound mitigation by measuring sound levels across a bare concrete wall and one with a living wall installed by fasteners onto the concrete block wall [13]. The results demonstrated that the average decrease in dB levels was around 2-8% compared to a bare concrete block wall, providing minimal acoustic benefits for the assembly.

3 Measurements

Acoustic measurements were conducted in four chosen locations with living walls. The photos of the four locations are shown in Figure 2. Each location was visited during hours with least or no occupants using the space, for the purpose of conducting measurements to evaluate the performance of the space without human interference. Background sound levels were conducted using a Quest meter. The different acoustic metrics such as reverberation time were measured using sine-sweep impulse responses with a Bruel & Kjaer dodecahedron speaker system. **NOTE:** It must be pointed out that the measurement of RT in the 125 Hz band was dependant on the existing background levels and hence it was not possible to obtain the RT values at some of the four locations.


Location 1 Location 2* Location 3 Location 4

Figure 2: Measurement locations. *NOTE: Location 2 - Living Wall – St. Gabriel's Passionist Church, Toronto, Ontario, Canada, The Passionist Community of Canada, Owner. Larkin Architect Limited, Architect.

Location 1 is a restaurant with the living wall installed in the dining room space. The floor area of the dining room is 176 m^2, and the living walls cover a total area of 20 m^2 of the end wall. An interior waterfall is integrated between the two portions of the living wall.

Location 2, the church common area (Northex of the St. Gabriel's Passionist Church), has a floor area of 246 m^2. A

21 m^2 living wall was built on an end wall. The living wall is not accompanied by a waterfall. The overall building strives towards sustainability in the built environment.

Location 3 is a hub for promoting healthy practices for the community. The 14 m^2 of the living wall is located in the main lobby atrium of the center, with a floor area of 150 m^2 on the main level. The living wall has an adjacent waterfall.

Location 4 is the largest of all locations in floor area and total covered living wall area, with 740 m^2 and 126 m^2, respectively. The living wall is installed in the atrium of a college library. The living wall soars through four floors of the library.

3.1 In-situ acoustic measurements

All the four living walls chosen for the current research have similar construction and installation techniques. The living wall is composed of a structure that is mounted on the constructed wall, in which layers of felt are attached. The plants are inserted into the growth medium, constitute the felt with a hydroponic mechanism. A water pipe system runs behind the wall and a basin positioned at the bottom collects and recirculates the water for a continuous flow to water the plants.

The plants used are composed of mainly the large leaf type, and a mixture of different species is utilized to resemble a naturally organic ensemble.

3.2 Results and discussion

Location 1

The layout of Location 1 and the measurement locations are shown in Figure 3 below.

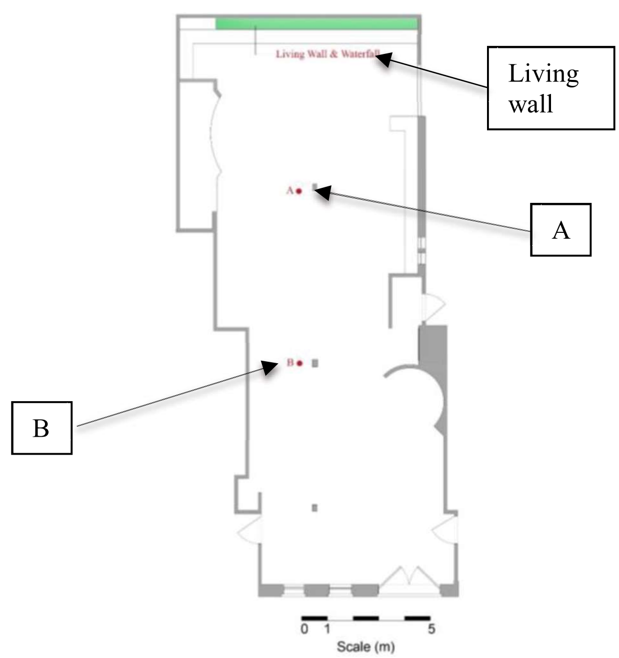

Figure 3: Location 1 floor plan.

The A-weighted average for the measured background noise level in the space at Point A is 53.7 dBA and Point B is 46.4 dBA. The impulse response test measurements were carried out with the microphone at Points A and B. Two sets of measurements were done for each point location.

The noise from the waterfall further affected the reverberation time measurements at lower frequency ranges. However, other than the lower frequency values, the reverberation time obtained from the measurements have reasonably close values to the recommended design values for the volume of the restaurant space. The reverberation results are sown in Figure 4 below.

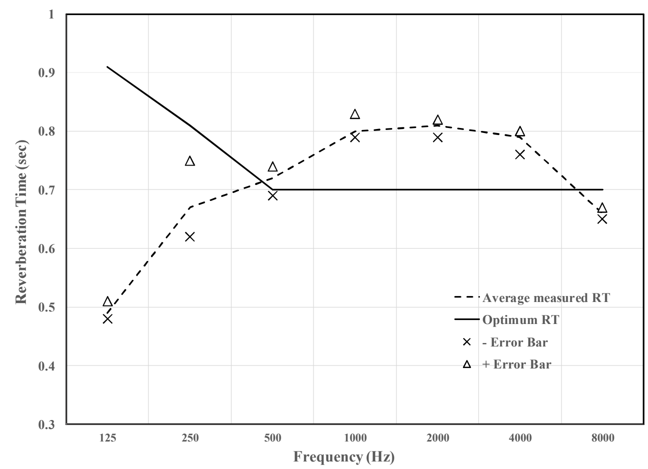

Figure 4: Reverberation time results for location 1

The obtained measurements of the clarity index (C80) show values that reach the extreme end of the acceptable range (-5 to +10 dB), where the values are 9.0 to 11.6 dB. This indicates that the quality of clarity of the sound reaching the listener is slightly "muddy".

The background noise levels across the octave band center frequencies measured in Location 1 are averaged and the RC number of the space was evaluated. The Room Criteria rating for Location 1 is RC-49 and is higher than the recommended RC-40 for a restaurant dining room space. The results are summarized in Table 1 below.

Table 1: Ambient sound levels of the living wall, location 1

Band Frequency, Hz	63	125	250	500	1 K	2 K	4 K
Location 1 SPLs, dB	61	56	48	46	45	42	34

The results of Table 1 show that the sound character is 'hissy' as the high frequency levels much higher than the acceptable RC-40.

The acoustic performance of the dining room is summarized in Table 2 below.

Table 2: Acoustic results of location 1

Acoustic Metric	Ambient sound	RT@500 Hz	C_{80}, dB
Condition	RC49 Hissy	0.7	9 to 12
Acceptability	NO	No	Yes

Location 2

The layout of Location 2 and the three measurement locations are shown in Figure 5 below.

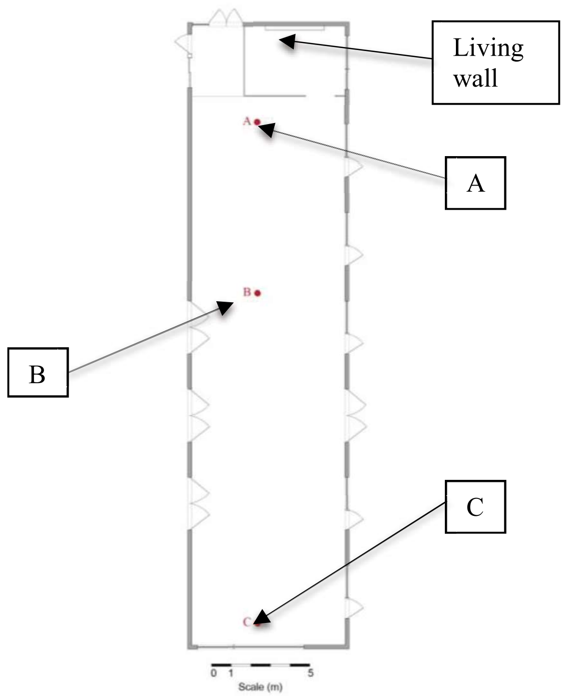

Figure 5: Location 2 floor plan - Narthex – St. Gabriel's Passionist Church, Toronto, Ontario, Canada, The Passionist Community of Canada, Owner. Larkin Architect Limited, Architect.

The background noise level was measured at 3 points (A, B and C) within the space and the average results are summarized in Table 3. The A-weighted average for Point A is 46.4 dBA, Point B is 45.4 dBA, and Point C is 45.6 dBA.

Table 3: Ambient sound levels of the living wall, location 2

Band Frequency, Hz	63	125	250	500	1 K	2 K	4 K
Location 2 SPLs, dB	56	52	47	42	40	38	27

The impulse response test measurements were carried out with the microphone at Points A and B. Two sets of measurements were done for each point location. The reverberation time results are shown in Figure 7. While the measured reverberation time of the space is higher than the optimum values for the volume and use identified for the space, the clarity of sound lies within the ideal range of -5 to +10 dB, verifying good speech intelligibility between the listener and the sound source.

As the living wall in this location was accessible for covering, two additional sets of impulse response testing were executed, to obtain values that facilitate the calculation of the absorption coefficient of the living wall. Quarter-inch MDF boards were used to cover 3.70 m^2 portion, more than 15% of the living wall's total area.

An increase in the reverberation time of the space is observed when covering a small portion of the living wall, justifying its effective acoustic absorption. Hence, it can be predicted that covering the entire wall or replacing its surface area would ultimately affect the acoustic performance of the space, further increasing the reverberation time and reducing the sound absorption.

Figure 6: Measurements with covered portion – Location 2

*NOTE: Location 2 - Living Wall – St. Gabriel's Passionist Church, Toronto, Ontario, Canada, The Passionist Community of Canada, Owner. Larkin Architect Limited, Architect.

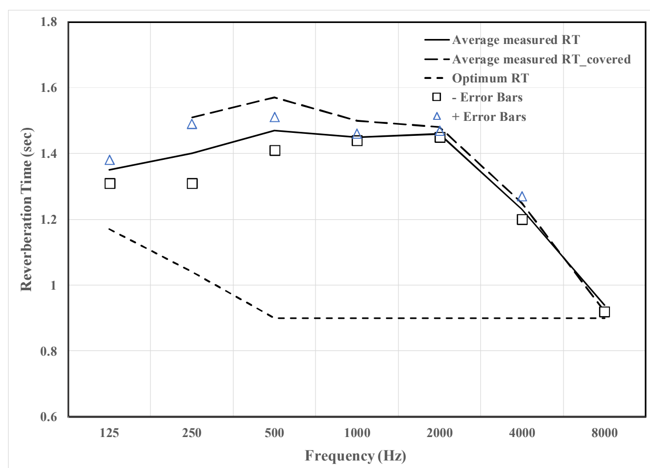

Figure 7: Reverberation time results for Location 2 (error bars for the uncovered case only are shown)

The Room Criteria rating for the church common area is identified as RC-42 and is much higher than the recommended RC-35 for this location. Because of the hard or sound reflective surfaces, such as concrete, glass, brick and floor tiles, the reverberation within the space is higher. The installed living wall area is not as significant when compared to the other surface areas, having only a minor effect on the acoustic properties of the space. The results of Table 3 show that the sound character is 'hissy' as the high frequency levels are much higher than the acceptable RC-35.

The acoustic performance of the lobby area is summarized in Table 4 below.

Table 4: Acoustic results of location 2

Acoustic Metric	Ambient sound	RT@500 Hz	C_{80}, dB
Condition	RC42 Hissy	1.45	-1 to 8.3
Acceptability	NO	➢ than 0.9 No	Yes

A portion of the living wall was covered with a hard, sound-reflecting board to assess the effect on the overall reverberation time due to the sound absorption of the living wall. The outcome demonstrated an increase in reverberation time in the experimentation with the covered portion of the living wall, verifying the sound absorption capacity of the living wall. However, due to difficulty covering the entire wall, the overall sound absorption of the living wall was not possible to determine.

Location 3

The layout of Location 3 and the three measurement locations are shown in Figure 8 below.

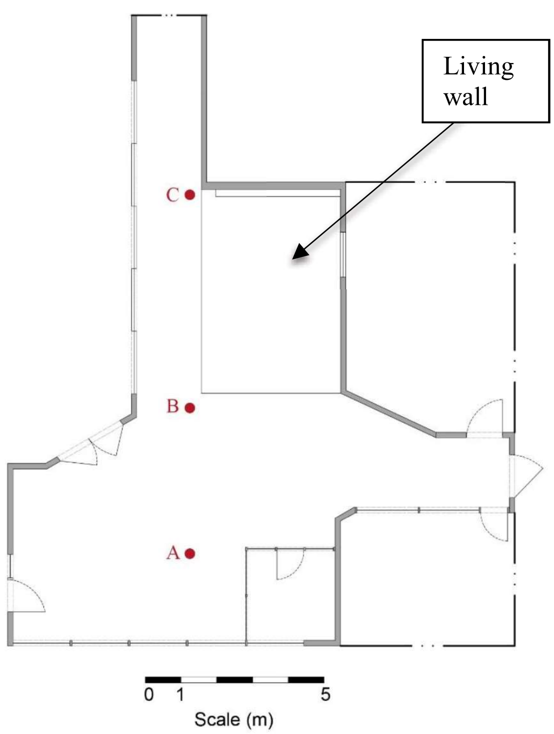

Figure 8: Location 3 floor plan

The background noise level was measured at 3 points on the main floor level and are summarized in Table 5. The A-weighted average for Point A is 56.1 dBA, Point B is 59.0 dBA, and Point C is 56.3 dBA.

Table 5: Ambient sound levels of the living wall, location 3

Band Frequency, Hz	63	125	250	500	1 K	2 K	4 K
Location 3 SPLs, dB	62	65	57	50	48	49	48

The impulse response measurements were conducted at Points B and C. Two sets of measurements were done for each point location. It is observed from the results of the acoustic measurements that the presence of the waterfall in this location led to high background noise level, affecting the measurements in the lower frequency range. The reverberation time results are shown in Figure 9. The clarity of sound within the space measured for the lower frequency ranges 125 – 500 Hz, demonstrate acceptable values, while the values in the higher frequency ranges of 2000 -8000 Hz exceed the ideal values significantly, causing the sound reaching the listener to be highly 'muddy' with minor intelligibility.

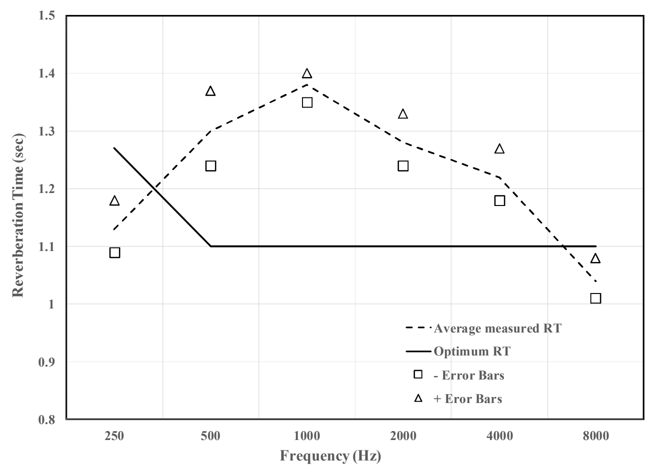

Figure 9: Reverberation time results for location 3

The Room Criteria is evaluated as RC-54 for this location, which is higher than the recommended RC-40. In this case, the effect of the waterfall had a significant impact on the results of the conducted measurements, raising the sound pressure level in the lower and higher frequency ranges much higher than the ideal values. The results of Table 5 show that the sound character is both 'rumbly' and 'hissy' as the low and high frequency levels much higher than the acceptable RC-40.

The acoustic performance of the lobby atrium is summarized in Table 6 below.

Table 6: Acoustic results of location 3

Acoustic Metric	Ambient sound	RT@500 Hz	C_{80}, dB
Condition	RC54 Rumbly & Hissy	1.3	-36 to 9
Acceptability	NO	➢ than 1.1 No	NO

Location 4

The layout of Location 4 and the five measurement locations are shown in Figure 10 below.

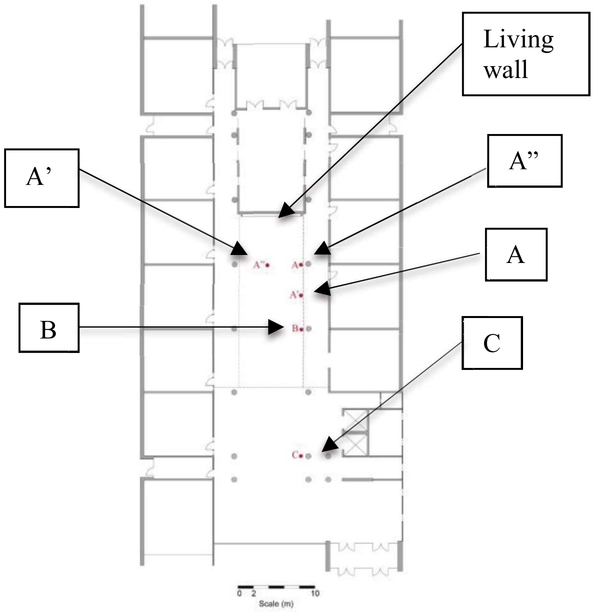

Figure 10: Location 4 floor plan

The background noise level was measured at 3 points within the ground floor area, Point A, B and C and are summarized in Table 7.

Table 7: Ambient sound levels of the living wall, location 4

Band Frequency, Hz	63	125	250	500	1 K	2 K	4 K
Location 4 SPLs, dB	54	48	46	45	41	38	34

Similar to the previous locations, the evaluated Room Criteria at RC-41 is higher than the recommended value of RC-30. The majority of the surface area of construction material are hard surfaces, or tile, concrete and glass, have a more significance impact on the overall acoustics of the space, when compared to the effect of the living wall. While the living wall in this location covers a total of 126 m^2 and its mechanical system causes an increase in the background noise, this leads to higher sound levels that need to be absorbed across the 740 m^2 floor area. The results of Table 7 show that the sound character is both 'rumbly' and 'hissy' as the low and high frequency levels are much higher than the acceptable RC-30.

The impulse response test measurements were carried out with the microphone at Points A, A' and A". Two sets of measurements were done for each point location. The reverberation time results are shown in Figure 11. The clarity values demonstrate higher values than the ideal design recommendation, although the average measured RT is lower than the optimum RT. As previously mentioned, having a lower reverberation time will lead to an increase in the clarity of the sound, however that is applicable to a certain degree. The ideal values of RT ensure that the sound reaching the listener has a well-defined clarity.

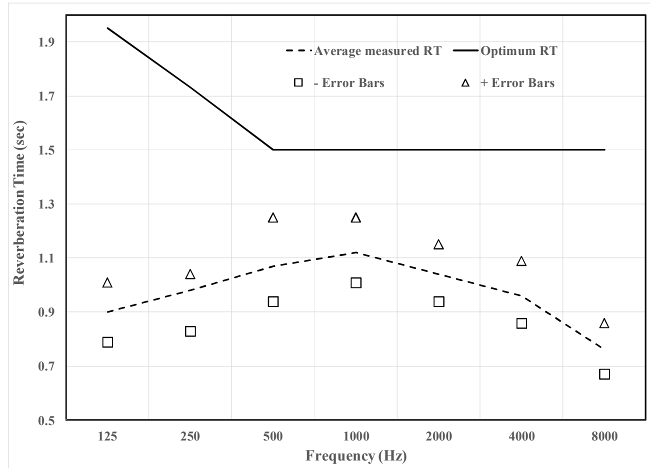

Figure 11: Reverberation time results for location 4.

The acoustic performance of the lobby atrium is summarized in Table 8 below.

Table 8: Acoustic results of location 3

Acoustic Metric	Ambient sound	RT@500 Hz	C_{80}, dB
Condition	RC41 Rumbly & Hissy	1.5	6 to 21
Acceptability	NO	➢ than 1.1 No	NO

The results presented so far for, the four locations, showed that the living walls, as applied, did not provide acceptable acoustic comfort to the four spaces. As a final exercise, the living wall was used as absorptive wall covering to a highly reverberant gallery space at Ryerson University to determine if the reverberation time can be adequately reduced to an acceptable level. The results are discussed below.

4 Application

The Paul Crocker Gallery, shown in Figures 12 and 13, is a multi-purpose space, located at Ryerson University's Department of Architectural Science. In addition to being used, primarily, as an exhibition space, the gallery is used as a 'Crit' space where the review of student's work takes place with about 20 people. The Gallery is used in the current case study, to evaluate the acoustic performance of the space to be used as a critique space, where speech intelligibility becomes a significant acoustic parameter to be achieved. The gallery is constructed with concrete ceilings, gypsum/plywood composite partition (with 4" airgap) walls with felt covers at the entrance, floor tiles, and three glass doors. The acoustics of the gallery varies with the density of occupants in the space, as the presence of people affect the performance of the room as well.

The objective of the acoustic simulation of the gallery is to increase the overall sound absorption of the space, ultimately reducing the reverberation time. The main acoustic metric applied for the gallery results is the reverberation time (RT).

Figure 12: Front view of Paul Cocker gallery

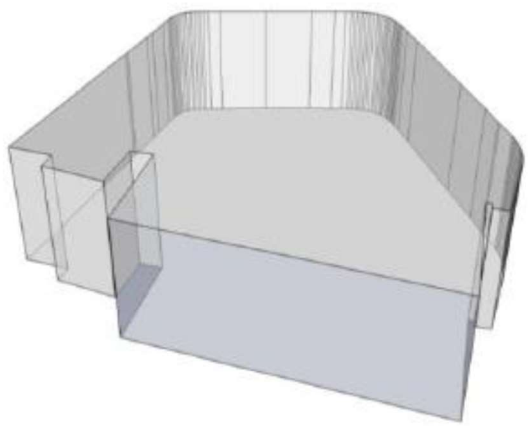

Figure 13: 3D sketchup model of Paul Cocker gallery

The acoustic absorption coefficient values for typical building envelope materials were obtained from Reynolds [14]. The absorption values for the living walls were obtained from Thomazelli et.al. [15]. The room acoustics software, 'ODEON' was used for simulations of the gallery [16]. The optimum reverberation time for the gallery space with a volume of 350 m^3, and requirements for high speech intelligibility would be around 0.5 seconds at 500 Hz.

The first simulation was undertaken to validate the bare gallery results to that of the measured reverberation evaluated with a dodecahedron source located near the central column seen in Figure 12. The absorption coefficient values used for the simulation, including that of the living wall (from Reference 15) are shown in Table 9.

The living wall was simulated within the model of the gallery to evaluate the installation area necessary to assess the prospect of using it as a passive sound absorption mechanism within an interior space, such as that of the gallery, to provide the required acoustic performance for occupant use. Three different trials were carried out, simulating various living wall areas installed within the space. Figure 15 below demonstrates the average measured reverberation time compared with the 3 trials (16.5 sq.m, 25.12 sq.m, and 45.94 sq.m of living wall) and the optimum reverberation time for the space. Figures 14 and 15 also include measured values of reverberation times using a sine-sweep signal and the Bruel & Kjaer dodecahedron speaker systems.

Table 9: Absorption coefficients of gallery surfaces

Band Frequency, Hz	63	125	250	500	1 K	2 K	4 K
Ceiling	.01	.01	.01	.01	.02	.02	.02
Floor	.02	.02	.03	.03	.03	.04	.07
Walls	.22	.4	.07	.06	.05	.3	.35
Glass	.35	.35	.25	.18	.12	.07	.04
Felt	.08	.08	.08	.3	.6	.75	.8
Living Wall	.01	.1	.1	.8	.9	.9	.9

The validation results are shown in Figure 14 below.

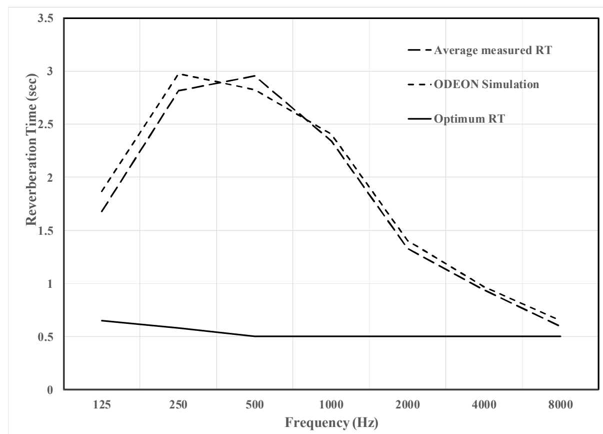

Figure 14: Validation of the bare gallery simulation

It can be seen from Figure 14 that the gallery simulation is satisfactory and additional simulations with the living wall can be undertaken with acceptable precision. The results also show that the gallery is highly reverberant across the frequency bands up to 4000 Hz.

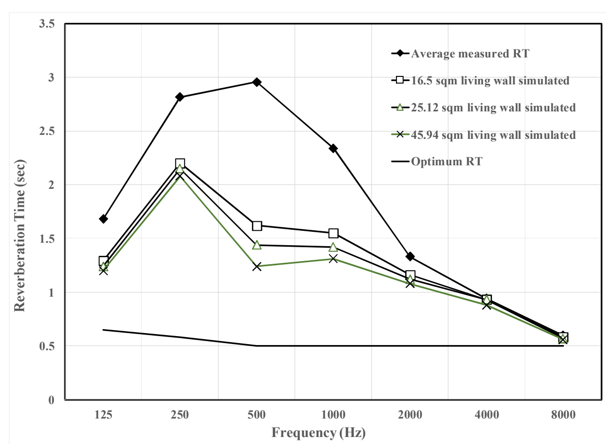

Figure 15: Reverberation time with three simulations.

The results of Figure 15 showed that the living wall area was not sufficient to provide the required reverberation time. Finally, the entire wall area of the gallery was covered with the living wall and the results are presented in Figure 16 below. Integrating the living wall within the Gallery space to provide acoustic comfort and high speech intelligibility is not achieved through the simulation, where the entire available wall area of 111.87 m^2 is covered with the living wall. The application in the gallery space requires an increased area of the living wall due to the already poor acoustic conditions of the space, where the existing wall surfaces were not sufficient. In addition, the average absorption coefficient of the living was not high across the frequency spectrum [15].

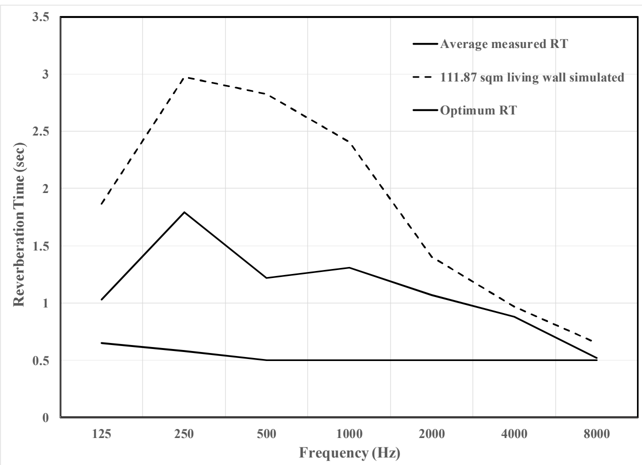

Figure 16: Reverberation time of the final Simulation

The final simulation, shown in Figure 16, used the entire available wall are of 118 sq.m. Even then the reverberation time of the galley did not meet the required optimum reverberation time.

5 Conclusion

The aim of this paper was to evaluate the potential of integrating living walls as passive interior absorption techniques to provide indoor acoustic comfort as the necessity of acoustic comfort reflects on the occupant productivity levels within the space [3]. The application of living walls was assessed through a series of acoustic measurements and experimentations carried out on in-situ living walls.

The absorption coefficient used for the simulations was obtained from the experimental results of Reference 15.

The RC rating evaluated for each of the four sites showed a higher value than the recommended design guideline for the spaces. The noise generated from the mechanical system of the living wall and the presence of the waterfall in some of the cases need to be attenuated, in order for the living wall to provide the acoustic comfort, and its sound absorption be at full potential.

The application of the living wall within the case study simulation did not achieve the desirable guideline acoustic parameters, which includes the reverberation time of 0.5 seconds to be achieved at 500 Hz within the space.

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