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Original article

Improving traffic noise simulations using space syntax: preliminary results from two roadway systems

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Noise pollution is one of the four major pollutions in the world. In order to implement adequate strategies for noise control, assessment of traffic-generated noise is essential in city planning and management. The aim of this study was to determine whether space syntax could improve the predictive power of noise simulation. This paper reports a record linkage study which combined a documentary method with space syntax analysis. It analyses data about traffic flow as well as field-measured and computer-simulated traffic noise in two Bulgarian agglomerations. Our findings suggest that space syntax might have a potential in predicting traffic noise exposure by improving models for noise simulations using specialised software or actual traffic counts. The scientific attention might need to be directed towards space syntax in order to study its further application in current models and algorithms for noise prediction.

KEY WORDS: *noise exposure; noise mapping; noise pollution; prediction; theoretical models*

Noise pollution is one of the four major pollutions (air, noise, water, and soil) in the world. Approximately 80 million people in the European Union suffer unacceptable noise levels (>65 dB) and over 170 million are exposed to noise levels between 55 and 65 dB (1, 2). Noise levels above 85 dB can cause hearing impairment (3). Even when environmental noise is not loud enough to cause physiological and psychological symptoms, it significantly affects the quality of life (4, 5).

According to the World Health Organization (6), at least one million healthy life years are lost every year from traffic-related noise in Western Europe. Bulgaria has been estimated to have lost about € 11.6 million annually due to traffic noise-attributed myocardial infarction (7).

Noise pollution continues to grow in extent, frequency, and severity as a result of population growth, urbanisation, and technological development (8). It is a common cause of various types of psycho-social and health-related impairments (9-12). In Europe, road traffic noise constitutes the dominant source of noise annoyance (13).

Land use and transportation development policies have significant effects on urban environment and health (14). In city planning and management it is therefore essential to assess traffic-generated noise in order to implement adequate strategies for noise control (15, 16). Traditionally, local authorities address this issue by creating strategic noise maps based on computer simulations, taking into account the plan of the city, acoustical properties of buildings, open spaces, street corridors, and the distribution of noise in this system (15). This is an alternative to measuring the acoustic characteristics of the whole city, which may not be feasible due to the great number of measurement points, time, and resources required (16). There are various simulation software packages to predict noise. In Bulgaria, for example, LimA v. 5 (Brüel & Kjær, Nærum, Denmark) (17) was used to create strategic noise maps. To achieve high quality in simulations, a precise mathematical modelling of the environment, of the sources, and of the propagation law of sound is needed (18), and such high quality is mandatory because many protected facilities in Bulgaria like schools and hospitals are exposed to unacceptably high noise levels.

Noise mapping simulations might be somewhat problematic because "noise map accuracy can be greatly affected by several data inputs at the model building stage", including grid resolution (16). A general limitation of this approach is that simulations take into account only the factors associated with the distribution of sound waves in reference to their possible source and the barriers that they come in contact with. With "NMPB-Routes-96", which is used in Bulgaria, on the other hand, the noise level is overestimated in downward propagation conditions (18). Quartieri et al. (19) therefore proposed a purely theoretical statistical procedure for traffic-noise prediction, independent of experimental data.

Studying the application of space syntax (SS) - an architectural technique developed to predict human navigation in urban environments - in traffic prediction, we encountered an interesting phenomenon; some SS measures seemed to be highly associated with traffic-generated noise. Further investigation of their relationship showed that those SS measures actually could predict noise exposure above and beyond traffic counts and could improve the predicting model when complemented by traffic counts as predictors of noise. This potential contribution of SS to noise prediction models has not been addressed in literature before. The first step towards implementing SS in actual noise predicting simulation would be to understand the predictive potential of SS, like Penn and Croxford (20) suggested in their research, by replicating its findings on a larger scale and by modelling the unique variance in noise exposure that they were hypothesised to explain.

The SS theory was developed in the 1970s, and it reflects the relationship between the configuration of the road network and vehicular and pedestrian flows (21-23). Being an alternative to the classical theories of traffic assignment (21), SS has the ability to capture the trends of vehicular travel demands (24). Traffic flow has not been contextualised in the spatial configuration of Bulgarian cities (25). There is also a gap in the literature about implementing SS in noise prediction. Nevertheless, SS has been found to predict well average and extreme vehicular carbon monoxide concentrations (20). Hence, as both air and noise pollutions are caused by traffic, SS might be able to predict noise exposure as well.

The aim of this study was to determine whether SS could significantly improve the predictive power of noise simulation. In this paper we propose possible use of SS in noise control and look into the mechanism of its explanatory power. We hope to inspire future research that would ultimately explore its potential in noise prediction and identify the practical benefits of including SS in simulation algorithms.

MATERIALS AND METHODS

Study design

This paper reports a record linkage study that combined the documentary method with space syntax analysis. It analyses field-measured and computer-simulated traffic noise levels in the two most populated Bulgarian agglomerations. As it does not involve human participants and uses official municipality reports, it was not subjected to ethical evaluation by the University Committee.

Study area

The cities of Sofia and Plovdiv were selected for the analyses because they are the two most populated agglomerations in Bulgaria; moreover, relevant official data sources were available which ensured a satisfactory sample size.

Sofia is the capital and the largest city in Bulgaria, with a territory of 492 km^2. It is located at the foot of Mount Vitosha in the western part of the country and has a population of over 1.2 million (26). The city centre is highly integrated with areas stretching along the major boulevards towards the periphery (Figure 1). The periphery consists of concentrically located neighbourhoods with lower integration.

The city of Plovdiv is the second largest city in Bulgaria with a population of 341 thousand people (26) and a territory of 101.98 km^2. It is situated on the banks of the Maritza River. Plovdiv has a well-defined core with high southwest integration (Figure 2). There is an old grid of small winding streets in the centre of the city. The surroundings have a concentric character with stronger integration towards the south and west. Several highly integrated lines stretch through the city and outwards. There are also some spatially isolated

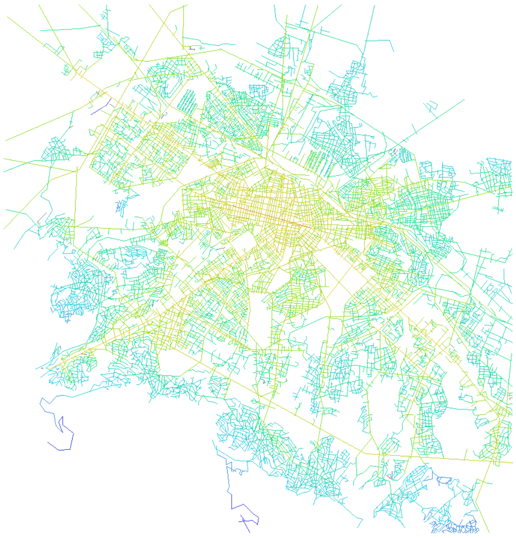

Figure 1* *Axial total integration map of the city of Sofia. Red colour indicates higher while blue indicates lower integration*

areas close to the agricultural fields in Plovdiv's surroundings, the Roma ghetto, the old part in the city centre, and a northern district neighbourhood across the Maritza River (25).

Data extraction

The analyses included 69 street segments in Sofia and 52 in Plovdiv because these were covered by official records that included LimA-simulated and field-measured traffic noise levels (See Appendix).

Field noise measurements had been carried out by municipality experts following the ISO 1996-1/2005 (27) and ISO 1996-2/1987 procedures (28). Sound levels were measured in the field using "Brüel & Kjær Type 2240" sound meter and "Brüel & Kjær Type 4231" calibrator. These data were extracted from the reports "Development of strategic noise map of Plovdiv agglomeration" (29) and "Development of strategic noise map of Sofia agglomeration" (30). Plovdiv field measurements were taken twice and then averaged to improve their accuracy. Those field measurements had been used to validate the strategic noise maps created in compliance with Environmental Noise Directive 2002/49/EC (31) by comparing them to the computer-simulated noise levels. Noise map simulations were made with the LimA v. 5 software (17), using as input data geographic information to construct a city plan and calculated noise levels in order to calibrate the analyses. Traffic-generated noise was calculated based on the French national method "NMPB-Routes-96" (32) and the French standard "XPS 31-133" (33). Correction for the roadway surface was applied according to "EN ISO 11819-1" (34). The simulations assume standard meteorological conditions: 10 °C, 70 % humidity, and "quiet" wind conditions.

Figure 2* *Axial total integration map of the city of Plovdiv. Red colour indicates higher while blue indicates lower integration*

Axial maps of Sofia and Plovdiv

The graphic representation of Sofia's and Plovdiv's streets was based on cartographic information (35) and was made using MapInfo Professional v. 9.0 (MapInfo Corp., New York, NY, USA). Street layer was drawn by hand to adjust for street functionality and the like, as complex plans take too long to analyse with automatic generation of an axial map. Axial maps of Plovdiv and Sofia were created by identifying the minimal set of longest and fewest accessible lines representing the roadway structure of the city. Subsequently the axial map was converted into a segment map (removing axial stubs with less than 25 % of the line) (36). Because choosing adequate radius for the analysis is arbitrary and varies across roadway systems, the segment analysis was performed with a series of specified metric radii (n, 250, 500, 750, 1000, 1250, 1500, 2000, 2500, 3000, 4000, 5000) in order to avoid the edge effect (36, 37). This was done because some segments might be closer to the boundary of the axial map and distort the values. Angular segment analysis breaks axial lines into segments and then records the sum of the angles turned from the starting segment to any other segment within the system (37). The angle of turn is closely related to how people perceive the world (38, 39). For angular segment analysis for the segment map we used Depthmap v.10 (University College London, London, England) (37, 40).

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Variables

SS variables (unweighted and weighted choice and integration) were derived from segment maps of Plovdiv and Sofia assuming different radii around each segment. Integration is a measure of how accessible each segment is from all the others, and therefore how much potential it has as a destination for movement (36). Choice measures the through-movement potential of each segment within that radius in contrast to the to-movement potential measured by integration (36). Choice is a more intuitive model of movement than integration (37). Weighting the choice measure by the product of the lengths of the origin and destination nodes helps integrate axial and road-centre lines (36, 37).

The main outcome variable was field-measured equivalent noise level (Laeq). Independent variables were LimA-simulated Laeq for the same street segments and a combined choice and integration variable at radius "n" as both a destination and a route according to the formula proposed by Hillier:

Integration x [log (Choice+2)] (36).

The analyses were adjusted for the city where measurements were taken as a "dummy" variable.

Traffic counts were represented by light motor vehicles (total laden weight <3.5 t) per hour and heavy motor vehicles (total laden weight >3.5 t) per hour. Mean velocity of light and heavy vehicles, type of traffic flow (accelerated pulsed flow/decelerated pulsed flow/combined flow), direction of traffic flow (one-way/two-way), and the number of lanes on the street segment were included as well. These data had been collected by the local authorities in order to use them as input for constructing noise maps (29, 30)

Statistics and data analytic strategy

The data were screened for univariate outliers and winsorised accordingly (41). Missing values were tested for response pattern with Little's MCAR test and replaced using the expectation-maximisation algorithm. To check the normality of distribution we used graphical analysis and D'Agostino-Pearson K^2 test (42). First, we computed correlations between SS variables and field-measured Laeq. For comparison of two correlation coefficients we used the tools proposed by Weaver and Wuensch (43). Then we ran three hierarchical regressions to determine 1) the predictive power of SS measures above and beyond the LimA-simulated Laeq while controlling for relevant confounders; 2) the same model on local scale in Sofia and Plovdiv; 3) the improvement of traffic count-predicted Laeq after adding SS measures while controlling for roadway characteristics associated with field-measured Laeq.

In order to make inferences from the data without making strong distributional assumptions in the parametric tests we used the bootstrapping method (5000 samples) with bias-corrected confidence estimates. The significance level was set at $p<0.05$ (two-tailed).

All statistical analyses were performed with the SPSS software (IBM SPSS Statistics for Windows, Version 21.0, 2012. Armonk, NY, USA.).

RESULTS

The partial correlation matrix of all SS measures and field-measured Laeq controlling for the city in which the measures were taken revealed that the highest coefficients were associated with Choice-n ($r_{(118)}=0.482$; $p<0.001$), Integration-n ($r_{(118)}=0.531$; $p<0.001$), Weighted choice-n ($r_{(118)}=0.386$; $p<0.001$), and Weighted integration-n ($r_{(118)}=0.485$; $p<0.001$). In order to improve the associations with field-measured Laeq we computed two combined "Choice + Integration" measures – one weighted and one unweighted – according to Hillier's formula and included them in the correlation matrix (36). "Choice-n + Integration-n" (Cn+In) had significantly higher ($t_{(118)}=2.086$; $p=0.039$) correlation with field-measured Laeq ($r_{(118)}=0.604$; $p<0.001$) than "Weighted choice-n +Weighted integration-n" ($r_{(118)}=0.538$; $p<0.001$). We performed all follow-up analyses using both measures, but we report mainly Cn+In, because it yielded a better model fit. However, we compare the results with those obtained from WCn+WIn, which theoretically is the better choice of predictor because it helps integrate axial and road-centre lines (36, 37). Cn+In also had a stronger association with LimA-simulated Laeq ($r_{(118)}=0.628$; $p<0.001$) than any other SS measure.

Cn+In alone explained 37 % (Adjusted R^2) of the variance in field-measured Laeq ($\beta=0.955$; $p<0.001$), controlling for the city where the measurements were taken. Then we performed a hierarchical multiple regression with field-measured Laeq as dependent variable, LimA-simulated Laeq in the first block of predictors, and Cn+In in the second block. The city of measurement was also included in both blocks in order to adjust the associations for it. The coefficients for the model are presented in Table 1.

The quantile-normal plot of the residuals confirmed normality of errors, and the residual versus fit plot confirmed linearity and equal variance. Multicollinearity was not detected (VIF<5; tolerance >0.200). Overall, LimA-simulated Laeq predicted 59 % of the variance in field-measured Laeq, controlling for the city where the data were collected. When Cn+In was added in the second regression block, the model improved by 2.4 %, which was statistically significant. Moreover, when adjusted for the city and LimA-simulated Laeq, Cn+In turned out to be a significant predictor and therefore had unique contribution to the model.

Although we controlled for the city where the measurements were taken, we wanted to see how Cn+In would perform at a local scale. We conducted hierarchical regressions similar to those described above for each of the two cities (without "city" as covariate). For brevity, Table 2 shows only the model summary with R^2 statistics. Cn+In improved the model for Sofia and Plovdiv by 1.9 % and 3.5 %, respectively. While for Sofia this change was statistically significant (we consider p=0.05 marginally significant), for Plovdiv it was not, which might be attributed to the fewer measurements taken in Plovdiv and therefore lower statistical power. This might further be illustrated by the fact that after taking a random sample from the data collected for Sofia with a size equal to that of Plovdiv, the statistical significance exceeded 0.05.

Compared to Cn+In, WCn+WIn produced 1.8 % improvement in the model, controlling for the city where the measurements were taken, which was significant at p=0.023. At individual city level it yielded a 1.9 % and 3.2 % increase in R^2, respectively.

In the final regression we included the counted light and heavy motor vehicles per hour as predictors of field-measured Laeq, controlling for the city where the measurements were taken, the number of lanes of the segment, and the velocity of vehicles, which all correlated significantly with field-measured Laeq (See Table 3). They accounted for 60 % of the variance in field-measured Laeq. Adding Cn+In improved the model significantly by 5.8 %. The difference between the two tested types of prediction models (the first with the LimA-simulated Laeq and the second with motor vehicle counts as predictors) is that while the first implies how SS might improve simulation software's performance and noise mapping, the second suggests that it may improve the predictive capacity through traffic noise formulas based on traffic counts such as those proposed by Quartieri et al. (19) and the French national method "NMPB-Routes-96".

DISCUSSION

Key findings

Overall, our findings suggest that SS might have some potential in predicting noise exposure above and

Table 1 *Coefficient for hierarchical multiple regression model predicting field-measured Laeq from LimA-simulated Laeq and space syntax measures Cn+In, while controlling for the city where the measurements were taken*

Block	Predictor	B	SE	β	t	p	95% BCa CI	
							Lower	Upper
I	LimA-simulated Laeq	0.759	0.089	0.772	13.009	<0.001	0.580	0.917
	Plovdiv	-0.024	0.424	-0.004	-0.060	0.957	-0.894	0.799
	R^2=0.596	Adjusted R^2=0.590		$F_{(2, 118)}$=87.209		p<0.001		
II	LimA-simulated Laeq	0.634	0.090	0.645	8.684	<0.001	0.456	0.795
	Cn+In	0.0001	0.00004	0.319	2.729	0.008	0.00003	0.0002
	Plovdiv	1.497	0.689	0.223	2.206	0.030	0.105	2.721
R^2=0.621	Adjusted R^2=0.611		$F_{(3, 117)}$=63.797		p<0.001	ΔR^2=0.024	Sig. ΔF=0.007	

The city of Plovdiv is coded as a "dummy" variable in reference to the city of Sofia. The p*-values and SE are bootstrap-generated. LimA – noise simulation software; Laeq - equivalent noise level; Cn+In – combined space syntax measure of choice and integration with "n" radius.*
B-unstandardized regression coefficient; SE-standard error of B; β-standardized regression coefficient; t-t-test; BCa CI-bias-corrected and accelerated confidence intervals

Table 2 *Improvement in noise prediction models in both cities of measurement after adding space syntax measure Cn+In*

City	Block	R^2	Adjusted R^2	Change statistics			
				ΔR^2	ΔF	df	Sig. ΔF
Sofia	I	0.668	0.663	0.668	134.804	1; 67	<0.001
	II	0.687	0.677	0.019	3.959	1; 66	0.050
Plovdiv	I	0.289	0.275	0.289	20.304	1; 50	<0.001
	II	0.323	0.296	0.035	2.501	1; 49	0.120

The predictor in the first block is LimA-simulated Laeq and in the second block Cn+In is added. LimA-noise simulation software; Laeq-equivalent noise level; Cn+In-combined space syntax measure of choice and integration with "n" radius

beyond the simulations currently available through specialised software LimA and actual traffic counts. Unweighted measures for the total roadway system provided the best fit of the regression models, but their superiority to the weighted measures was negligible. According to Hillier (36), the segment length weighting version of the measure partially neutralises the fact that block size in cities grows from the centre outwards. Having a measure with a fixed radius, on the other hand, is particularly useful, because it can facilitate noise predictions. If SS can indeed be incorporated in noise predictions, it will be challenging to determine what radius should be used for each roadway system. Would that radius depend on the segments where the measurements should be predicted? We need a theoretical basis for determining the SS measures, because establishing the correlations between SS and noise levels empirically will also give us the actual noise exposure and would render the use of SS irrelevant, as finer predictions could be achieved by hypothesising future noise exposure based on these measured values.

Alternatively, our goal should be to provide adequate predictions without knowing the actual noise levels, for example, in newly developing or already existing street networks that have undergone significant alteration in traffic flow for whatever reason. According to Quartieri et al. (18) the aim of traffic noise modelling is to help plan new infrastructures in order to avoid post-construction mitigation actions that often present a greater cost and to minimise measurement campaign in existing road

Table 3 *Regression coefficients for hierarchical multiple model predicting field-measured Laeq from traffic counts and space syntax measure Cn+In, controlling for roadway characteristics*

Block	Predictor	B	SE	β	t	*p*	95 % BCa CI	
							Lower	Upper
I	LMV/h	0.001	<0.001	0.415	5.153	<0.001	0.001	0.002
	HMV/h	0.008	0.004	0.175	2.317	0.022	0.001	0.016
	Plovdiv	1.783	0.465	0.266	3.833	<0.001	0.861	2.704
	Lanes	0.157	0.235	0.047	0.670	0.504	-0.308	0.623
	VLMV	-0.003	0.028	-0.010	-0.0997	0.923	-0.058	0.053
	VHMV	0.117	0.029	0.427	3.956	<0.001	0.058	0.175
	R^2=0.619	Adjusted R^2 =0.599		$F_{(6, 114)}$=30.925		*p*<0.001		
II	LMV/h	0.001	<0.001	0.276	3.426	0.001	<0.001	0.001
	HMV/h	0.009	0.003	0.181	2.600	0.011	0.002	0.015
	Plovdiv	3.670	0.599	0.548	6.129	<0.001	2.483	4.856
	Lanes	0.028	0.219	0.008	0.129	0.897	-0.405	0.462
	VLMV	0.001	0.026	0.003	0.035	0.972	-0.050	0.052
	VHMV	0.104	0.027	0.381	3.801	<0.001	0.050	0.158
	Cn+In	<0.001	<0.001	0.464	4.526	<0.001	<0.001	<0.001
R^2=0.678	Adjusted R^2=0.658		$F_{(7, 113)}$=33.966		*p*<0.001		ΔR^2=0.058	Sig. ΔF<0.001

The city of Plovdiv is coded as a dummy variable in reference to the city of Sofia. The p-*values and SE are bootstrap-generated. LMV/h-light motor vehicles per hour; HMV/h-heavy motor vehicles per hour; VLMV-velocity of light motor vehicles; VHMV-velocity of heavy motor vehicles; Laeq-equivalent noise level; Cn+In-combined space syntax measure of choice and integration with "n" radius.*

B-unstandardized regression coefficient; SE-standard error of B; β-standardized regression coefficient; t-t-test; BCa CI-bias-corrected and accelerated confidence intervals networks. In our study we propose an interesting insight in the possibility to theoretically derive the needed SS radii and measures without any data on actual noise levels. In fact, just like the field-measured Laeq, the LimA-simulated Laeq correlated better with Cn+In than with any other SS measures. If this proves valid for various roadway systems, then researchers might consider implementing some form of SS to improve noise simulations with radii selected based on correlations with computer-simulated noise levels. Quartieri et al. (19) proposed a statistical model for overcoming the need of experimental data, something they call "parameter free" model. "In this way" – they stated – "one can avoid the noise measurement campaign, in spite of collecting only easy to obtain road info, resulting in a strong save of time and resources" (19). However, a limitation to their approach is that it still requires traffic-flow data. Our goal was to inquire whether predictions could be based on the physical environment and geomorphology as much as possible. Much work needs to be done to justify this hypothesis. Our study is a by-product of a wider research not directly aimed at traffic prediction; it should therefore be considered a hypothesis and its practical implications should not be extrapolated beyond the analysed sample without scrutiny.

Because there is no information in the literature about the mechanisms through which SS might explain noise exposure independently of traffic counts, we propose several options. The main purpose for which SS was developed as a theory was to explain drivers' and pedestrians' behaviour and route choice when navigating through a roadway system (21-23). On the other hand, because SS is a one-dimensional representation of space (44), it can not account for the variance in noise exposure by supplementing geomorphological or geometrical data to simulations, unless it captures some of the correlated variance or linear combination of other traffic-flow and roadway factors. We therefore believe that SS somehow reflects and encompasses some of the variances in noise exposure explained by traffic-flow and some roadway characteristics such as the number of lanes, street-line length, speed limit, etc. Penn and Croxford (20) suggested that "since the pedestrian consumer, the vehicular producer and wind dispersion are all related to the spatial configuration of the built complex, […] spatial variations in pollutant concentrations […] might […] lead to differential exposure of the pedestrian population as they moved through the city". We hypothesize that part of the explanatory power of SS is due to the fact that it corresponds to the accessibility of a street as both destination and pathway to other destinations. Thus more integrated streets with higher choice values are more likely to attract pedestrians and business and lead to the construction of city centres, malls, markets, schools, cafés, etc., which generate some of the street noise. Moreover, these facilities are also more likely to be exposed to traffic noise. In these terms, SS may not only predict exposure levels but the distribution of exposed facilities and populations as well. Conversely, it is not likely to explain peripheral streets and highways. Regardless of whether its predictive capacity is socio-topological in nature, linking street segment use and functioning with noise exposure, or it acts as a mathematical "reflection" of correlations between other factors and noise exposure, if its performance is consistent, it might be of practical use. Moreover, should SS be incorporated in algorithms relying on traffic-counting such as Quartieri's and his group's (19), it might help model that traffic flow.

Limitations

There are some major limitations to our study which render the interpretation of its results preliminary. First, controlling for "city" balanced the predictions and yielded only a 2.4 % improvement in the model after inclusion of Cn+In. However, this should be critically interpreted because of the small number of measurements. In real life one would want to predict traffic noise in a specific city and hence such control variable distorts the model. It might be argued that controlling for city is not the same as analysing the data for each of the two cities separately, and this argument would be true. However, because of the significant difference in sample sizes, in Plovdiv the association between Cn+In and field-measured Laeq was not significant. Statistically significant does not always correspond to scientifically important (45). Fewer measurements taken might also be associated with unequal distribution throughout the city (for example, measurements taken at arterial streets and highways neglecting inner-neighbourhood streets).

There are also issues with expertise, quality of noise measurement, and simulation protocols performed by local authorities in different cities. Some inaccuracies arising from our record linkage, which is susceptible to human error, are also possible, although, if present, they should not have significantly affected the results. Hand-drawing the axial maps implies some imprecision but it is a viable option and it allowed us to exclude some pedestrianised streets.

From the statistical point of view, critics might be concerned about several issues. On one hand, small sample sizes at local scale are typical for SS studies (46). On the other, there is no consensus for statistical data handling in SS. Are outliers to be winsorised and what are the means to detect them? Paul (47) for example, reported significant improvement in their R^2 value after removing the outliers, but whether to keep outliers depends on whether they are meaningful values in the sample and relies on subjective judgment by the analyst. The presence of outliers in a dataset might be justified on some occasions. Also, some authors considered a *p*-value of 0.10 marginally significant (48). Hayes also suggested that we should not be so strict in adhering to a 0.05 criterion (49).

The observed 3.5 % improvement in the predictive model of Plovdiv corresponds to 2.1 dB, if we assume that we are trying to predict Laeq=60 dB. This might not considerably affect decision-making and transportation policy, but if SS can be easily implemented, why not take the advantage of those 2.1 dB? Moreover, if SS theorists, acoustics experts, and computer scientists find practical benefits in our findings from both theoretical and empirical point of view, they might find ways to refine SS and give it more predictive power.

Variables associated with street geomorphology and traffic laws, which are supposed to affect traffic flow, were not included in the regression model using the LimA-simulated Laeq as predictor because the city plan and geomorphology are parameters already present in noise simulation algorithms. Nevertheless, other simulation packages should be tested by including SS measures.

Finally, SS is often criticised for the so-called “edge effect”, which is associated with the total radius “n” that we used (36).

Implementation

This study might inspire further investigation into the ways to enhance the predictive capacity of current simulation algorithms. The next logical step for experts in the field of acoustics and architecture would be to replicate our findings and to conceptualise SS in this new light. Larger sample sizes, simulations with different programs, and inclusion of SS in the actual mathematical procedures of noise mapping will provide sufficient data whether our hypothesis holds. Finally, experimentation and field testing might be of use in revealing the intrinsic mechanisms through which SS adds explanatory power to noise modelling.

CONCLUSION

This paper provides an insight into the possibilities of implementing space syntax in traffic noise prediction with the aim to improve noise prediction or at least make it less dependent on empirical data collection. In our study, space syntax improved traffic noise predicting power of both traffic counts and simulation models, but the intrinsic mechanisms of this effect remain unclear. Currently we are broadening our research by including data from more diverse roadway systems. However, it is beyond the scope of this paper and the competence of its authors to study the mathematical justification of such approach.

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Sažetak

Primjena prostorne sintakse radi poboljšanja simulacija buke: preliminarni rezultati iz dvaju cestovnih sustava

Buka je jedan od četiriju glavnih oblika onečišćenja u svijetu. Da bi se urbanim planiranjem i upravljanjem gradovima mogle osmisliti i primijeniti odgovarajuće strategije ograničavanja buke, ključni je korak procijeniti razinu prometne buke u nekom gradu. Cilj je ovog istraživanja bio utvrditi može li prostorna sintaksa, koja se od 70-ih godina prošlog stoljeća rabi za predviđanje kretanja ljudi u gradskom okolišu, pridonijeti većoj prediktivnoj snazi simulacija buke. Analizirani su podaci o prometnim tokovima i o prometnoj buci dobiveni mjerenjima na terenu i računalnim simulacijama u dvama bugarskim gradovima: Sofiji i Plovdivu. Rezultati upućuju na to da prostorna sintaksa može poslužiti u predviđanju izloženosti prometnoj buci s obzirom na to da je u ovom istraživanju poboljšala postojeće modele simulacije buke koji se temelje na računalnim izračunima odnosno stvarnim mjerenjima. Nadamo se da ćemo ovim privući pozornost znanstvene zajednice na prostornu sintaksu kako bi se nastavila istraživati njena primjena u postojećim modelima i algoritmima predviđanja buke.

KLJUČNE RIJEČI: *izloženost buci; mapiranje buke; onečišćenje bukom; predviđanje; teorijski modeli*

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Appendix *Basic input data for the analyses*

Street segment №	LMV/h	HMV/h	VLMV	VHMV	Field-measured Laeq [dB]	LimA-simulated Laeq [dB]	Cn+In
Sofia							
1	5779	234	70	70	81	79.2	44955.23
2	1516	163	55	45	71.8	73.2	37773.19
3	1819	164	10	10	72.2	74.02	40042.09
4	1074	71	50	50	71	72.18	29812.51
5	1322	125	40	40	70.2	72.06	36661.1
6	2908	201	65	45	74.4	73.2	31151.4
7	2040	178	60	40	71.3	70.41	32376.08
8	1345	70	45	40	72.5	73.35	31904.9
9	3753	57	40	30	71.8	69.2	25665.94
10	3197	18	45	35	68.1	65.94	26684.81
11	1746	230	60	50	70.3	72.7	36910.77
12	6417	208	70	70	80.1	78.55	44940.01
13	1635	74	65	60	75.04	69.47	43874.7
14	1800	67	65	55	79.9	76.46	43326.24
15	3334	114	50	40	69.7	67.56	35042.3
16	2249	81	70	50	72.6	74.05	38659.8
17	1647	124	40	30	71.1	73.91	38996.72
18	4213	91	75	60	75.6	75.47	37377.41
19	1629	111	65	50	73.2	70.93	33825.75
20	2183	137	60	50	72.4	75.83	38642.21
21	1667	59	35	35	70.6	69.7	27197.07
22	1756	37	45	40	71	68.14	41555.27
23	1850	159	60	60	72.3	72.4	37708.98
24	2528	132	50	45	72.5	70.19	30387.78
25	1319	71	60	55	71.6	72.95	28192.88
26	2498	29	40	40	73.1	75.48	42071.28
27	1864	38	35	30	71.9	74.84	42349.43
28	1251	27	40	40	70.2	70.73	38187.25
29	1881	30	40	40	75.4	72.58	34537.03
30	1356	23	50	45	72.88	73.69	42605.67
31	3445	311	55	55	73.8	75.18	36218.34
32	495	2	45	35	66.5	64.6	24396.26
33	3436	336	45	35	70.2	69.94	41887.45
34	1764	181	40	35	70.2	71.98	37874.36
35	1245	71	30	35	70.2	69.07	37217.7
36	887	35	40	40	69.2	68.76	42207.48
37	1205	77	30	35	68.9	65.79	20579.16
38	799	75	30	35	70.3	67.61	25340.46
39	311	13	25	30	65.5	65.23	16927.15
40	131	2	25	20	60.8	62.81	17508.96
41	1095	57	45	40	70	68.16	24935.67
42	1442	91	45	40	70.7	68.94	24854.3

Street segment №	LMV/h	HMV/h	VLMV	VHMV	Field-measured Laeq [dB]	LimA-simulated Laeq [dB]	Cn+In
43	1168	81	40	40	70.1	68.05	31957.86
44	1824	334	50	50	75	73.9	22958.04
45	1107	233	65	60	73.4	76.14	34981.51
46	100	7	35	30	62.2	64.69	19908.12
47	2342	186	70	80	76	77.86	29711.56
48	216	16	40	20	64.5	66.91	17481.98
49	932	73	35	35	68	66.41	29942.46
50	950	80	60	60	75.1	72.91	31056.65
51	803	143	50	40	72.7	74.96	26290.04
52	30	3	50	30	60.4	62.09	17530.29
53	1954	31	60	60	72.6	75.44	46932.51
54	1467.68	40.93	36.7	30.51	67.96	69.84	21772.55
55	778	100	50	50	71.4	60.95	21873.29
56	270	112	60	50	71.3	68.69	25431.56
57	826	74	55	50	70.9	68.77	25619.7
58	69	12	40	30	63.8	65.98	15005.46
59	1300	211	50	45	72.1	74.19	29197.91
60	2157	156	60	50	74.4	74.06	34286.43
61	520	75	50	45	70.6	72.98	29172.59
62	986	190	50	40	72	73.38	31011.59
63	233	53	50	40	67.9	68.13	30577.52
64	1249	17	40	40	71	68.71	36661.86
65	77	10	40	30	62.3	63.99	22525.88
66	582	12	40	35	70	69.07	31922.18
67	1864	19	40	35	70.2	68.76	27189.62
68	177	3	5	5	64.5	66.83	32919.91
69	1543	62	50	45	69.7	67.44	30478.71
Plovdiv							
70	355	25	40	30	65.31	66.68	12965.27
71	863	46	46.04	36.04	69.57	68.48	16720.02
72	723	66	40	40	73.03	70.39	14134.13
73	975	63	40	30	70.8	72.04	16024.48
74	962	60	46.69	30	72.63	73.15	16205.69
75	637	35	60	30	70.8	69.68	13918.76
76	825	28	46.69	40	68.67	70.49	16760.89
77	903	53	40	20	71.52	71.03	17463.83
78	948	56	50	30	70.22	68.05	16792.72
79	971	25	50	50	68.14	70.33	18944.17
80	696	9	40	30	72.33	69.6	19525.87
81	592	28	50	40	70.13	67.68	17039.14
82	962	64	50	43	71.18	71.51	17430.56
83	972	96	40	30	71.82	69.63	17501.33
84	945	100	50	40	71.47	68.64	16536.43
85	955	62	55	55	72.36	71.72	14256.89

Street segment №	LMV/h	HMV/h	VLMV	VHMV	Field-measured Laeq [dB]	LimA-simulated Laeq [dB]	Cn+In
86	498	0	20	7.5	65.51	68.33	10946.33
87	960	55	55	55	71.19	68.19	15864.3
88	87	5	35	35	66.95	68.32	14214.69
89	973	69	45	45	70.35	71.07	16139.52
90	259	5	30	30	66.36	69.34	18871.25
91	393	5	30	10	67.62	67.24	19092.04
92	369.7	31.99	27.33	20.07	67.35	71.61	16497.82
93	1064.29	66.91	43.33	22.37	71.55	67.31	17899.69
94	835	18	30	30	68.91	69.9	16530.74
95	335	12	30	20	69.06	70.27	12999.37
96	659	43	60	40	68.9	70.38	17452.76
97	1286	89	55	30	70.78	67.53	16208.06
98	372	19	40	30	69.58	66.21	18144.33
99	887	50	50	30	70.85	70.36	18513.17
100	1113	39	50	40	70.95	73.98	19666.89
101	503	11	60	40	69.23	67.84	19650.3
102	635	32	50	30	68.66	68.79	16078.42
103	606	16	50	30	68	66.22	12653.95
104	949	61	60	40	73.07	70.29	15792.13
105	750	42	50	30	67.9	66.98	14598.81
106	836	45	40	30	70.59	70.31	11039.68
107	714	41	40	40	69.3	70.48	16470.02
108	634	43	40	30	66.05	67.35	16072.92
109	940	74	60	40	70.67	67.77	17837.2
110	934	67	60	40	72.45	72.48	18895.05
111	295	32	40	30	66.33	67.48	8638.1
112	332	37	40	30	67.66	66.57	8305.71
113	656	54	50	40	69.68	71.59	19787.06
114	914	71	60	40	71.44	71.25	19758.51
115	949	87	40	40	74.6	72.59	19602.74
116	978	68	50	40	72.7	70.92	19193.2
117	952	76	50	30	72.88	70.98	20738.31
118	526	29	30	30	69.81	66.03	14540.07
119	962	75	40	40	73.72	70.94	13063.25
120	895	25	50	30	71.14	73.6	19195.69
121	382	14	40	30	68.67	66.87	10866.59

LMV/h – light motor vehicles per hour; HMV/h-heavy motor vehicles per hour; VLMV-velocity of light motor vehicles; VHMV-velocity of heavy motor vehicles; LimA-noise simulation software; Laeq-equivalent noise level; Cn+In-combined space syntax measure of choice and integration with "n" radius