

Creating an urban street reverberation map

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Summary

Reverberation increases sound levels in streets and adversely influences the perceived sound field quality. To assess this, it is studied if "reverberation maps" could be useful. Knowledge on street reverberation could be used as a valuable alternative to physical methods such as ray tracing, beam tracing etc. to obtain an estimate of expected noise levels and sound quality indicators. But also on itself, a map showing the reverberation times of the streets could be very informative.

In this work a reverberation map of some neighborhoods in Ghent, Belgium, is produced. To enable fast determination of EDT and $T30$ on different positions in a multitude of streets, a dedicated measurement set-up is mounted on the roof of a car. It is investigated to what extent interpolation between measurement points and extrapolation to other areas is possible on the basis of the geometry and architectural aspects of the street and surrounding buildings, features that are available from geographical information layers.

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1. Introduction

Large percentages of the urban population are exposed to high traffic noise levels, causing annoyance[1], sleep disturbance[2] and other negative health impacts[3].

To estimate noise exposure, noise maps are a useful tool. Typically, noise maps are estimates of the long-term averaged noise levels and are commonly based on numerical calculations using geometrical acoustics. In a highly complex city lay-out, a high number of sound reflections occur, which have to be taken into account when accurately predicting the noise level. However, the maximum number of reflections is chosen to be low and fixed to limit computation times. In this way accuracy is lost as the noise level is only calculated based on the first few reflections. To have an estimate of the influence of later reflections, knowledge of the reverberation time EDT and $T30$ could be of help. Furthermore, as these parameters describe the sound energy decay, a map depicting the reverberation time in the city-streets, combined with knowledge on the traffic pass-by and noise sources in those streets, is most useful to identify problem cases.

Other parameters related to room acoustics could also be used. Examples are center time T_s , which

indicates the point of gravity of the impulse response energy, and clarity C_{80} , which gives the ratio of early sound energy to reverberant sound energy[4].

Measurements of such parameters are based on an in-situ measurement of the impulse response[5]. In order to obtain a high number of impulse response measurements in a reasonable time, a dedicated measurement set-up is proposed, which allows fast and mobile measurements of the impulse response and reverberation time in streets. However, even the measurement of the impulse responses with the mobile measurement system is time consuming. It thus remains difficult to measure the impulse response of a high number of locations in a multitude of streets, prior to the construction of a noise map. Therefore it will be checked if a correlation can be found between different geometrical and architectural properties and acoustical parameters.

2. Measurement set-up

The determination of the acoustic parameters is based on in-situ measurements of the impulse response. For these impulse response measurements an omnidirectional loudspeaker is needed, which reproduces an excitation signal. The response to this signal is then recorded by one or more omnidirectional microphones. As these measurements have to be conducted on a multitude of different positions, while the urban traffic should be disturbed as little as possible, the set-up



Figure 1. Mobile measurement set-up. An omnidirectional speaker is mounted on the roof of a car. An omnidirectional microphone Type 4189 of Bruël & Kjær is mounted in front and behind the speaker at 2.5 m distance.

should enable both mobile and fast measurements.

For this reason it is decided to build the set-up with omnidirectional speaker and microphones on the roof of a car. The loudspeaker is placed near the middle of the roof, while two Bruël & Kjær omnidirectional microphones Type 4189 are placed at a distance of 2.5 m at both sides of the speaker (fig. 1). In this way, two impulse response measurements can be conducted simultaneously. The excitation signal used for the measurements is an exponential sweep of 30 s and covers the 63 Hz to 16 kHz octave band. With this test signal, each frequency is excited at a different moment in time, while each octave band contains an equal amount of energy. This measurement cycle is repeated minimum three times at each location. In this way disturbed measurements can be filtered out.

While performing the measurements, the position in the street is logged and architectural aspects are noted. The street geometry (length, width and height) was found in GIS databases.

2.1. Signal processing

From the recorded sweep the impulse response can be extracted by spectral division with the emitted sweep. The resulting impulse response is analyzed in octave bands and for each band filtered impulse response a levelfunction is calculated, describing the energy decay in function of time. Since the measurements of the impulse response are conducted in an urban environment, they are likely to be contaminated with noise. This results in a lower signal-to-noise ratio and thus limits the decay of the sound produced by the loudspeaker (and levelfunction) in the street. Choosing an appropriate test signal such as an exponential sweep, high emission levels and repetitions can partly counter this. Other techniques to lower the influence of the background noise include subtraction of a mean squared average of the noise from the band filtered response and truncation of the impulse response, of which the truncation point is determined as the

crossing point between the decaying slope and averaged noise level of the time-averaged band response[6]. From the processed band levelfunctions the reverberation time can then be calculated by using the slope of the best fitted line between $[0\text{ dB}, -10\text{ dB}]$ for EDT and $[-5\text{ dB}, -35\text{ dB}]$ for $T30$.

2.2. Influence of the car

The measurements of the impulse response and related parameters are valid only if the influence of the car and set-up on the results can be ignored. Therefore, reference measurements are conducted in an open rural area with no reflecting boundaries, except for the soil. Five successive measurement cycles are conducted and the reverberation time is analyzed, which should be significantly lower than the reverberation measured in the streets. Fig. 2 depicts the resulting mean reverberation time EDT and $T30$. These results are calculated from an average of five measurement cycles. A comparison is made between results from the microphone at the back and front. As can be noted from fig. 2(a), the EDT is lower than 0.07 s at octave bands higher than the 63 Hz octave band. The standard deviation from the mean value is negligible and the results from both the back and front microphone are alike. However, for the 63 Hz octave band, the deviation and difference between microphones is higher. Investigation of the used loudspeaker learns that these frequencies are not accurately reproduced. This octave band will thus be omitted.

For the $T30$ (fig. 2(b)), somewhat higher values are found. However, when comparing to street measurements, these are still sufficiently limited. The highest value (at the 125 Hz octave band) is near 0.26 s . The standard deviation is larger than for the EDT , but still acceptable. Some difference in $T30$ between front and back can be observed, but the difference between both microphone positions is limited ($\Delta_{max} \approx 0.09\text{ s}$ at 500 Hz).

In general the influence of the car and measurement set-up on the resulting reverberation time is negligible compared to reverberation times measured in most street configurations. However, more open streets, with gaps between buildings, could have very low reverberation. Care should be taken to interpret such results, so a selection procedure will be built in to detect reverberation measurements which are not significantly different from the reference measurements.

3. Urban street reverberation measurements

In order to produce a reverberation map of a city and investigate whether the reverberation can be correlated to architectural and geometrical parameters, the reverberation is measured at 77 points in Ghent, Belgium. Streets of various width, building height, length

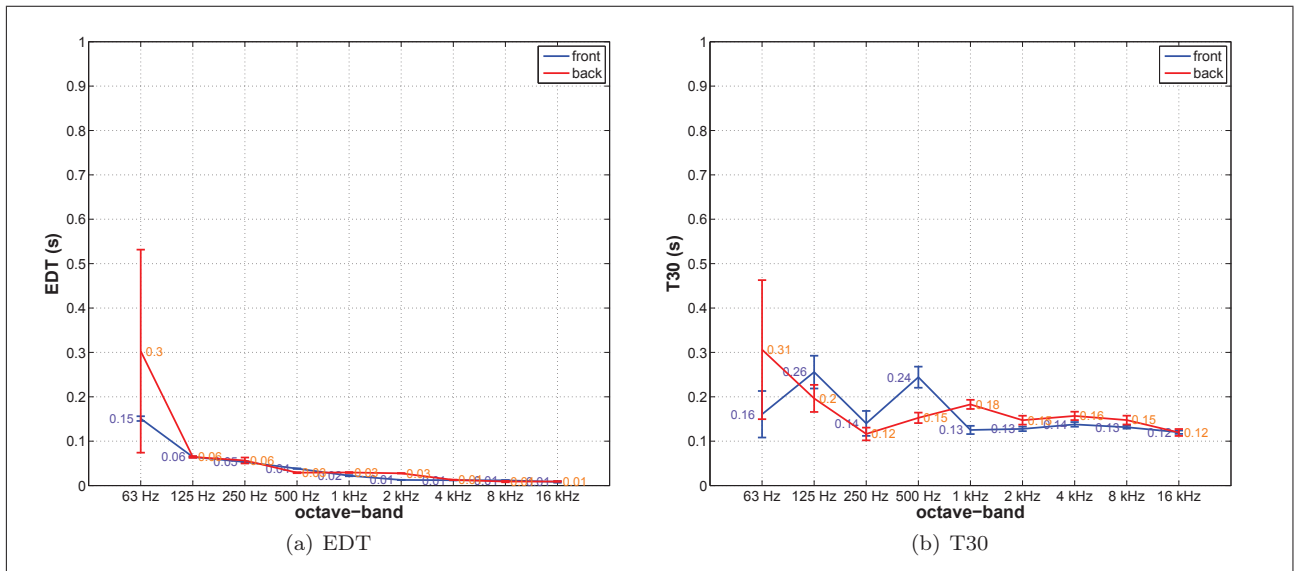


Figure 2. Measurement of the mean EDT and $T30$ for the reference situation, based on five measurement cycles. In blue the results when using the front microphone, in red the results for the microphone at the back. The standard deviation from the mean value is also indicated.

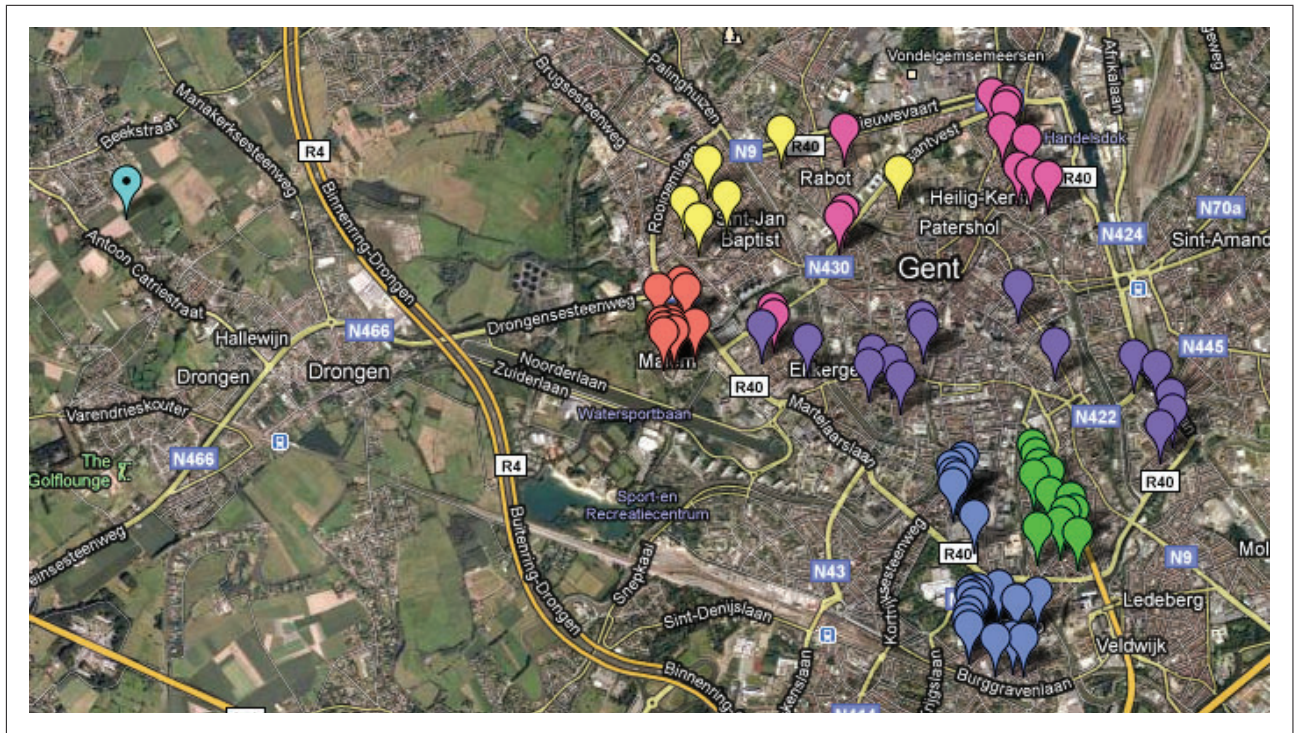


Figure 3. Geographical map indicating the different locations (77) measured in the city of Ghent. The marker at the left indicates the reference measurement position. The colors indicate different measurement dates.

and architectural styles were selected and for each of the locations, the reverberation EDT and $T30$ is measured. Fig. 3 shows a map of Ghent with the different measurement positions and also the location of the reference measurement position.

Fig. 4 resp. fig. 5 shows a reverberation map of the EDT resp. $T30$. A difference is observed in the course of EDT and $T30$. For the EDT a lower value is measured in the city outskirts. Streets in these areas are

typically wider and detached housing is more common. In the city-center, the reverberation increases. $T30$ is a less sensitive parameter than EDT , as little differences are observed between measurements at center areas and outskirts. These maps however only depict the reverberation at discrete measurement points within streets.

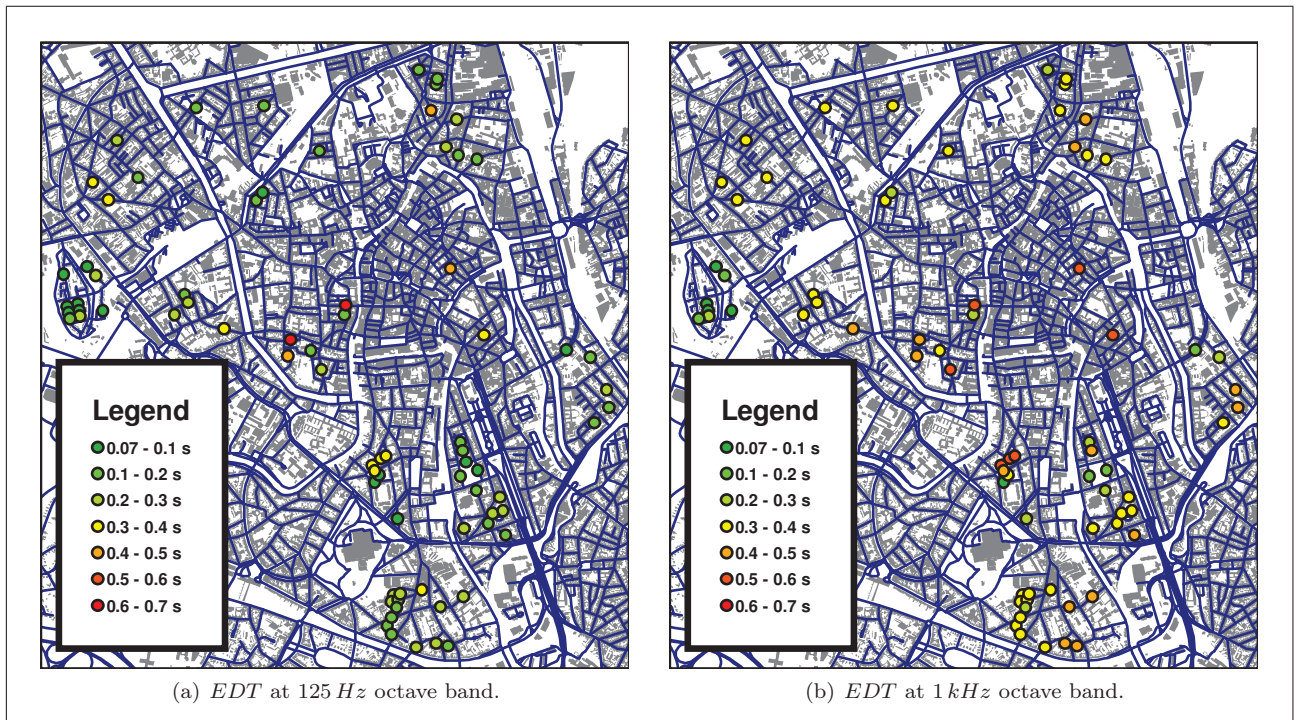


Figure 4. Reverberation map of Ghent for *EDT*, measured at the 125 Hz and 1 kHz octave band.

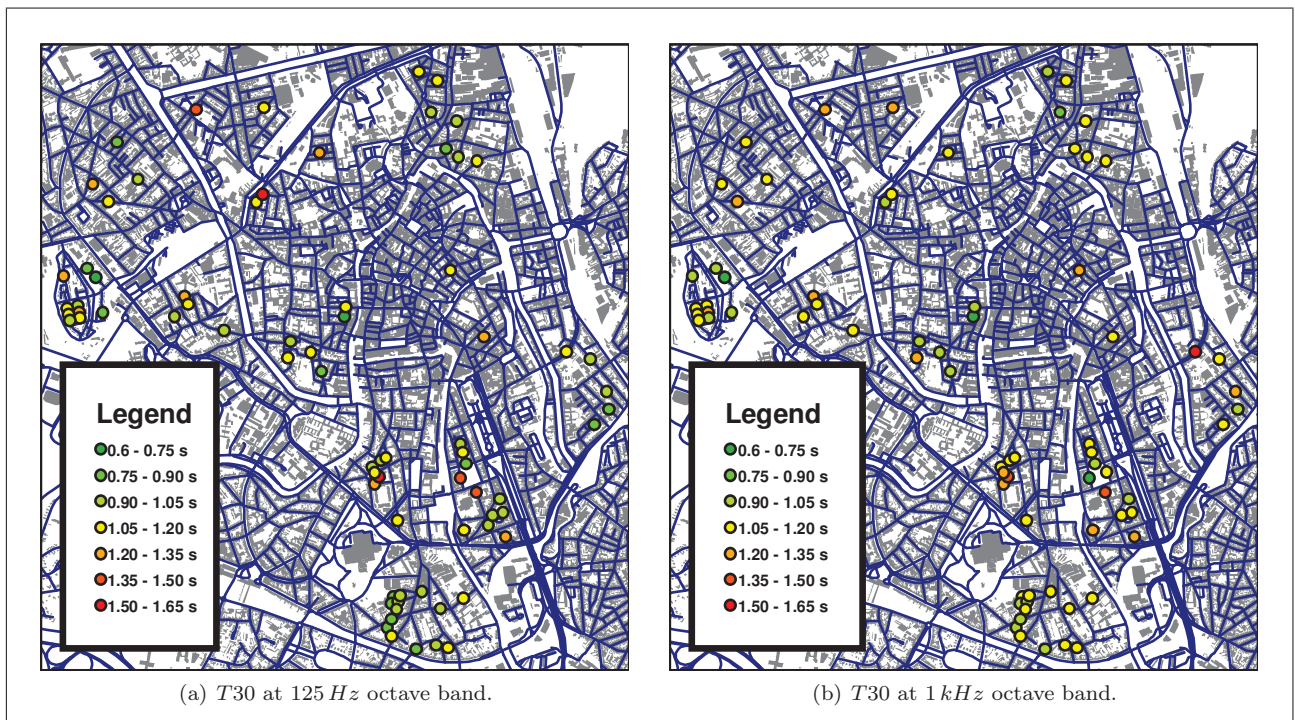


Figure 5. Reverberation map of Ghent for *T30*, measured at the 125 Hz and 1 kHz octave bands.

3.1. Correlation analysis

Rather than measuring the reverberation at a huge number of discrete locations, a time consuming work, it can be investigated to what extent the reverberation time could be calculated in function of the geometrical and architectural parameters. If this would be the

case, a reverberation map with higher resolution could be created, based on simple parameters. Therefore, the reverberation time is plotted in function of street width, height, length and height-width ratio. In fig. 6 the correlation between *EDT* and the width resp. height-width ratio is shown for the 125 Hz and 1 kHz

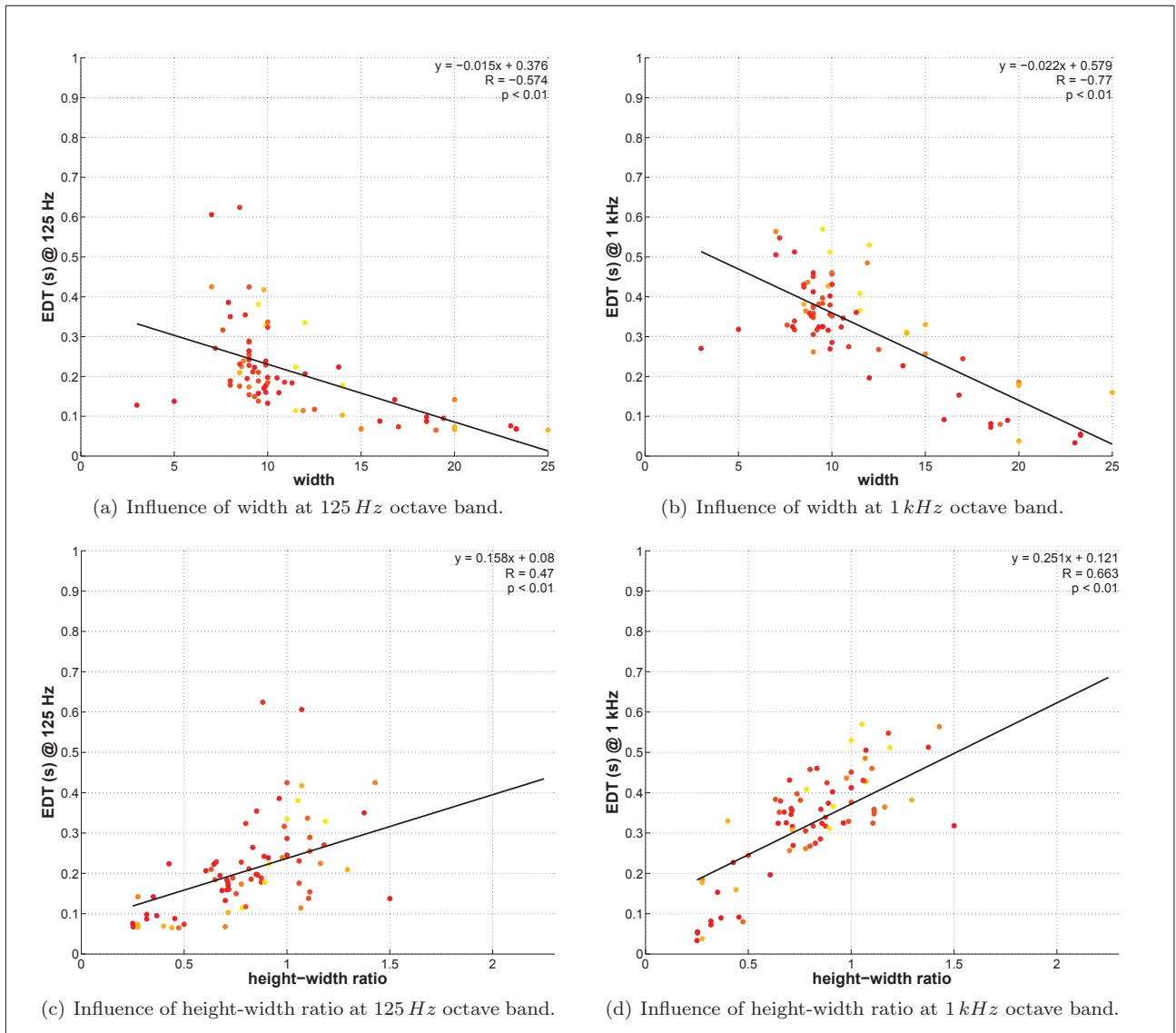


Figure 6. Correlation analysis of EDT at the 125 Hz and 1 kHz octave bands in function of width and height-width ratio. The fitted line is indicated, as well as the correlation coefficient and significance. The color scale indicates the amount of facade roughness, with yellow meaning many irregularities and red meaning little.

octave band. It is seen that EDT correlates negatively with the width. As the street width increases, energy is less contained in the street, so the EDT decreases. The EDT correlates positively with the height-width ratio. The higher this ratio, the more the street can be seen as a street canyon, the more the sound energy remains in the street. These correlations become higher as the frequency rises. The measurements show that EDT is not correlated with the length of the street (not depicted).

In fig. 7 the correlation between $T30$ and the width resp. height-width ratio is given. The figures show a small positive correlation with width and a small negative correlation with height-width ratio. This correlation is however very small and furthermore not significant in most cases ($p > 0.05$). This is the case for all octave bands.

In both figures the color of the points indicates the amount of facade roughness, with yellow meaning many facade irregularities and ornaments and red meaning only little. Quantification of the level of irregularities was based on visual evaluation of the facades. At first sight, no obvious correlation is seen between the amount of roughness and both EDT and $T30$. However, further research should be conducted to incorporate a more thorough evaluation of the architectural details.

4. Conclusion

In this paper a new method is designed to measure the reverberation time and other impulse response related parameters in a fast and mobile way. By putting the measurement equipment on the roof of a car, street

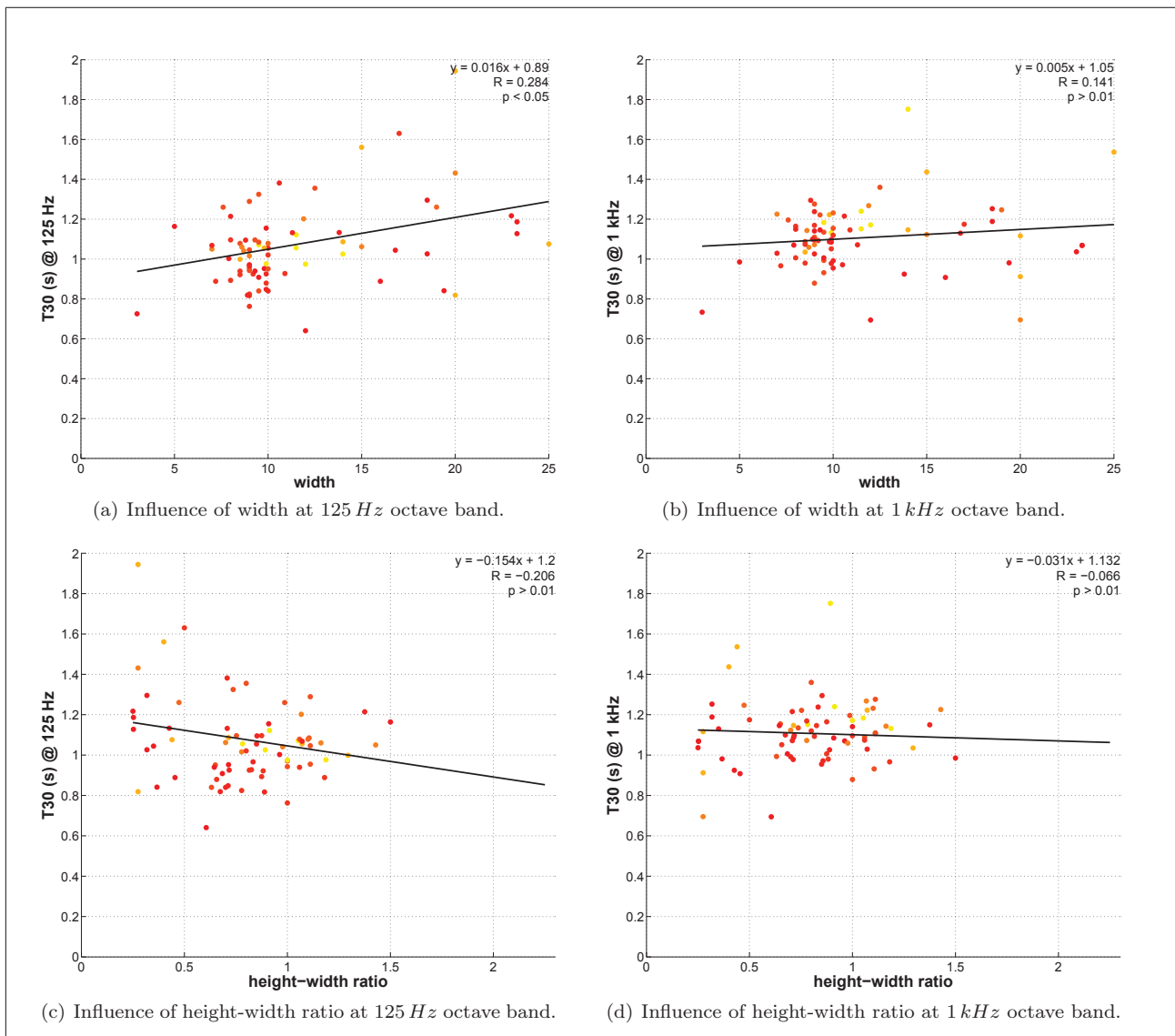


Figure 7. Correlation analysis of T_{30} at the 125 Hz and 1 kHz octave bands in function of width and height-width ratio. The fitted line is indicated, as well as the correlation coefficient and significance. The color scale indicates the amount of facade roughness, with yellow meaning many irregularities and red meaning little.

reverberation measurements have been conducted in 77 streets in the city of Ghent, Belgium. The resulting EDT and T_{30} is analyzed in octave bands and plotted on a map to identify regions with low or high reverberation. In districts further from the city-center the reverberation time (EDT) is typically lower due to more openness of the streets.

In an attempt to predict the reverberation in the city, a correlation analysis is conducted. It is found that the EDT correlates highly with the street width and height-width ratio. However no significant correlation between the geometrical parameters and T_{30} can be found.

In following work other acoustical parameters such as center time T_s will be investigated and further research for the influence of facade geometry will be included.

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