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Generating a structural map of urban zones noise sensitivity using the concept of Local Climate Zones mapping

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ABSTRACT

It is a widely accepted assumption that there is a connection between urban structure and sound propagation. Various studies have shown this connection, e.g. based on complexity parameters or parameters like the sky view factor of various urban building structures.
This study focuses on a deeper analysis of topological relationships between urban morphology, sound propagation and noise as an environmental stressor. In particular, the impact of urban forms and structures on the propagation of noise and the suitability of discretized urban zones as a basis for robust estimation of noise exposure will be examined. Therefore, the urban structure will discretized into structural units based on the concept of Local Climate Zones by using free data, such as satellite imagery and open source data. To verify the results for the identified and discretized structures, noise propagation will be calculated for the generalized structure types by using the software CadnaA. The research ultimately aims to generate a so-called "structure map" of noise sensitivity of urban zones.

Keywords: Noise, Environment, Noise Mapping, Annoyance
I-INCE Classification of Subject Number: 51, 76

1 INTRODUCTION

In 2015, more than half of the world´s population already lived in cities, and the number continues to rise. The UN expects urbanization to reach 60 % by 2030 and about 75 % by 2050. Therefore, cities are the places where most people live and work, where governments, trade and transport meet. Cities also continue to gain economic importance. Today up to 80 % of the gross domestic product is generated in cities [1, 2]. This continuing trend poses a variety of challenges, such as the increase of

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environmental stressors, mobility problems and socio-economic polarization [3, 4]. If one also considers that humans are directly affected by the environment in which they live, the urban setting has a direct influence on their well-being and health. It is therefore becoming increasingly relevant how this environment must be designed in order to enhance positive effects and keep to the negative impact to a minimum [5].

The resulting conflict is particularly evident in the field of transportation. The increased use of the transportation system leads not only to a sharp increase of carbon dioxide emissions, but also to a significant increase of the traffic induced noise levels [4]. Air pollution and noise are a burden and a threat to large sections of urban society: *"54% of Germans feel disturbed or annoyed by traffic noise [6]"*. At the same time, noise has a major impact on health: *"[...] at least one million healthy life years are lost every year due to traffic noise in Western Europe [7, 8]"*.

Providing sufficient housing and infrastructure in the 21st century, is a priority not only in all major cities in Europe, but throughout the world. The importance of sustainable urban development, including health aspects, should not be overlooked [2]. It is important to examine the existing structures and their influence on well-being and health. This enables a sustainable redesign and further development of cities. The existing possibilities for calculations of noise pollution are computational expensive and data intensive. A simple derivation of sound sensitivity from a cities structure can help to get a first and good impression of the connection between the built city and noise pollution and the resulting health effects.

2 THEORETICAL BACKGROUND

Similar problems exist in the field of urban climate research. The concept of Local Climate Zones (LCZ) made it possible to derive the localization of the Atmospheric Urban Heat Island (UHI) by identifying different landscape and city structures. The approach of the following analysis is to proof the transferability of the LCZ concept to create a fast and cost-efficient possibility to deduce sound pollution from urban structure units (USU) and thus to enable conclusions to be drawn about the connection between urban structure, health and well-being. In order to demonstrate the similarities between the concepts a literature review is presented.

2.1 Urban Heat Island

An UHI is an urban area which is warmer than the rural surroundings [9]. Factors that contribute to this phenomenon are among others the geometry of urban buildings, the thermal properties of the building substance, the radiation properties of the surfaces and the anthropogenic heat release [10]. Densely built-up areas lead to an increase of surface area on which solar radiation is absorbed. The absorption of solar radiation is additionally enhanced by the occurrence of multiple reflections on building walls. The use of building materials with low reflectivity (e.g. asphalt) also leads to increased absorption of solar radiation. In addition, buildings are obstacles to atmospheric currents and urban development therefore increases the roughness of the earth's surface. In simple terms, it can be said that the thermal, humid, aerodynamic and radiation characteristics of a city differ significantly from those of rural areas [11, 12].

2.2 Local Climate Zone concept

To break down this dichotomous view between city and suburban space and to enable a more detailed analysis of the UHI STEWARD & OKE proposed the LCZ concept in 2012. They defined LCZs as regions of uniform surface cover, structure, material, and human activity that span hundreds of meters to several kilometers in horizontal scale. Each LCZ has a characteristic screen height temperature regime [13]. STEWARD & OKE distinguished 17 zones at local level. The parameters shown in Table 1 are used to determine the affiliation of different areas to one of these zones.

Table 1: Local Climat Zone Classification System
According to STEWARD &OKE 2012

Sky view factor	Ψ_{sky}	Fraction of sky hemisphere visible from ground
Aspect ratio H/W	H/W	Mean height to width ratio of street canyons
Mean building/tree height	Z_H	Geometric average of building height
Terrain roughness class	R_a	Approximates surface roughness by calculating the mean absolute departure of the elevation values from the mean plane.
Building surface fraction	λ_b	Proportion of ground surface with building cover
Impervious surface fraction	λ_i	Proportion of ground surface with impervious cover
Pervious surface fraction	λ_v	Proportion of ground surface with pervious cover
Surface admittance	μ	Ability of surface to accept or release heat
Albedo	α	Surface reflectivity at local scale, under a clear midday sky
Anthropogenic heat flux	Q_F	Mean annual anthropogenic heat flux density at local scale

Several approaches have been developed to identify LCZs of urban areas using specific databases, such as satellite images and earth observation data. The set of methods includes approaches using Geo wiki, supervised classification based on pixels [14, 15], object based image analysis [15, 16] and Geographic Information System (GIS) based methods [17].

2.3 Local Climate Zone mapping

AMAN et al. gave a overview of the advantages and disadvantages of currently used methods in 2018 [18]. One of them is WUDAPT (World Urban Database and Access Portal Tools) [19]. The approach is based on open source data and tools. The WUDAPT community provides 3 levels of LCZ map. Maps of the city are referred to as the 'level 0' product as they represent the first level of information about urban areas. Level 1 and 2 represent more detailed and higher information resolution [20]. For the lowest level of detail (L0) WUDAPT uses remote sensing data and software tools [21, 22]. The LCZ classification process comprises three main steps: first, the pre-processing of the satellite raster data; second, the digitization and pre-processing of the corresponding training areas; and third, the application of the classification algorithm [23, 24]. The final result is an LCZ map of an urban region in which each LCZ type has universal values that describe aspects of urban forms and functions (see Fig. 1) [18].

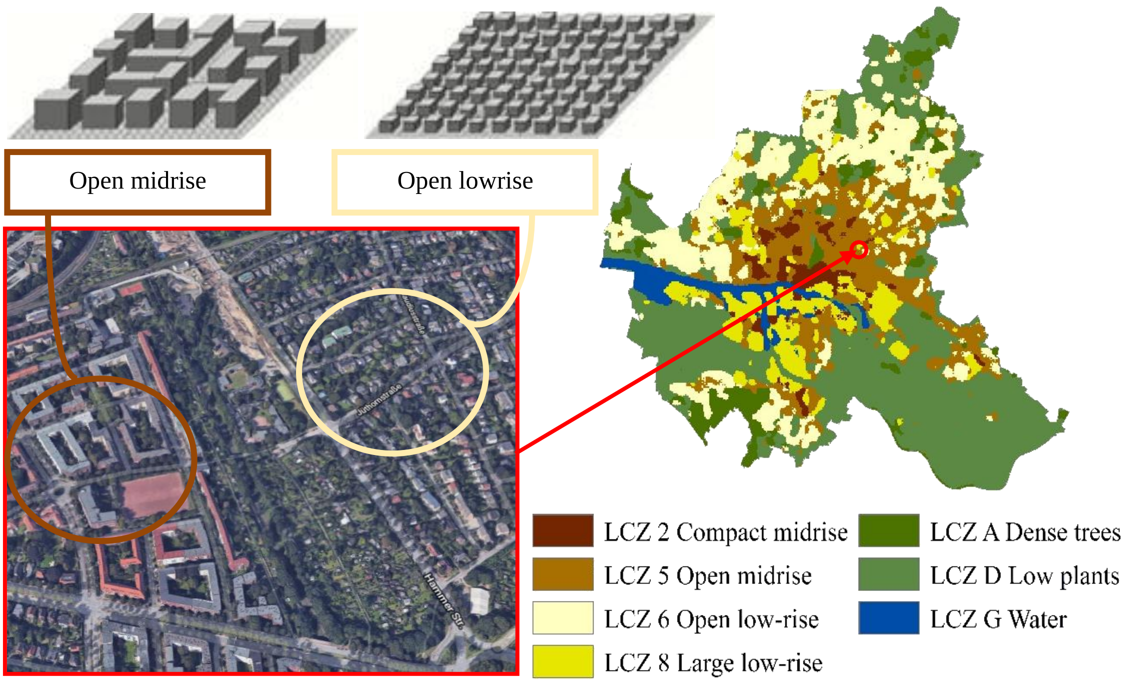

Fig. 1: LCZ for Hamburg
According to REN et al. 2017
Data sources: KOTTAS 2016

WURM et al. (2016) proposed a different approach. By using Shape-Based Features and the application of an Linear Discriminant Analysis (LDA), they proved the feasibility to classify different LCZ building types based on the country-wide building model at the level of detail 1 (LoD1) [25]. The analysis was based on 1D, 2D and 3D parameters, of which the majority are originated from landscape analysis [26, 27]. The LDA indicated that the complexity index according to ANGEL et al. 2010 [27] has a particularly high contribution to the discrimination of building types. Among the 3D features, 3D shape index and height contribute most importantly to the classification

[25]. Other parameters that provided a high degree of explanation are listed in the Table 2.

Table 2: Some of the most important shape based features for the classification of building types
According to WURM et al. 2016

Area	Building Area [m²]
Length vs. with [m]	Elongation of the Building footprint in terms of length, with and their ratio
rectang	Compares the object to a rectangle with the same size where 0 equals no similarity and ideal similarity
asymm2D	The areal asymmetry of an object describes the relative length of the object compared to a regular object
BI_2D	2-D border index expresses how jagged the perimeter P is of an object. It is similar to the compactness 2D
SI_2D	2-D shape index describes the smoothness of the outer shape of an object
nPeriInd	Normalized perimeter index Proportion of perimeter of a circle with the same area as the building object with the same perimeter as the building object
SI_3D	3-D shape index describes the smoothness of the outer shape of an object
nPI	Proximity index is based on the calculation of the Euclidian distance between single pixels on an object and the object center
Frac	Fractal dimension is shape index based on perimeter-area relationships; the perimeter-area method quantifies the degree of complexity of the planar shapes.

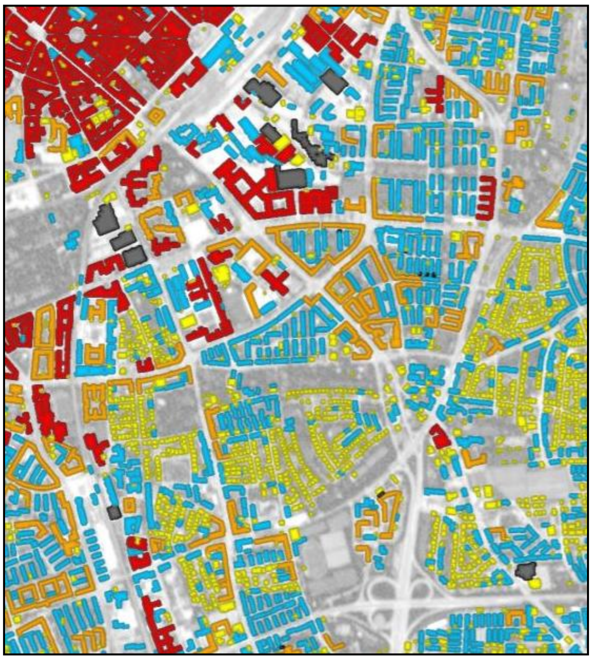

Fig. 2: Spatial subset of exemplary classification results of the five building types for the test site Munich for a small area.

Colors represent building types: yellow - semi/detached houses; red - block development; orange-perimeter block development; blue-terraced houses; and black-halls.
Background image: RapidEye/BlackBridge
Source: WURM et al. 2016

2.4 Sound propagation in urban areas

The propagation of sound waves is subject to similar physical laws as radiation. In undisturbed rooms, the law founded by FERMAT that radiation always propagates in the fastest way from transmitter to receiver can therefore also be applied to sound propagation [28]. In the case of ambient noise and road traffic, however, undisturbed propagation is rarely the case. On the way from sound source to receiver, interference and thus changes in the sound pressure level can occur in many different ways. These modifications between sound source and sound receiver are described by the process of transmission. Influencing factors included in the calculations and how the different interfering factors affect the level at the immission site are defined in ISO 9613-2: 1996 [29]. The sound pressure level L_W^* at the sound source will therefore be reduced at the immission site (L_p). Mathematically the reduction can be described as follows:

[1] $$L_p = L_W^* - A_{div} - A_{atm} - A_{gr} - A_{bar} - A_D - A_G + A_{ref}\ dB$$

Table 3: Influencing parameters on sound propagation
According to ISO 9613-2

A_{div}	Geometric propagation
A_{atm}	Attenuation by air absorption
A_{gr}	Attenuation by the ground due to porosity (degree of sealing)
A_{bar}	Attenuation by shielding
A_D	Attenuation by vegetation
A_G	Attenuation buildings and other constructions
A_{ref}	Sound level increase due to reflection

The lower boundary layer is particularly relevant for sound propagation outdoors. In this boundary layer, turbulent currents are of minor importance, whereas wind speed and temperature gradients are relatively large [30]. Depending on the sound height, direction and the diffraction of the sound caused by the meteorological conditions, refraction and reflection of the sound may occur at temperature layers and on the ground [31]. The influence of the soil varies depending on the degree of sealing [32]. In addition to the vegetation, in urban areas buildings function as obstacles and reflection factors. Therefore it is not surprising that the influence of urban forms has been analyzed intensively in recent years [33].

2.5 Urban morphology as noise predictor

Nowadays it is a widely accepted assumption that there is a connection between urban structure and sound propagation. Various studies have shown this on the basis of so called complexity parameters or parameters like the Sky view factor (SVF) of various urban building structures. E.g. VILLAVERDE et al. showed that there is a correlation between the complexity of an area and the total noise pollution in 2014 [34]. They analyses the relationship between total noise pollution and the street width to building height ratio (SW/H). For regular areas, the joint multifractal spectrum shows a clear positive correlation between the SW/H ratio and the total noise pollution. However, for irregular morphology this relationship is positive but it occurred less frequently [34]. SILVA et al. 2014 came to a similar conclusion. For generalized USU they calculated the sound propagation and determined indicators which allowed statements about the compactness of different USU. It was thus possible to demonstrate that the mean sound level on the façade increases with the increase of the ratio of open space (ROS), for example [35]. In a study in 2017 SILVA et al. showed that the noise levels are inversely proportional to the SVF [36]. Further studies have been carried out over the last 15 years. They all came up with similar results. With the help of noise mapping they proved that different types of residential blocks result in different traffic noise burden [37–43]. Table 4 gives an overview of the most important parameters examined in these studies.

Table 4: Frequently used parameters for determining the influence of the USU on sound propagation

Area [m²]	Building Area
CI	Compactness Index is the Σ volume frame / Σ urban area
PI	Porosity Index is the permeability of the urban form, the ratio of the empty surface on the total surface area
RAF	Road Area Fraction
DFBR	Distance of First-row Building to Road
CAR	Complete Aspect Ratio
BSAPAR	Building Surface Area to Plan Area Ratio or density
HWR	Height-to-Width Ratio
BFAI	Building Frontal Area Index
SVF	Fraction of sky hemisphere visible from ground
FRAC	Fractal dimension is shape index based on perimeter-area relationships. The perimeter-area method quantifies the degree of complexity of the planar shapes

This brief overview of the approaches and methods of the two research fields already gives an idea of the similarities between the forms and parameters used. In the following, both categories are directly compared.

3 URBAN STUCTUS UNITS VS. LOCAL CLIMATE ZONES

The assumption is, that if similar urban forms and similar parameters are involved, the algorithm for classifying LCZs must be transferable for the sound sensitivity of the different forms. This is illustrated by a comparison of the research defined areas and the parameters used for identification.

3.1 Analysis of the qualitative attributes

In particular, the more recent studies show a great similarity in the choice of USU to the classification of LCZs. Fig. 3a shows selected USU according to ZHOU et al. 2017 (upper line). Below are the LCZ generalized according to STEWARD & OKE and correspondingly classified urban areas. The similarities are clearly visible.

Fig. 3a: USU vs. LCZ

Top: "Characteristics of different residential blocks development in Tianjin"
From left to right: Low-rise small - Unit community - Modern residential - High-rise small
Source: ZHOU et al. 2017.

Middle and Botom: "Illustrated LCZ and High-angel photograph of corespondening urabn area"
From left to right: Compact Lowrise - Open Midriese - Compact Midriese - Compact Highrise
Source: STEWART 2008.

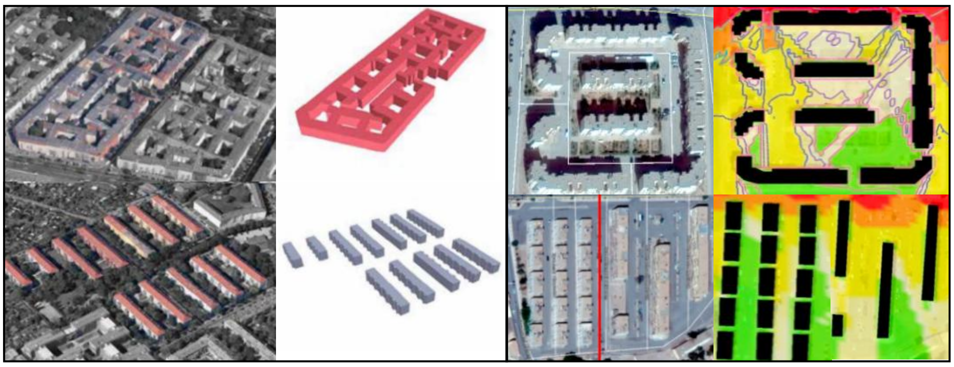

Fig. 3b: Generalized LCZ vs. Generalized USU

1.and 2. from left: Building types as viewed from aerial imagery (Google Earth) and as they are represented in the building model (right) block development (top) terraced houses/row houses (bottom).
Source: WURM et al.2016

1.and 2. from right: satellite view of selected neighbourhoods (right) and noise map (left) of two study areas.
Source: BOUZIR & ZEMMURI 2017

This becomes even more obvious when looking at the generalized forms for calculating the parameters. Fig. 3b compares the LCZs determined by WURM et al. 2016 versus two study areas of BOUZIR & ZEMMURI 2017.

As described in the chapters above, both studies are based on landscape structure metrics and other shape parameters. The following comparison shows that the shapes not only resemble each other externally, but in both fields of research almost identical parameters are used.

3.2 Analysis of the quantitative parameters

If the parameters used for the classification of the LCZ and their derivation from remote sensing data, as well as the parameters used for the calculation of sound propagation and for the determination of the sound sensitivity of USU are grouped together thematically, the common components become even clearer. As can be seen in Table 5, four groups can be formed.

Table 5: Thematic groups of exemplary parameters

<table>
<tr><th></th><th>LCZ</th><th>USU</th></tr>
<tr><td rowspan="2">2D</td><td colspan="2">Building Area</td></tr>
<tr><td>Building surface fraction</td><td>Building Plan Area Fraction</td></tr>
<tr><td rowspan="3">3D</td><td colspan="2">Aspect ratio</td></tr>
<tr><td>Roughness</td><td>Complete Aspect Ratio</td></tr>
<tr><td colspan="2">Sky view factor</td></tr>
<tr><td rowspan="2">Complexity</td><td>Rectangle</td><td>Compactness Index</td></tr>
<tr><td colspan="2">Fractal dimension</td></tr>
<tr><td rowspan="4">Reflection/ Absorption Index</td><td>Impervious surface fraction</td><td rowspan="2">Attenuation through ground</td></tr>
<tr><td>Pervious surface fraction</td></tr>
<tr><td>Surface admittance</td><td rowspan="2">Reflection on ground and obstacles</td></tr>
<tr><td>Albedo</td></tr>
</table>

The first group consists of 2D shape parameters which deal mainly with the relationship between built-up area and free area. The second one comprises horizontal parameters and the resulting roughness. Group three summarizes parameters that describe the degree of complexity of the buildings and the building structure. The last group is more general and refers to the parameters that deal with the reflection and absorption properties of the environment and the material used.

4 CONCLUSION

The literature analysis shows that generalized urban structures are considered both in the field of sound exposure and UHI analysis. Already, the purely external form shows that the classified and defined areas are nearly identical. Additionally, it is not only this external similarity of USU and LCZ, but also the parameters used to discretize the structure of LCZ that are similar to those used to determine the influence of USU. For example, SVF and complexity parameters are often used in both contexts as well. Based on this, it can be assumed that a similar discretization of the city structure with regard to its sound propagation sensitivity must be possible. Therefore, it should work out to transfer the concept for mapping LCZ from open source data to the noise sensitivity of USU. To verify this, further tests must be performed.

The next step is to calculate the relevant parameters for sound propagation for the study area Hamburg and to perform a discriminant analysis to classify the USU according to their influence. To verify the results for the identified and discretized USU, noise propagation will be calculated for the generalized structure types.

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