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A decision-support tool for the control of urban noise pollution

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Abstract *Improving the quality of life is increasingly seen as an important urban planning goal. In order to reach it, various tools are being developed to mitigate the negative impacts of human activities on society. This paper develops a methodology for quantifying the population's exposure to noise, by proposing a classification of urban blocks. Taking into account the vehicular flow and traffic composition of the surroundings of urban blocks, we generated a noise map by applying a computational simulation. The urban blocks were classified according to their noise range and then the population was estimated for each urban block, by a process which was based on the census tract and the constructed area of the blocks. The acoustical classes of urban blocks and the number of inhabitants per block were compared , so that the population exposed to noise levels above 65 dB(A) could be estimated, which is the highest limit established by legislation . As a result, we developed a map of the study area, so that urban blocks that should be priority targets for noise mitigation actions can be quickly identified.*

Keywords *Noise pollution, Population exposure, Quality of life, Vehicular flow*

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Introduction

Nowadays, urban areas are experiencing a fast process of development, not only from the point of view of economics, but also from social aspects.. Associated to this development, various types of problems and impacts arise, which affect the environmental integrity.

Although improving the quality of life of the population depends on acquiring and maintaining healthy habits[1], cities often have environmental features that affect the development of these urban activities. Noise pollution is one of these features. Urban noise results from the combination of various noise sources, such as transportation, industries, construction sites, recreational activities, schools and commercial areas.

Among these, due to the growth of vehicle fleets and the lack of territorial planning in urban centers, traffic noise is considered as the main source of noise pollution. . According to the World Health Organization[2] (WHO), more than half of the world's population occupies urban spaces. In addition, there are alarming estimations of demographic growth. For the quality of life and health, the WHO states that the average sound exposure should not exceed 55 dB(A), and this limit is even more restricted during sleeping periods, when the threshold should be 45 dB(A). Sound pressure levels over 65 dB(A) could cause negative effects such as interference in speech intelligibility, difficulties in sleeping or resting, disturbance and a drop in the quality of doing work and leisure activities. , The sound pressure level above 85 dB(A) may cause hearing loss for human beings.

Many studies report this evidence either by damage caused to hearing loss[3] and sleep disturbance[4-6] , or cognitive performance in adults and children[7], psychological diseases[8] and cardiovascular and heart disease [9-11].

Improvement in the urban quality of life, therefore requires monitoring exposure conditions of the population, which is a fundamental step for planning and health intervention[12]. Environments that exceed noise levels determined by legislation require this monitoring so that control and acoustical attenuation solutions can be reached. Reducing traffic noise is a challenge for many countries. Worldwide, there are actions planned to combat noise pollution caused by urban traffic noise. These actions could be specially exemplified by the case of the European Community (EC), where the development of noise maps is a mitigation strategy which is widely applied. The noise map is a tool requested by the European Directive[13] in order to detect levels of sound pollution and promote measures for its attenuation.

Noise maps are used as strategy tools for urban planning, aiming at the local population´s quality of life, allowing noise quantification, evaluation of population exposure, the development of future scenarios, the identification of conflict areas and the proposals for solutions[14].

This strategy, however, is not yet a common tool applied in Brazil. There are some legal or standardized Brazilian instruments for noise considerations, such as: Federal Law nº 10.257/2001, which is known as the City Statute[15]; the CONAMA resolution 001/1990, which addresses noise emissions[16]; the CONAMA resolution 002/1990, which establishes the Silence Program[17]; the CONAMA resolution 020/1994, which establishes the Noise Seal[18], and the technical standards NBR 10.151:2000[19], NBR 10.152:1987[20] and NBR 7.731:1983[21]. In this context, this paper proposes a Brazilian methodology that allows quick access to information, to optimize the establishment of priority actions and identify the community´s exposure to noise. For this purpose, we propose an adapted method for the acoustical classification of urban blocks[22] in order to quantify the population exposed to noise during the peak hours of traffic flow. The proposed method is applied at several points in the city of São Carlos, SP, Brazil.

Method

The method of this research consists of the following steps: delimitation and physical characterization of the study area; data collection; validation and application of a prediction model for the acoustical mapping; acoustical classification of the urban blocks; evaluation of the community exposure to noise.

Delimitation and physical characterization of the study area

The State of São Paulo, in the Southeast of Brazil, occupies an area of 248,800 km² with about 40 million inhabitants, who represent 22% of the Brazilian population. São Carlos is a city located in the central region of the State (22º01'S and 47º54'O) with a total area of 1.137,303 km², where 67.25 km² represent the urban area with an approximate population of 236 thousand inhabitants[23].

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The urban fraction for this study occupies a region that includes three important traffic corridors for the city (Av. São Carlos, Av. Dr. Carlos Botelho and R. XV de Novembro). According to the Municipal Master Plan, this fraction presents a mixed use and occupation, with residential buildings, schools, commercial areas and services.

For a physical characterization, the width of the roads and heights of the buildings were estimated for each urban block of the study area. In this estimation, we considered that each building floor was 3 meters high, while the buildings of single ground-floors or ground-floors of multi-floor buildings were considered to be 4.5 meters high. This data collection was supported by cadastral maps (available from the Municipal Government of São Carlos) and site visits, as well as Google Earth® images (online access).

For the data collection, reference points were selected in the urban fraction in such a way that they were situated close to the middle point of the urban blocks that faces the streets, so that the road crossings were excluded from the samples. (Figure 1).

Data Collection

The traffic flow and fleet composition (light and heavy vehicles), were characterized and counted from the reference points. These were the points also considered for the sound pressure level measurements. This data collection took place on week days (Tuesday, Wednesday and Thursday) at peak hours of traffic flow (from 7 to 8 a.m in the mornings, and from 5:30 to 6:30 p.m in the afternoons). Weekends and holidays were avoided due to atypical conditions.

The parameter taken as the identifier of the sound pressure level was the Equivalent Noise Level (LAeq), defined by equation 1[24].

$$L_{Aeq} = 10.\log \frac{1}{T} \int_0^T \frac{P^2(t)}{P_0^2}\, dt \qquad \text{(Equation 1)}$$

where,

T is the integration time;

Pt is the instant sound pressure;

P_0 is the sound pressure of reference 2,0 x 10^{-5} N/m²;

LAeq is the equivalent continuous noise level in dB(A).

For the LAeq data collection, we applied a Hand-Held Analyser 2270-L Brüel&Kjær, which was equipped with a device for wind protection attached to the microphone in order to reduce interferences. The equipment was configured to measurements of the outside environmental noise, considering the methodological specifications suggested by NBR 10.151[19] and ISO 1996[24], placed far from surfaces reflective to sounds, keeping a minimum distance of 2.0 meters from walls and 1.2 meters from the ground.

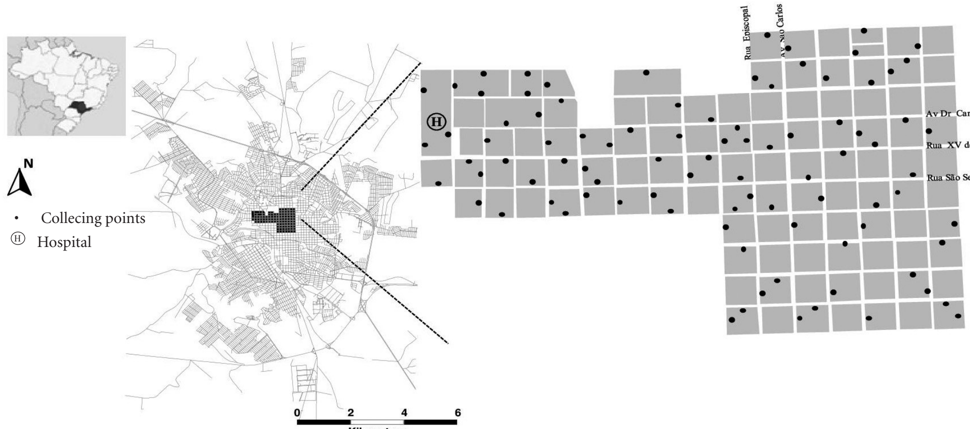

Figure 1. Location of the city of São Carlos, São Paulo state, Brazil, highlighting the study area and the points of data collection.

Validation and application of a prediction model for noise mapping

The applied calculation model was the French model called "Nouvelle Méthode de Prevision du Bruits des Routes" (NMPB Routes-2008, in English, the New Method for Road Traffic Noise Prediction). This method was recommended as an interim option during the implementation of the European Directive 2009/49/EC. The NMPB Routes-2008 was presented in detail by Dutilleux et al.[25] and can be described by Equation 2:

$$L_{LT} = 10log\ [\text{p x } 10^{\frac{LpF}{10}} + (1 - \text{p}) \text{ x } 10^{\frac{LpF}{10}}]$$

(Equation 2)

Where,

p is the percentage of occurrence of favorable meteorological conditions for sound propagation. It assumes a value 1 (one), if the conditions are favorable, and 0 (zero), if the conditions are homogeneous. The conditions are favorable, when the wind, temperature and humidity cause deflections to downwards, intensifying the sound level near the ground. The homogeneous conditions correspond to deflection upwards;

L_{pF} is the sound pressure level for favorable conditions, according to Equation 3;

$L_{p,F} = LW - A_{div} - A_{atm} - A_{solo,F} - A_{dif,F} - A_{ref}$ (Equation 3)

L_{pH} is the sound pressure level for homogeneous conditions, according to Equation 4.

$L_{pH} = LW - A_{div} - A_{atm} - A_{solo,H} - A_{dif,H} - A_{ref}$ (Equation 4)

In Equations 3 and 4, the LW represents the acoustical power of the vehicular traffic, generated by the average speed, the traffic composition and type of paving. A_{div} is the attenuation due to geometric dispersion, A_{atm} is the attenuation caused by atmospheric absorption, A_{dif} is the diffraction caused by obstacles, A_{solo} is the ground effect, and A_{ref} is the absorption of the vertical surfaces.

Nesses casos, a complexidade do fenômeno envolvido e os cálculos necessários levam ainda a uma modelagem auxiliada por programa computacional.

In these cases, because of the complexity of the phenomena under consideration and the calculations required, a computer aided modeling program should be used. For this purpose, the prediction method applied here was the CADNA-A, v.4.1 computational program (Computer Aided Design Noise Abatement, Datakustik)[26].

The traffic noise in this computational program is represented as a linear source, for which the attributes correspond to the road characteristics and the traffic flow.

The program can be run using the input data of real sound pressure levels measured on site or by counting vehicular flow and composition.

Due to the fact that the software was developed for specific conditions of French cities, a validation process is always necessary before it is applied to conditions of Brazilian cities. In our case, the validation process for the study area was previously performed and presented in the study of Giunta et al.[27]. The latter indicated that the best option for the input data is the LAeq values, because of the precise results obtained. These authors also highlight thatif the vehicular flow is used as input data, the simulated values may result in an average difference of 2 dB(A) less than the real values.

Thus, the input configuration of the simulation corresponded to the collected data of sound pressure levels (LAeq) and the street characteristics, both of them for the periods of peak hours. The absorption coefficient of the façade surfaces assumed the value of 0.37 (which is the default value of the software). In this calculation process, receptors were inserted at the middle point of the front part of the urban blocks and in the inner part of the blocks, thus enabling us to calculate simulated values of sound pressure levels.

Acoustical Classification of the urban blocks

Classifying and analysing the blocks was based on a methodology adapted from Mendonça et al.[22]. This method consisted of determining an arithmetic average of values simulated for the four middle points of the front part of each urban block, together with the values of four points placed in the inner part of the urban blocks, positioned 30 meters from the points of the front part. This average generates the value for the acoustical classification of the urban blocks.In our specific case, the method is similar, however it considers the the logarithm average values instead of the arithmetic average. We believe that this kind of logarithmic approach has a better correspondence with the nature of the LAeq parameter, because of its logarithm characteristics. Afterwards, the classification of the following acoustical ranges was carried out: below 60 dB(A); between 60 and 65 dB(A); between 65 and 70dB(A) and above 70db(A).

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Community exposure to noise

The population of each urban block was calculated based on the census tract defined by the IBGE. This estimation considered the value of the censor sector of IBGE (I), the constructed area of the urban block (A_Q) and the total area of buildings in each census tract (A_{SC}), as shown in Equation (5):

$P_Q = P_{SC} \times (A_Q/A_{SC})$ (Equation 5)

Where:

P_Q is the number of people exposed to noise per urban block;

A_Q is the constructed area of the specific urban block (m^2);

P_{SC} is the number of inhabitants for each sector of the census tract;

A_{SC} is the total area of buildings in each sector of the census tract (m^2).

According to the technical standards of NBR 10.151[19], the limits of the urban zones presenting mixed uses with commercial tendencies should not exceed 60 dB(A) during the day and 55 dB(A) during the night. These limits were the guide to comparing information of the acoustical classes and the population classes, so that the number of people exposed to noise in the peak hours could be calculated.

Results and discussion

The classification of the urban blocks using the logarithm average method is shown by the results in Figure 2 (peak hours of the mornings and afternoons, respectively).

These results show that most of the urban blocks in the study area of São Carlos presented high levels of noise, passing the limits established by current regulations. In the peak hours of the mornings, there are 19.8% of urban blocks classified in the range of 60 to 65 dB(A), while in the afternoons there are 16.8%. Most of the urban blocks are classified in the range of 65 to 70 dB(A). While during the peak hours of the mornings, 65.3% of the urban blocks are classified in this latter range and 68.3% in the peak hours of the afternoon. For the same periods of peak hours, the classification above 70 dB(A) represented only 4.9% and 5.9%, respectively.

There are only a few urban blocks of the area that were classified in the lowest range, representing 9.9% in the mornings and 8.9% in the afternoons. The area corresponding to letter "H" (Figures 1 and 3), represents a hospital, therefore we expected to register the lowest sound emissions among the points. Instead, though not reaching the critical limits, the levels of this area present ed the values already in the limits of the ranges established by current regulations.

Various studies have shown that Brazilian cities are noisy, such as Lima and Carvalho[3] for the

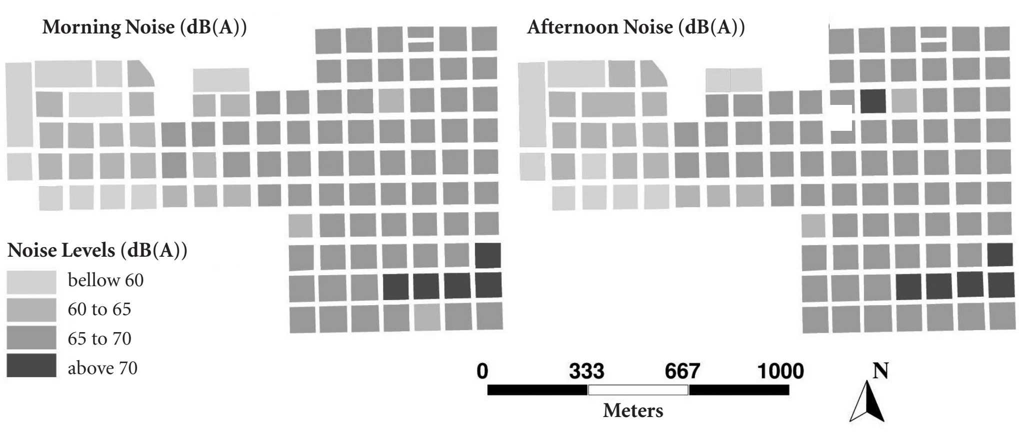

Figure 2. Acoustical classes of the urban blocks in the city of São Carlos, SP, in the mornings (7 to 8 a.m.) and in the afternoons (5:30 to 18:30 p.m.), by ranges of conformity.

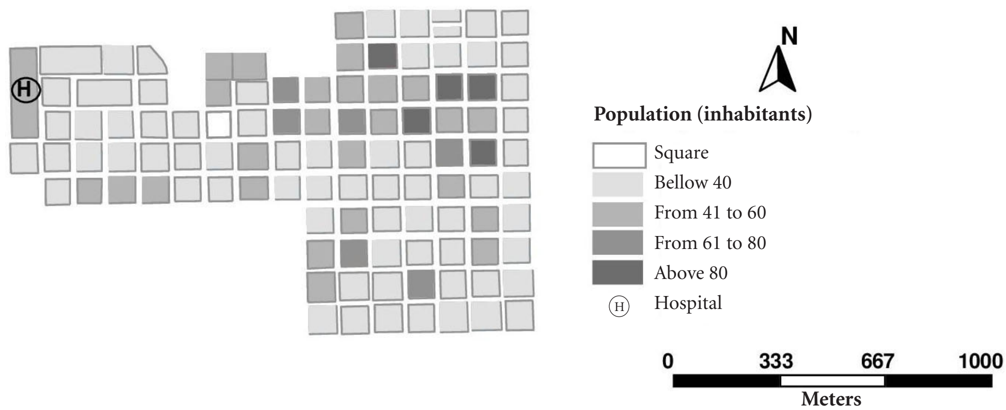

Figure 3. Number of persons exposed to environmental noise per urban blocks in the city of São Carlos, SP.

city of Mossoró, Costa and Lourenço[28] for Sorocaba, Brito and Sinder[29] for Taubaté, Souza and Giunta[30] for Bauru and Valadares et al.[31] for some cities in Minas Gerais.

From the point of view of the consequences caused by high noise levels and indicated by the WHO[2], this situation is even worse, when large-sized cities are taken into account. Cantieri et al.[32], for instance, showed that in Curitiba the average values of noise reached 81.9 dB(A) and Pinto and Mardones[33] observed that levels above 65 dB(A) are registered in many roads of the city of Rio de Janeiro.

However, the noise disturbance and exposure of population is not a feature exclusively found in Brazilian cities. This urban issue has also been documented in Korea[34], the United States[35], some states of Pakistan[36], Belgium and neighboring countries [37], Ireland[38,39], some cities in Finland[40] and Spain[41].

In an attempt to identify the number of people exposed to the most intense noise in the study area, the data of acoustical classes of the urban blocks (Figure 2) and the number of inhabitants per urban block (Figure 3) were compared, allowing access to the portion of the population exposed to noise. The largest concentration of inhabitants coincides with the highest values of sound levels. This fact shows the acoustical fragility of the area, generating conflicts for inhabitants as well as for pedestrians.

A total of 4,202 inhabitants live in the study area. Most of them are exposed to sound levels above 65 dB(A), representing 70.0% in the peak hours of the morning and 74.7% in the peak hours of the afternoons. Even though these values are for outdoors conditions, it can be observed that there is a high potential of noise exposure in these urban blocks. Thus, the importance of addressing building façades cannot be neglected. Openings of buildings facing the environment of the noisiest blocks expose the inhabitants to limits above those considered healthy. Furthermore, the number of people exposed to noise may be even more, if we remember that the number of pedestrians was not computed in this study, which could result in a higher number than that presented here.

In order to quickly detect the blocks that should be priority concerning noise control actions, some maps were developed as shown in Figure 4.

The urban blocks highlighted in Figure 4 correspond to those sheltering more than 60 inhabitants, all of them exposed to high sound levels [above 65 dB(A)] in both periods of peak hours, thus conflicting with the recommendations. These are blocks of streets and avenues with a large vehicular flow.

There are five urban blocks, for which mitigating measures for noise reduction should be taken into account, as seen in Figure 5. These

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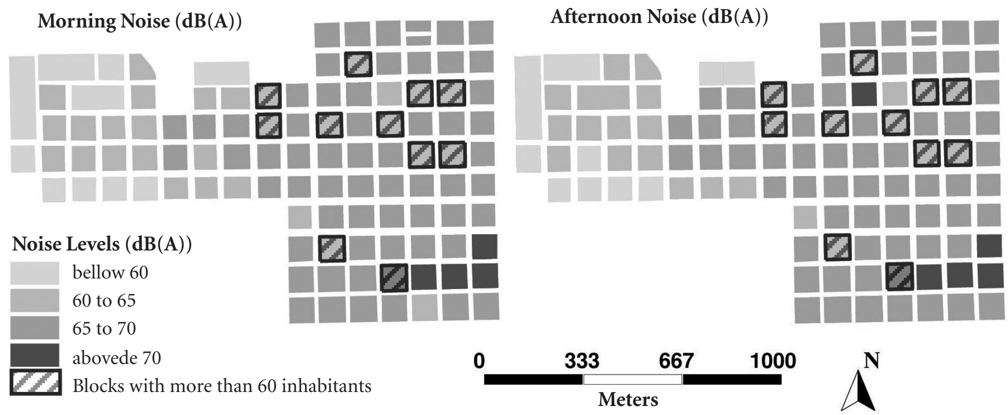

Figure 4. Blocks classified by noise levels, highlighting those with more than 60 persons, in the city of São Carlos, SP.

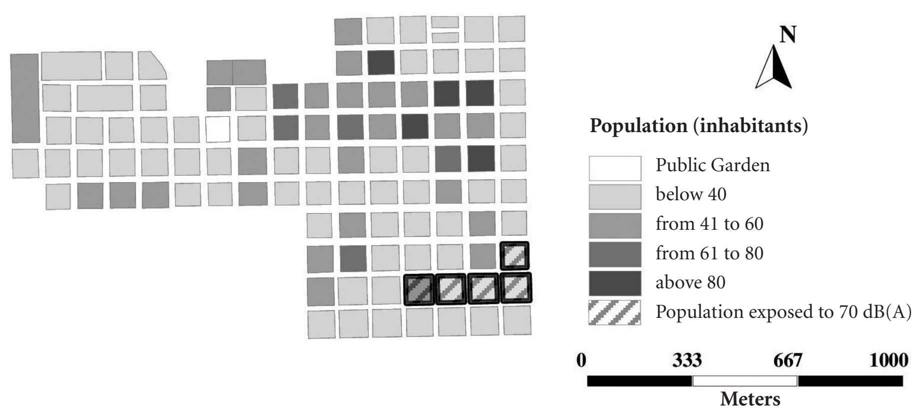

Figure 5. Classes of number of persons exposed to environmental noise per urban blocks in the city of São Carlos, SP, highlighting those where the population is exposed to noise levels above 70 dB(A).

blocks are currently found in critical noise conditions, because they exceed the 70 dB(A).

A way of mitigating this issue is discussed by Alesheikh and Omidvari[41]. The authors observed high levels of noise in residential areas and indicated the need to verify the emissions of the old vehicle fleet and optimize the quality of public transportation in order to achieve a minimization of the noise disturbance caused by these factors.

In the case of the city São Carlos, the Master Plan considers a densification of the study area by classifying it as an induced occupation area. As a consequence, a vehicular flow increment and the intensification of noise sources should be predicted for this area. Nevertheless, the general guidelines for this area should be more restrictive than the current ones. The densification of the area should be very cautious in terms of noise consequences, even for the urban blocks under the limits of 55 and 60dB(A), aiming at maintaining the quality of life of the inhabitants.

Conclusions

There is a lack of information concerning noise pollution and the damage it causes to the population in urban centers of Brazilian cities.

In this context, noise maps are a useful tool, helping to verify noise levels, identify areas contaminated by noise and quantify population exposure.

An analysis of noise contamination by urban blocks enabled us to identify levels in specific urban points, which helps decision making to prevent and control noise and population exposure.

This study presented the noise mapping technique in a specific scale, which is a different scale considered from the municipal guidelines for occupation zones. Although urban decisions cannot be taken based only on specific issues, the guidelines of the scale of occupation zones are too general, when considering the densification of some areas. Indeed, this may create a deterioration of the environment, due to the intensification of noise emissions that cause disturbance for the population.

The approach by urban blocks is an efficient solution resulting in easy interpretation of the acoustical environment. This method can clearly show the blocks which exceed the limits and, therefore should not experience urban densification or not receive a vehicular flow larger than the current one. There is a need to establish priorities and restrictive actions to control and prevent sound emissions in order to reduce the community exposure to noise. In addition, the classification of urban blocks can be also a tool for environmental education and for the awareness of the population.

This proposal can also be extended to other kind of uses and occupation zones, thus comparing current regulations to any of the acoustical situations presented by the urban area.

Collaborators

MT Suriano collected the data, wrote the text and prepared initial analysis with LCL Souza, who outlined the study and gave substantial contributions to the paper; ANR Silva incorporated the data in a GIS, and prepared maps, complementing the analysis. All the authors worked on the final revision for publication.

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