Accuracy of computer simulation software using hybrid models for microscale urban environments

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Abstract

To investigate environmental acoustics in large urban areas, macroscale simulation software uses calculation methods based on simplified algorithm models. However, in order to examine microscale acoustics environments such as a street or a square, those simplified algorithms may not be enough. The technological advances of the last decades in acoustic simulation software based on hybrid calculation methods, such as raytracing and image source, now allows new experimentations in urban environments. Several researches have shown the reliability of results of hybrid models when compared to in-situ measurements in closed spaces. Hybrid calculation models may also be used to simulate small open urban environments, however there are few studies showing the reliability of the results. This research aimed to investigate the accuracy of hybrid computer calculation models in microscale urban spaces. An open space with an “L” shaped edification was selected in order to provide proper reflections for the study. Acoustics measurements in situ were done using the method of impulse response. Computer models were also created using software Odeon v.13. Accuracy was evaluated comparatively using JND values of acoustics parameters as reference. Analyzed parameters were T30, EDT and SPL. Energy-Time curves and Impulse Responses were also compared. It was found that parameters have a good agreement between simulated and measured results, especially in mid-high frequencies. There is also a position dependent variation in T30 due to the detachment of the building and approximation to the free field. Results showed that hybrid models based software can be successfully used in the acoustic characterization of microscale urban environments.

Keywords: environmental acoustics, urban space, microscale, hybrid models
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1 Introduction

The investigation of macroscale environmental acoustics is usually done with calculation methods based on simplified algorithm models [1]. One of the justifications for such methodological approach is the great geographic dimension of a macroscale study, such as a city or an entire neighborhood. However, in order to examine microscale acoustics environments, those simplified algorithms may not be enough.

It can be considered a microscale urban space, all small size urban spaces such as, streets, esplanades, squares, gardens, patios among others. Due to their reduced size it is reasonable that such spaces need more attention and therefore a higher precision for their investigations. Recent research in microscale urban spaces have been using different approaches based on image source and raytracing methods, which are generally used for room acoustics investigations. Both methods are grounded in geometric acoustics, and simplistically, they are based on the principle of a sound wave that propagates through the shortest path between source and receiver in a straight line, or a “ray”. The reflections of that ray may be considered specular or diffuse [2] [3]. Such calculation methods may be used separately or combined, where part of the simulation is calculated by the image source method and part with raytracing method. Those combined methods are called hybrid methods [4].

Round robin researches have shown the reliability of results of hybrid models when compared to in situ measurements in closed spaces [5] [6]. However, there are few studies showing the reliability of results of such methods when compared to in situ measurements in open urban spaces [7] [8] [9]. Such lack of studies is not trivial. Some of the acoustics interfaces of sound propagation in urban microscale spaces, such as a square, may be slightly different when compared to a closed space such as a concert hall. Relations of free field and reverberant field, for example, may lead to very different acoustic behavior when comparing open and closed spaces.

One of the possible reasons for the low number of comparative researches in open spaces is the difficulty to perform acoustic measurements using methods such as the impulse response without a significant interference of background noise. Therefore, several microscale researches appropriate methods applied to hypothetic scenarios. Hence, to contribute to fill this gap, this research aimed to investigate the accuracy of hybrid computer calculation models in a real microscale urban space.

2 Method

It was investigated the accuracy of results from the comparison between measurements of an actual urban space using the impulse response technique and a computer simulation of the same space using Odeon v13 software. Acoustic parameters analyzed were Reverberation...
Time (RT), Early Decay Time (EDT) and Sound Pressure level (SPL). The essential steps of this research, such as site selection, measurements and virtual model simulation, are detailed as follows.

2.1 Site selection and measurements

The first fundamental step of this research was to determine the actual urban space. The chosen place would have to necessarily attend minimum requirements such as a low background noise in order to not compromise measurements results. However, even the quietest urban space is problematic for impulse response measurement due to the inherent background noise of voices, horns, traffic, alarms, engines, compressors and so on.

In that way, some places found at university campuses allow a good relation between an urban space and a low noise environment. Usually such spaces are of great geographic dimensions, capable of reproduce conditions of an entire neighborhood and they are usually unoccupied during weekends, especially on Sundays, with no educational or recreational activities, being a perfect site for acoustic measurements without the interference of loud background noises. The parking lot of the School of Civil Engineering, Architecture and Urban Design (FEC) at University of Campinas, UNICAMP, is such space and therefore it was chosen to represent an actual urban space in this investigation. The left part of Figure 1 compiles the morphological characteristics and predominant materials of the chosen space.

The configuration of the buildings provides an “L” shape which is able to provide the proper reflections for this study. Acoustics measurements using the impulse response technique were done at the chosen site. Measurements were performed with Dirac room acoustic software using an exponential sweep of 10.9s. Parameters analyzed by frequency in octave bands from 125Hz to 4000Hz were Reverberation Time (T30), Early Decay Time (EDT) and Energy Time Curve (ETC). Impulse to noise ratio (INR) were checked in all measurements to be above 40dB.
Sound Pressure Level (SPL) was measured using a pink noise signal in an omnidirectional sound source. Background noise was also measured with a sound level meter type 2270 from Bruel & Kjaer. There was no need to compensate background noise since obtained values were below 10 dB from the source signal for the analyzed frequency bands. Temperature and air humidity were included in the computer models and were respectively 28.3°C and 61.5%.

An omnidirectional speaker was placed 1.6m high from the ground at a plateau, in higher landing place compared to the receivers, which were about 2.1m below that baseline. Receivers were positioned in ten different locations at a height of 1.5m (Figure 1). Five receiver points (R1-R5) are located every 10m from the sound source in line, parallel to the higher buildings at the lower landing place. Remaining points (R6-R10) were located at the same radius distance of the other 5 points taking into account the position of the sound source. Those points were located diagonally to the higher buildings, projecting them to an open field.

2.2 Virtual models and simulations

Virtual models of the urban space were made and calculated using a hybrid calculation method, ray tracing and image source, at Odeon 13 Room Acoustic Software. Software like Odeon is usually used for room acoustics modeling of theaters and concert halls. One of the recommendations for such software is to reduce geometry of models to achieve good results [4]. Due to the lack of comparative studies between geometry hybrid methods applied to urban microscale spaces, two models were built, one with a detailed geometry and the other with a simplified one. The first model considered all the architectonic details found in the buildings like projecting pillars, concrete beams, brise-soleils and galleries. The second model was built by usual recommendation for room acoustics, with a simplified geometry. This simplification was compensated with the increase of the scattering coefficient, with a value of 0.7 for the simplified surfaces.

Due to these differences in geometry, it was necessary different software setup configurations in order to reach a good agreement when calibrating measured and simulated results. This methodological option of different setup configurations do not consist in an independent variable that would compromise accuracy, because the established reference parameters for the accuracy are the measured values of the actual urban space. And therefore, to adjust the setup it does not matter if the geometry is detailed or simplified, because for both models the objective is to get simulated results as close as possible to the measured results found at the real investigated site.

Each model was calibrated by inserting the measurement impulse response audiofiles. This process is done with the “investigations of simulations parameters” tool, which will provide the best setup configuration to adequate simulated results to measured ones. Parameters investigated to be adjusted were the optimal number of early and late rays, and transition order (T.O.) for each model. Figure 2 shows the average error in just noticeable difference (JND) for five transition orders (0 to 4) as a function of the number of rays using as reference acoustic parameters RT, EDT and SPL at both models, detailed and simplified.
At the detailed model, considering a variation of T.O./Late rays, with a fixed number of early rays automatically given by the software, the smallest average error found was approximately 4.2 JND when T.O. = 1 and late rays = 5000. When investigating a variation of T.O./Early Rays with a fixed number of 200000 late rays, the average error was even smaller, 3.6 JND with T.O. = 3 and early rays = 100. Thus, this last setup was used to the detailed model due to the smaller possibility of average error in JND between measured and simulated results.

At the simplified model the smallest average error in JND for both variations, T.O./Late rays and T.O./Early rays, were obtained when T.O. was 0. The number of late rays with the smallest average error was 100000, with a result of slightly over 2.5 JND. The number of early rays seemed to be steadier, and therefore it was allowed automatically determination of their number by the software at the setup configuration. The best value established by the software was 0 early rays. Final setup configurations for the simplified model were T.O. = 0, early rays = 0 and late rays = 100000.

Both transition orders (T.O.), from the simplified model (T.O. = 0) and the detailed model (T.O. = 3), may be considered low [10]. The increase of T.O. does not necessarily means a better result, because the transition order only determines at which reflection order the software changes from the early image source method to the late ray tracing method [4].

Therefore, the best performance at the simplified model where T.O. = 0 means that there are not relevant surfaces to early reflections acting at the image source method and that the results may be better due to the predominance of the ray tracing method. One of the reasons for this
A particular setup result is the large amount of 100% absorbent surfaces. The surfaces in the model that represent the open sky received 100% of absorption coefficient in all frequency bands, allowing a smaller number of possible images to the reflection of sound energy in the model. This reflected energy reduction is also caused by the reduction of the geometry details in the building, which is compensated with the increase of the scattering coefficient, 0.7 for all simplified surfaces. The hybrid models used for the calculation, the reduced geometry associated to the large amount of absorptive surfaces of the open sky drives to the predominance of the ray tracing method, justifying the low transition order.

At the detailed model, even with the same large amount of full absorbent surfaces representing the open sky, there is a larger amount of reflective surfaces due to the large amount of architectonic details in the buildings, allowing the 3rd order reflections have an influence for the image source method.

Other setup configurations such as source and receiver position and sound power source by frequency band were the same for every model. The same setup was also used for in situ measurements. Absorption coefficient of prevailing materials (grass, interlocked concrete floor tiles, painted concrete hollow blocks, glass windows and metal doors) were established based on the materials’ library in the software and some of them (concrete hollow blocks, interlocked floor tiles and grass) were optimized by the genetic algorithm tool in Odeon [4]. All calculations were made in precision mode.

3 Results and discussion

The accuracy of both studied models were analyzed as a function of the error degree related to the JND for each acoustic parameter according to the procedures proposed by Bork [10]. Equation 1 was applied to the average of the 10 receiver points. The closest to zero is the value of “Error”, the more accurate is the parameter.

\[
Error = \frac{|AP_{measured} - AP_{simulated}|}{JND}
\]

Where:
- \(AP_{measured}\) is the average measured value of the analyzed acoustic parameter
- \(AP_{simulated}\) is the average measured value of the analyzed acoustic parameter
- \(JND\) is the subjectively just noticeable difference for the analyzed acoustic parameter

Figure 3 shows the error in JND of acoustic parameters T30, EDT and SPL for both models simplified and detailed one. For T30 and EDT the tendency of the curve is the same for both models. The error difference, however, is meaningful with a variation of more than 6 JND at mid frequencies for EDT and around 4 JND at high frequencies for T30. For EDT and T30 the detailed model had a better accuracy performance when compared to measured results. T30 showed an error of less than 1 JND at frequencies of 1000Hz and higher. EDT showed an error of less than 1 JND at 500Hz and 1000Hz. When analyzing SPL, both models presented a low
error degree, below 2 JNDs. Different from T30 and EDT, the simplified model had smaller errors in JND for SPL parameter.

Source: The authors.

Figure 3: Error in JND as a function of frequency for T30, EDT and SPL.

Facing the good performance of the simplified model in SPL, further analyzes were made in order to better understand this behavior. Therefore, it was analyzed the error in JND for each receiver point at the frequency of 1000Hz. This particular frequency was chosen because it was the most accurate in general error analysis (Figure 4). Due to the way the receiver points were distributed at the studied space, located at the same radius distance from the source (Figure 1), the graphics at Figure 4 are segmented in two parts. The first part shows the receivers from R1 to R5, closer to the buildings. The second part shows the receivers from R6 to R10, more distant from the buildings and more likely to reproduce an open field. When analyzing the error in JND of SPL at 1000Hz, it can be seen that the error in JND are below 1 JND on most receivers at the detailed model. The simplified model presented most of the points over 1 JND.

The inversion seen at the predominance of errors in JND at SPL between the detailed and simplified model (Figure 3) and the analysis of error by receiver point (Figure 4) may be caused by the greater amount of sound energy due to the increase of the scattering coefficient of the simplified model. The increase is necessary to fill the gaps between the stronger reflections and to get a smoother decay, more equivalent to the measured curves [11]. This can be seen at the energy time curve (ETC) of receiver point R2 (Figure 5). This indicate that the general error in JND of the SPL at the simplified model seems to be, in average, closer to the measured values, but when analyzing point by point, the detailed model still has the best accuracy.

The point-by-point error analysis for T30 showed that there is less possibility for error at receiver points closer to the buildings (R1-R5) than at receivers far from the buildings, more at the open field (R6-R10) and tending to behave more like an free field sound propagation area. For EDT, the opposite occurred, probably to the reason that EDT is more a location dependent parameter, thus receiver points closer to the buildings had higher errors. In general, the point-to-point frequency analysis of error in JND showed a better accuracy of the detailed model.
A last analysis approached the absolute values for all parameters as a function of receiver point for the frequency of 1000 Hz between both models and in situ measurement. Figure 6 shows that the measured values of the farthest receivers from the sound source have a tendency to increase, both on T30 and EDT until they reach an area close to a free field situation, which makes their values drop. The detailed model had a better agreement when compared to the measurement, with the same tendency of its curve, different from the simplified model. Also, at the detailed model, the insertion of architectonic details improved the relation of results from receiver points close to the buildings (R1-R5), while receiver points close to the free field situation (R6-R10) had their values more distant from measured values.

The increased values of T30 along distance up to a point may be linked to the late reflections provided by the buildings before the point where free field prevails. The microscale urban space shows a similar behavior for T30 and EDT, which is position dependent. T30 seems to be highly influenced by the urban morphology context around it and therefore highly influenced by the shape of buildings details.
The analysis of the absolute values of SPL as a function of receiver points in the frequency of 1000Hz seems to confirm that the exchange of a high scattering coefficient instead of the details of the building did fill the gaps of the impulse response energy, increasing the sound pressure level in all receiver points when compared to the detailed model. However, variation is still small between the simplified and detailed models, and the behavior of both is stable.

4 Conclusions

This research aimed to investigate the accuracy of hybrid computer calculation models in a real microscale urban space through the analysis of the error in JND. Two models were investigated, one with a simplified geometry, the other with a detailed one.

It was possible to identify that the use of room acoustic software using hybrid method for parameter calculation can also be used with a good performance in the representation and analysis of microscale urban spaces. However, some recommendations applied to room acoustics are not necessarily the same for open urban spaces: even with the compensation of increasing the scattering coefficient to compensate the simplification of the model, for open urban spaces the detailing of the model presents better accuracy of the acoustic parameters when compared to real measurements.

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