The influence of urban form in urban noise propagation

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Abstract: _The urban form affects directly the natural habitats, ecosystems and the different species. Indirectly the urban form influences the behavior of the trajectory, which in turn affects the air quality, the global climate and of course the noise propagation.

This paper seeks to address the problems of the urban environment as an area of interaction between urban forms and urban noise. This interaction is intended to be monitored by urban indicators, comparing the effects of noise propagation in model of urban forms.

The model of noise prediction (NMPB96), allowed to develop studies about noise in façades (Ld, level of noise during the day), resulting in colors associated to noise categories.

The study will allow the creation of different scenarios and foresee still in the draft fase, the facades exposed to a higher noise level. The effects of noise in façades can be then minimized in advance, by adjusting the layout of their typology.

Key-Words: _ Urban noise, Urban form, Urban indicators, Noise indicators.

I. INTRODUCTION

THE urban form is defined on the relationship between outer space and buildings volume that exist in a specific soil or landscape. It is these elements that we must analyze at themselves, each other and their relations with other elements of the urban system.

The Urban form refers to a spatial impression of an urban transport system, as well as physical infrastructure areas; together, they provide a level of spatial arrangement to the cities.

In turn, the urban spatial structure refers to the set of relations arising from the urban form and its underlying interactions of people, merchandise and information.

Urban design takes into consideration density, street layout and transport.

In additionall subsequent issues of urban layout are related to growth, expansion and urban growth patterns that influence unequivocally the urban form. “Environmental planning holds the key to determining the pattern and extent of urban growth.”[1]

According to Roberto de Lotto [2]the global urban system has been analyzed in the three subsystems: built and settlement system, environmental and green system, mobility and accessibility system.Comparing the different lists of criteria, and considering only the common ones, Roberto de Lotto defines a final list:

Built and settlement system:

1) Morphological integration between the existing urban settlement and the new Masterplan
2) Poly-functionality of the texture with the introduction of lacking functions
3) Capacity to promote requalification of the surrounding area
4) Increase of services surface percentage in comparison to the urban average
5) Relationship with the surrounding built context about the height and the alignment of buildings
6) Readability of morphological texture
7) Typological articulation
8) Internal coherence of the intervention
9) Consistency of the urban design
10) Quantity and articulation of collective open spaces
11) Availability of collective open spaces
12) Locational choice of functions.

Environmental and green system;

1) Soil permeability percentage
2) CO2 balance (emissions compensated by trees planting)
3) Connection and integration of the new greensystem of with the whole urban one
4) Reconstruction of units of the ecological network
5) Rescue of natural and para-natural elements
6) Compactness and continuity of green system
7) General quality of the environment and landscape
8) Creation of new priority visual axis
9) Usability and accessibility of green spaces
10) Percentage of equipped parks and green areas
11) Creation and protection of private green spaces

Mobility and accessibility system:

1) Strengthening of the system of primary roads of traffic flows in the medium and short distance
2) Strengthening of exchanges between different modes of transport, by retraining and upgrading interchange among functional urban centers
3) Strengthening and integration of public transport services
4) Connection of slow mobility with public transport services
5) Breakdown of traffic for functions located inside areas
6) Percentage of pedestrian zone and restricted traffic areas
7) Accessibility and connection with the existing infrastructures
8) Connection of built and open spaces
9) Accessibility to green spaces
10) Permeability of the area and perception of internal paths

These elements for Lotto [2]can be used in different ways: as main planning goals, as formal check-list, as planning criteria. He supposed various hypotheses, in the first case a benchmarking analysis points out the better solution; in the second case the more desirable solution is the one that satisfies the maximum number of requirements; in the last one, the mathematical processing detects the best performance.

So the urban system needs to incorporate, then the component of building, foliage and the road.

On the other hand the perception of noise depends on the people, moments and places. According to Gomes[3]"The concept of sustainable city, synonymous of modernity, development, corresponds to healthier cities, with less noise,…". Noise is understood by an unpleasant sound or noise nuisance to humans and that is why it is difficult to determine objectively the awkwardness.

Therefore Noise sources are consideredactions, permanent or temporary activities, equipment, structures or infrastructure, which produce sound levels, which who remainatthe area or in their environment feeldiscomfort from the noise effect [4].

As a result we can consider the noise as a global noise set caused of a surround sound sources existing in far or near of a particular location at a given moment.

The interaction between sound sources and the urban layout can be characterized by the theoretical and conceptual bases of emission and propagation of noise.

Comparatively the influence of urban form according to Luz Valente Pereira [5]in morphological terms, is mainly based in terms of its location, topography, sun exposure, wind, quality and suitability of the soil and subsoil, and finally, in terms of landscape composition.

These items influence the large distributions of voids and fills of buildings and their typology, as well as the infrastructure layout, especially the road structure.

The study required a model that evaluatesthe ambient noise levels at the façades.

To predict different scenarios, and to avoid excessive exposition of noise at the façades, the environmental noise model NMPB96, is used with the urban selected forms.

In addition, the model applies computerized simulation to the emission and propagation of noise and identifies the several quantitative indicators of form and dimension of the urban layout.

As a way to suggest a model for quantitative evaluation of urban form typology, we use the different quantitative indicators of form together with the noise prediction model.

Following we present the form indicators that we pretend to use in the study of the different typology.

II. DEFINITION AND CARACTERIZATION OF URBAN FORM TYPOLOGIES

The conception of urban typologies concerns to arrangement, appearance and functionality of cities and, especially, to conception and use of public urban space [z].

A. Quantative Indicatorsof Urban Form

Trying to characterize the urban form is, in spite of the growing interest, an exploration of real differences that in a rigorous and exhaustive form is illustrated in incipient studies.

The indicators that we intend to study have a dimensional nature. Although they are based on studies from different authors, they are urban indexes and spatial metrics that can be applied to other typologies with external specificities from the presented models.

The metric space is a concept that generalizes the idea of geometric distance. A set in which there is a metric or scale, whose base is similar and it is easy to compare. This can be detected in the present study and after presenting thefollowing indicators to be used.

a) Urban Indexes

The urban indexes are multipliers that we can apply either to an area or to a reference surface or to an intervention area with edificatory possibility.

Occupation Index or Rate of Soil Occupation (% P) - is the indicator that relates the quotient between the surface of deployment and the land area represented in Fig. 1.

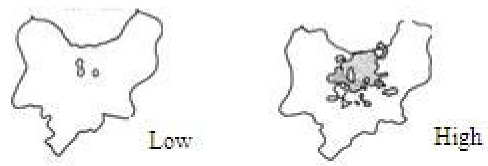

Fig.1. Illustration of Occupation Index (%)

The calculation of the Occupation Index (% P) is presented by Equation 1:

$$\%P = \frac{A_{imp}}{A_t} (1)$$

Meaning:
A_{imp}: Surface of deployment, [m^2];
A_t: Total Area, [m^2].

The urban form that has the largest area of implantation will have the higher content (% P).

Volumetric Land Index (Iv) - The indicator of Fig. 2 represents the entire space above ground, corresponding to all the buildings that exist or can be made in a building, except the elements or protrusions only with decorative purposes or the technical facilities and fireplaces. But this indicator includes the roof volume, expressed in cubic meters (m3).

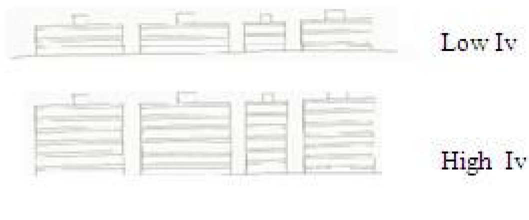

Fig.2. Illustration of(Iv) variationand of the relationship of number of floors

To calculate Volume Index of construction (Iv) we use Equation 2:

(2)

Meaning:
P: Surface of implantation, [m^2];
N: Number of floors, [-];
H: Floor height, [m].

Thus the urban form that has the most floors will have a highest value of Iv.

b) Spatial metrics

Landscape metrics listed below, are employed through the use of quantitative indices representative of the physical features of urban form type and study subject[6].

In the present study we will use the following quantitative urban indexes: Compactness Index and Index of porosity or permeability.

Compactness Index (CI)-This indicator measures not only the shape of the urban area (urban patch), but also considers the global urban landscape fragmentation [7]. The Fig. 3 illustrates the relationship between the urban form and regularity of fragmentation and its influence on the CI.

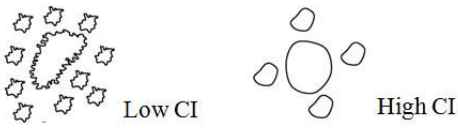

Fig.3. Illustration of the forms regularity variation that influence the index (CI)

The Compactness index (CI) is calculated based on de nextequation:

Meaning:
s_i : Patch area,[m^2];
p_i: Patch perimeter, [m];
P_i: Circle perimeters_i[m];
N: Total number of Patches, [-].

An urban area has higher values of CI for more regular and more compact urban forms.

Porosity Index (ROS) - is the permeability indicator which measures the proportion of open space, compared to the total urban area.

Fig. 4 illustrates the relationship of the area of open space and total occupied area and its influence on ROS.

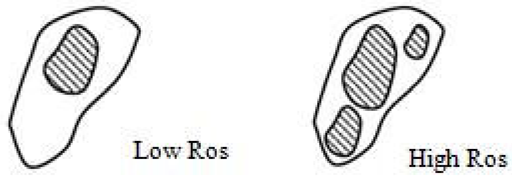

Fig.4.Illustration of the variation of open space with the total area that characterizes the index (ROS)

The Index of Porosity or Permeability is calculated by Equation 4 shown below:

Meaning:
s´:Summation of area of all the "holes" within the urban area studied, [m^2];
s :Summationofareaall patchs, [m^2].

An urban area has higher levels of ROS to urban forms with higher open spaces. This indicator is also called as the ratio of open spaces.

Complexity of the Perimeter Index (Fractal) - The complexity is defined by the perimeter fractal dimension. This index describes the complexity of the perimeter of an urban area through the relationship between perimeter and area [8], [9].For research we used the average fractal dimension of urban patches weighted by the area (Equation 5).

The value of fractal dimension is between 1 and 2. Lower values are obtained when the patch has a simpler form (the fractal dimension of a circle is equal to 1).If the perimeter is more complex and irregular; fractal dimension is greater (Figure 5).

This index is weighted by the area of the patch which means that larger patches contribute more to the mean value than smaller ones. [10].

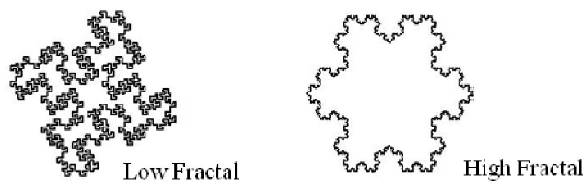

Fig.5. Illustration of the forms regularity and complexity variation that influence the index (Fractal)

The Fractal index (Fractal) is calculated based on the next equation:

Meaning:
p_i: Patch perimeter, [m];
ai = Patch area, [m^2];
aj= Total area, [m^2];

n = Total number of Patches, [-].

Form Index (Form) - this index is defined by the relationship between area, perimeter and the radius of the smallest surroundingcircle of the polygon.

The index form describes the complexity of the perimeter of an urban area through the relationship between perimeter and area [9],[11].For research we used the average fractal dimension of urban patches weighted by the area (Equation 5).

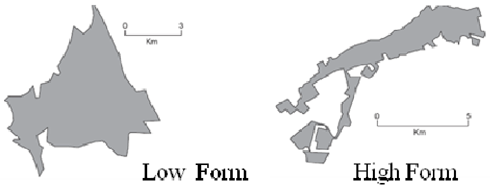

Fig.5. Illustration of the forms regularity and complexity variation that influence the index (Form)

The Form Index (Form) is calculated based on the next equation:

Meaning:
p_i: Patch perimeter, [m];
ai = Patch area, [m^2];
aj= Total area, [m^2];
n = Total number of Patches, [-].
r_i= Radius of the smallest surroundingcircle of the polygon, [m].

For a circular form, the value of this index is equal to 1, as the shape becomes more elongated and not circular the value of the form index increases (Figure 5).

When we have more than one urban area, the indicator considers a weighting depending on the size of the patch.

Thus, we can display various models of urban layout in order to systematize the types of urban form and select the most frequent types.

B. Theorical Model Neighbourhood Proximity

The mathematical expressions referenced previously will be applied to types of urban forms, presented in the near future in a theoretical model, the “NeighborhoodProximity Model “ofJoão Branco Pedro [12].

Neighborhood proximity means a residential unit functionally and spatially organized around an outdoor space, where neighborhood residents tend to establish relationships.

The sample, which funded this typological classification, was developed by João Branco Pedro [12], in which the immediate neighborhood typologies were defined according to two perspectives:

❖ The programmatic perspective, which is defined as sets of neighborhoods proximities, with identical functional programs (such as the number of houses, the number of habitants or similar occupation index);

❖ The morphological perspective, it is meant as a set of neighborhoods proximities, with similar formal characteristics (such asthe form of implementation of the set of buildings, the form of buildings in relationship with the streets, theform of local access road, the number of floors above the main entrance of the buildings of neighborhood proximity or the number of habitation from neighborhood proximity).

a) Requirements Applicable to Project Areas of Neighborhood Proximity

At this stage, we present the design parameters applicable to each of the spaces that compose the neighborhood proximity. That is, the circulation spaces, the buildings and unbuilt spaces, which are listed below.

The road system includes the minimum road hierarchy, the minimum width of the track, and the minimum impermeable components of the infrastructure. The residential Lots include the maximum height of buildings and the minim distance between the facades. The Green space, on the other hand, contemplates the minimum area of the Lots’ minimum area.

Therefore, and based on the articulation of these spaces, roads, housing and green, was chosen for the following types of linear deployment, as shown in Fig. 6.

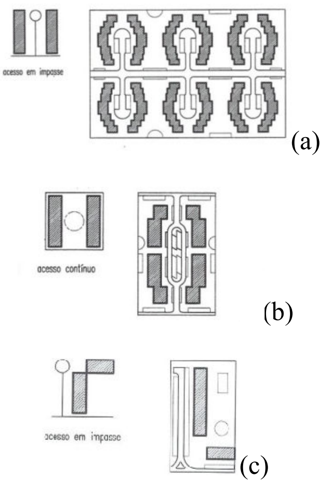

Fig. 6.Ilustration of one family buildings with two floors (a), 4 floors multifamily (b), with 8 floors multifamily buildings(c)

The Selected models are intended to diversify the sample, so it can be listed the different effects of noise propagation on the composition.

Accordingly, the proposal aims at models with concavities, convexities and a linear model with the absence of saliencies.

Thus, it is expected to obtain comparative results and to present some conclusions on how the urban form may influence the propagation of urban noise.

III. DEFINITION OF URBAN NOISE

It is understood by noise an unpleasant sound or of annoyance for human beings. The concept of noise is defined as the variation of atmospheric pressure, within the limits of the range and frequency band to which the human ear responds.

Since the human ear is more sensitive to certain frequencies than others, the level of disturbance is dependent on the spectral content of noise.

Thus, the definition of environmental noise is expressed by a logarithm of the ratio between the squares of the measured sound pressure and reference pressure. It is called sound pressure level Lp and is expressed in Bel (B) or multiplying by 10 is expressed in decibels (dB), as we can see in the next Equation:

$$Lp = 10 \times log10 \left(\frac{p}{p0}\right)^2 = 20 \times log10 \frac{p}{p0} \qquad (7)$$

Meaning:
Lp = is the sound pressure level expressed in dB
p = is the real value of sound pressure expressed in Pascal
p_0 = is the reference sound pressure and corresponds to the minimum threshold of human hearing ($p_0 = 2 \times 10^{-5}$ Pa)

As mentioned earlier, because the human ear does not have the same sensitivity over the frequency spectrum, the sound pressure level Lp is not truly representative of how it is received by man.

In order to characterize the sound pressure level emitted but not received by the human ear, the sound pressure level expressed in dB is weighted by a coefficient that depends on frequency, sound pressure level is weighted by weighting curves A, B, C and D.

So for the measurement of environmental noise and annoyance as the weighting is commonly used frequency weighting A, because it is the one that best correlates the measured valueswith the awkwardness of the sound. Thus, in studies of the ambient noise sound pressure level is usually expressed in dB (A).

In agreement with the established in Portuguese Legislation [13], the acoustic zoning map classifies the land in two classes: “sensitive areas”, which have allocated existent or foreseen residential uses, as well as schools, hospitals, recreation and leisure; and “mixed areas”, which overlap the uses of sensitive areas plus other ones like retail shops and services, parking, etc.. This legislation forces the consideration of outdoor noise levels in the planning process, namely in the elaboration of zoning plans. According to the provisions of the law, sensitive areas may not be exposed to an equivalent continuous sound level in all day-time (A-weighted average sound level – Lden(A)), higher than 55 dB(A) and 45 dB(A) in night-time (period between 9.00 p.m. and 7.00 a.m., Ln(A)); and mixed areas may not be exposed to a Lden(A) higher than 65 dB(A) in all day-time and 55 dB(A) in night-time.

Traffic noise levels can be evaluated by two different means: measurements and prediction. The measurement method is only feasible when applied to existent situations; the prediction methods are used with advantage from the very start of the planning process to the final detailed design of noise abatement measures.

The noise prediction method should provide secure results, which represent the real situation of noise levels under any conditions of emission and propagation[14].

Prediction methods have proved to be very useful and applied in a wide range of noise situations. When a calculation method is used, a large number of scenarios can be greeted by introducing different traffic flows, several types of pavement, variable number of reception points, and noise abatement measures designs. By contrast, measurements results give information only about a very limited situation (the specific traffic and weather condition at the time the measurements are made).

There are available in the market numerous prediction noise models, which constitute an important toolbox in the simulation of the acoustic situation, as referred by Bertellino and Licitra [15].

The model adopted for this research, named New Method of Forecast of the Traffic Noise (NMPB 96) was developed in France in 1996. It is the method recommended by Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 [16], relating to the assessment and management of environmental noise [l7].

I. The Most Important Factors that Influence the Propagation of Sound

The Noise is emitted by a sound source or a set of sources and spreads from the source on the form of mechanical concentric waves and in a slightly spherical form. Depending on the source, these waves may obtain a spherical, cylindrical or planar form.

The noise decreases with increasing distance between the source and the receiver station. This reduction depends on several factors such as the font type, the absorption characteristics of the surrounding soil and the existence of barriers.

In addition to the already mentioned, the weather conditions also have a strong influence on the propagation of noise, and the wind and the temperature are the factors with more emphasis.

IV. THE INFLUENCE OF URBAN FORM ON THE PROPAGATION OF URBAN NOISE

The combination of typologies and indicators presented previously served as the basis for the development of nine different scenarios, as a base comparable to the analysis that we intend to study.

Thus, the urban forms submitted (Type 1, Type 2 and Type 3) are based on a grid of 210mx140m, with a total gross floor area of 29 400 m2 and a perimeter of 700 m.

Each of the scenarios developed is served by two local distributor roads and local access roads. For this calculation was only included in the assessment, the local distributor roads. The routes considered in each scenario developed, possess the following characteristics:

• asphalt pavement without inclination;

• fluid flow of road traffic (300 total vehicles / h with 5% heavy);
• velocity of 50 km / h.

For the evaluation of noise levels at the facades, we developed a square grid calculation over all the facades of 1.5 m x 1.5 m and a distance from the facade of 0.5 m. The number of floors of buildings is variable (2, 4 and 8 floors) with a ceiling height of 3m, Ground floor inclusive.

V. RESULTS

The combinations of the different parameters mentioned above are reflected in the following illustrations:

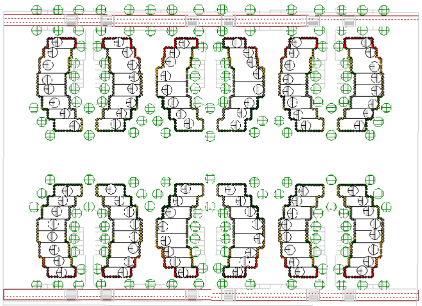

Fig.8. Illustration of Plant Form Type 1

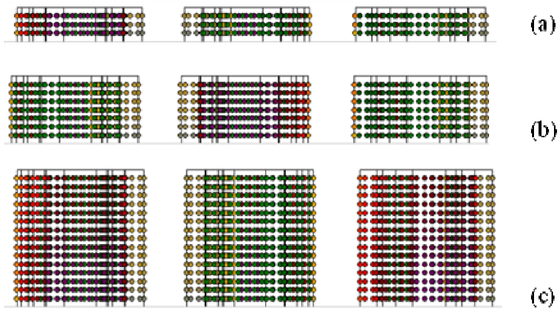

Fig.9. Location of the nodes evaluation in buildings with form Type 1, with two floors (a), 4 floors (b) and 8 floors (c)

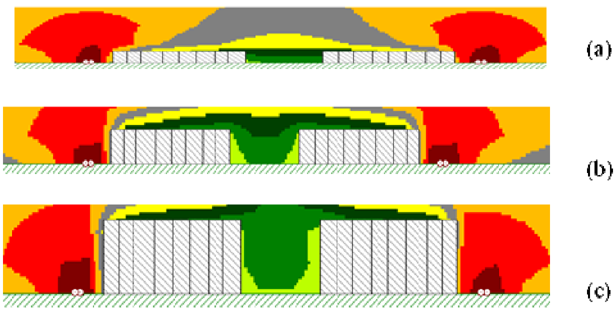

Fig.10. Vertical noise Map form Type 1, with 2 floors (a), 4 floors (b) and 8 floors (c)

The relationship of variation in the number of floors, with the effects of noise propagation in different facades is illustrated and was quantified, and its results are in Table 1.

As can be seen in Table 1, there is a slight reduction in Leq, with the increase in the number of floors in the case of maximum and average values. In the case of the minimum values of Leq, this trend is reversed. Fig. 10 illustrates the form of sound waves from the source and how it affects the most exposed facades.

As the number of floors increases the extent of the most exposed façade also increases, increasing the average and maximum Leq.

On the other hand, with increasing high the size of the protected area increases too, causing a reduction in the minimum Leq.

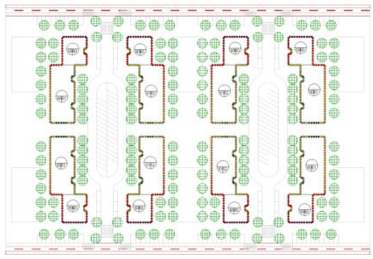

Fig.11.Illustration FormType 2

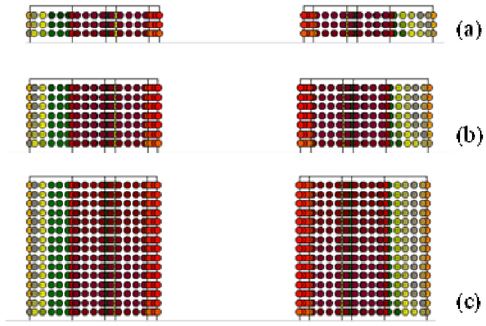

Fig.12. Location of the evaluation nodes in buildings with Type 2 form, with two floors (a), 4 floors (b) and 8 floors (c)

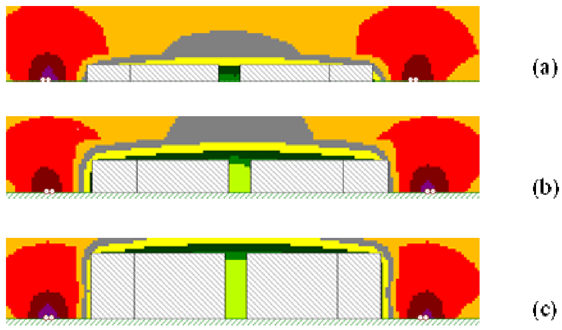

Fig.13. Vertical Noise Map from Form Type 2 ¬, with two floors (a), 4 floors (b) and 8 floors (c)

As in the previous case, there is a slight decrease of Leq with increasing of the number of floors in the case of maximum and average values.

In the case of the minimum values of Leq, this trend is reversed. Fig. 13 illustrates the form of sound waves from the source and how it affects the most exposed façades.

The analyses to be made, of the obtained results, are in accordance to with the above analysis for the Type 2 form.

Studies on previous forms contemplated concavities and convexities in its formal composition, the Type 3 form that is presented below and illustrated in Fig. 14, is a pure composition, without corners that can create additional changes in the propagation of waves of noise.

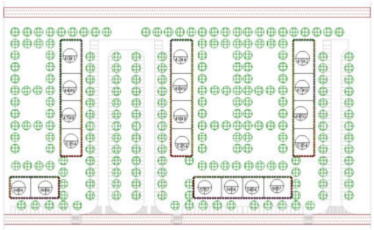

Fig.14. Illustration ofPlant of FormType 3

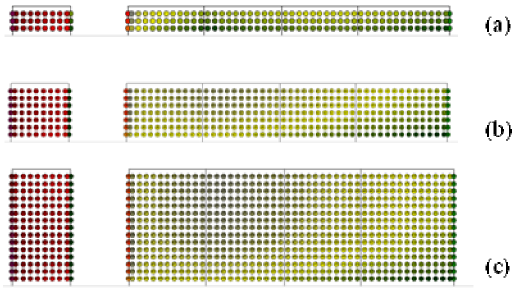

Fig.15. Location of the evaluation nodes in buildings with Type 3 form, with two floors (a), 4 floors (b) and 8 floors (c)

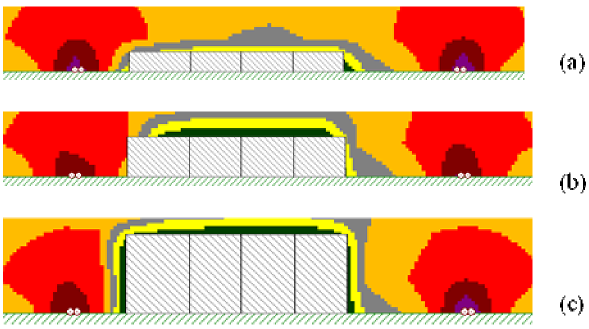

Fig.16. Vertical Noise Map from Form Type 3, with two floors (a), 4 floors (b) and 8 floors (c)

The relationship between the obtained noise level in the façades and the number of floors in the Form Type 3 is similar to the one obtained in the Forms Type 1 and Type 2. The average values of Leq will increase as the number of floors increases. Inverse tendencyis for maximum values of Leq.

VI. CONCLUSIONS

This study intended to approach the influence of urban form in urban noise propagation. This interaction was evaluated by calculating the urban indicators, which measure the urban form and the noise levels on the façade. Nine scenarios were considered with three type forms and with several heights. (2, 4 and 8 floors).

The indicators of urban form and noise for the nine developed scenarios are summarized in Table 1.

As can be seen in Table 1, in the three type forms, there is a small decrease of Leq with increasing the number of floors (the Volumetric Index Iv), for maximum and average values. In the case of the minimum values of Leq, this trend is reversed. As illustrated in Fig.s 10, 13 and 16, the form of sound waves from the source, being cylindrical, influence, in different ways, the most exposed façades. As the number of floors increases, the extent of the most exposed façade also increases, increasing the average and maximum Leq.

In contrast, with increasing height, the size of the protected area increases causing a reduction in the minimum Leq.

TABLE 1. RELATIONSHIP INDICATORS BETWEEN LAYOUT AND NOISE

Área Impl.]	**Form Type 1**			**Form Type 2**			**Form Type3**		
Nº Floors	2	4	8	2	4	8	2	4	8
p [%]	27,1	27,1	27,1	18,5	18,5	18,5	11,5	11,5	11,5
I_v] x10^{-3}	47,8	95,6	191,3	32,6	65,2	130,4	20,2	40,6	81,2
CI [-]	0,05	0,05	0,05	0,11	0,11	0,11	0,31	0,31	0,31
ROS [%]	73	73	73	82	82	82	89	89	89
Fractal	1,15	1,15	1,15	1,15	1,15	1,15	1,13	1,13	1,13
Form Index [-]	2,75	2,75	2,75	3,05	3,05	3,05	12,79	12,79	12,79
Leq(A) Min. [dBA]	37,0	36,6	36,4	34,7	34,0	33,5	46,6	46,6	46,5
Leq(A) Aver. [dBA]	49,1	49,4	49,6	50,6	51,1	51,1	59,0	59,1	59,1
Leq(A) Max. [dBA]	54,6	54,7	55,1	59,0	59,1	59,1	58,2	59,1	59,1

With increasing **porosity or permeability index** (ROS), the average values of Leq also increase, this is explained by the fact that the greater the permeability of the urban form is the sound waves more easily are able to reach the buildings inside.

With the increase of the **CompactnessIndex** (CI), medium values of Leq also increase. This is due to the fact that the greater the regularity of urban forms, the lower is the possibility of formation of shadow zones, that is more protected areas.

Regarding to the **Occupation Index** (p), when decreases it generates façades with higher noise levels. The more "occupied" the soil, the more obstacles exist and therefore the greater the possibility to form protected areas.

Concerning the **Fractal Index**, the variation obtained is consistent with the variation of facades noise levels. The Fractal Index mainly describes the raggedness of theurban boundary. The higher this value is, the more irregular the shapesare. This fractal dimension approaches one forshapes with simple perimeters and approaches two when shapesare more complex. Is expected an indirect correlation between Fractal Index and thenoise levels facades. The regularity of urban forms decreases the possibility of formation of shadow zones that is more protected areas.

Is expected an direct correlation between **Form Index** and the noise levels facades. With increasing **Form**

Index, the average values of Leq also increase, this is explained by the fact that the greater the compactness of the urban form more exposed are the buildings facades.

The relationship between noise and urban form intent to promote the creation of protected areas or shadow areas in urban context, as one of the objectives of this study.

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