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Sounds of Smart City: a subjective review of acoustical problems appearing in creating intelligent urban areas.

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Abstract
The article is a subjective review of the problems that, according to the authors, should be considered when planning and designing smart urban areas in the context of the presence of sounds in the Smart City structure. In the introductory part, the preliminary assumptions underlying the research presented in the article are generally discussed, and the results of literature analyses focused on the recognition of studies devoted to the acoustic aspects of Smart Cities are presented. The preliminary analyses also included other publications devoted to various conditions taken into account in the planning, design and construction of buildings and groups of buildings. The second chapter presents the assumptions of the preliminary research, the results of which - as per intention of the authors of the article - will constitute the basis for direction and planning of further research. In particular, chapter three presents and discusses the preliminary results of the opinion poll of the residents of Polish cities on sounds in their surroundings, while chapter four presents selected results of the study of the current state of activity related to strategic noise maps implemented in Polish cities, legally obliged to create, update and use such maps. The research results were confronted - in the next chapter - with solutions that can be used in the area discussed in the article and described in the available literature resources, and with the authors' own subjective thoughts and concepts. In particular, the subjective list of components creating the acoustic environment and shaping the acoustic comfort of living in smart cities is shown. The summary briefly presents further research intentions.

Keywords: Smart City, sounds of cities, acoustic climate, acoustic comfort of life, noise mapping

1 Introduction

Since the dawn of civilisation, humans have made it a priority to live safely. With the development of technology, we gained the skills and opportunities to build establishments, which, combined with being surrounded by other people, led to the creation of clusters of human establishments, with time transforming into settlements, and finally - into cities. In the structure of cities over time, apart from human establishments, buildings for other purposes (e.g. sacred or cultural) also appeared. Similarly to the need to stay safe, from the dawn of humanity we have been observing the importance of sounds, which have ‘always’ been a source of knowledge for people about the environment (including the dangers existing in this environment), and on the other hand they were a means of communicating and transferring information to members of various communities. The development of building clusters was also related to the developed role of sound, e.g. an element of religious rituals [1] or culture [2].
Nowadays, thanks to the achievements of science and new technologies, humans gain new opportunities to create their environment, including in particular - to create the closest space, which is the space of everyday life for humans. Using such opportunities, we try to create urban space referred to as ‘Smart’ space. Specific ‘recipes?’ for smart urban space can be both found in typical scientific studies and in popular science

sources, and there are usually quite general sets of rules / principles for creating or transforming urbanised space into smart space.
For example, in the study [3] we can find recommendations such as: 'Define your own city model using the "mantra of your city" or "Make sure that the created "smart" city is inhabitable, improve the quality of public space ("space for people")'. They are undoubtedly imprecise, but - after careful reflection - a wide range of problems can be identified to be solved on their basis. Such problems are indicated in the following areas: technical (engineering, architectural and urban solutions, IT solutions for the management of space and communal resources), social (sociological, cultural, psychological, educational problems, as well as health protection and broadly understood security) as well as management and economic (activities in public space, e.g. costs of infrastructure, equipment or costs associated with environmental degradation).
In the literature, there are considerations on the practical aspects of defined areas of issues, however, such solutions are mainly proposed in the field of computerisation [4], construction and urban planning [5], or broadly understood municipal tasks [6]. However, there are very few studies on the presence of acoustic issues in the creation of a smart urbanised space (e.g. [7]). Therefore, the authors of this study attempted to answer the question whether acoustic aspects can and must be taken into account when considering smart urban space? The attempt at such an answer was based on the assumptions presented in the next chapter.

2 Analysis of the research problem and assumptions of the research plan

The starting point for analysing the needs and possibilities of taking into account the acoustic component in the creation and use of Smart City space and for the formulation of the research problem was the assumption that in the research works presented here, sounds will not be treated in a traditional way. The research problem will therefore not be limited to noise as an element of the set of environmental threats and to searching for ways to reduce noise in the city space. Let's ask - first of all - what, in terms of acoustic impacts, should and can be taken into account in the creation of 'smart' urban space (Smart City). In the presented research, it was decided to base the answer to this question on a detailed analysis of the available literature sources. The results of such analysis became the basis for making an inventory of solutions offered by modern technologies and, for example, allowing for:

- shaping a safe public space based on smart acoustic space, using communication channels between 'life participants' in a smart city, including: using combinations of signals (e.g. visual and acoustic), to optimise the 'acoustic service' of residents (sound messages, alarm signals) [8],
- supporting communal task management processes (e.g. smart energy management [9],
- controlling the structure and intensity of traffic flows of road users (vehicles and pedestrians), increasing the safety of pedestrians in the space shared by vehicles, especially electric and / or autonomous (e.g. equipping such vehicles with visual and acoustic communication systems with pedestrians) [10],
- creating 'individualised acoustic spaces', eliminating undesirable (unwanted) sounds with methods developed in the field of the so-called active noise reduction technology [11],

Another element of the research plan was the assumption that sounds in smart urban space - apart from the aforementioned 'environmental' approach - can and should be seen as a positive factor shaping the positive feelings of residents. This approach can be linked to the identification of the 'city mantra' proposed in the paper [3]. It is obvious that the perception of sounds is very subjective and varied, depending, for example, on the age group, personal habits, or - last but not least - the cultural circle and tradition of the place. Therefore, a decision was made to forgo the identification of factors conditioning the perception of 'city sounds' by members of the research team, assuming that such identification would be, by nature, subjective. Therefore, the authors of this study decided to conduct - in the first phase of their research - a reconnaissance survey among city residents in Poland, asking them about their feelings and opinions about the 'acoustic component' in their places of residence. The description of the current state of this research is presented (briefly) in Chapter 3 of this study.

Finally, it was assumed that the expected result of the conducted research would be a specific solution improving the quality of smart urban space management. In the literature on the subject, studies with such an approach (e.g. [12]) can be found, but there are not too many.
The authors of this study decided that the created solution should use the resources already available in city management, such as those created on the basis of the EU 'Noise' Directive [13] with subsequent supplements and changes ([14, 15]) strategic noise maps in large European cities. In order to recognise the possibility of implementing such a solution, a list of questions was formulated for cities in Poland that are subject to the statutory obligation to create, update and use strategic noise maps, about their experiences and opinions. The description of the current state of this research is presented (briefly) in Chapter 4 of this study.

3 Exploratory survey research on the creation of smart urban space

The research, which was carried out in Polish cities in June and July of 2021, was aimed at providing residents' opinions on their perception of the city's acoustic environment. Due to the relatively new subject of research, it was decided to make them exploratory. Therefore, the requirement of representativeness was forgone and the focus was placed on the compilation of quantitative and qualitative data allowing for a better understanding of the urban audio sphere [16]. The preliminary working research hypothesis [17] referred to the perception of the relationship between the perception of sounds in the city and the quality of life. Generally outlined research questions focused on the issue of subjective determination of the importance of sounds heard in the city space and recognition of the type of sounds that residents would like to eliminate or transform.
The basic assumption in the research was the recognition that the inclusion of a wide repertoire of sounds individually perceived in the considerations on the city's audio sphere is extremely important. The perception of sounds by people is culturally distorted and depends on the perceptive abilities of an individual, therefore the data contained in the opinions expressed by residents should complement those obtained by technical measuring equipment.
The research tool used was a questionnaire carried out via a Google form, sent out via the Internet to city residents. The selection was a non-probability sample - an extensive snowball sampling method was used to reach city residents. Via social networks, a request was sent to share the form with people living in cities of various regions of Poland. Large cities were also invited to cooperate and they posted a questionnaire on their city websites. As for the preliminary exploratory nature of the research, a large sample was obtained: 770 completed forms (as of 20/07/2021).
The results of the research show that the working hypothesis is confirmed in the opinions of people participating in the research. In one of the survey questions, the respondents were asked to mark the answer to the following question: 'Do city sounds matter to you?'. About 85% of respondents stated that city sounds matter to them, only 8% gave a negative answer, and the rest (7%) answered 'I don't know'. The percentage distribution of answers allows for the following conclusion: city sounds constitute an important practical issue from the point of view of its residents. This confirms the need to conduct research in the field of sounds creating the acoustic environment and shaping the acoustic comfort of living in urban space. Fig. 1 shows a chart with percentages for individual responses to the question.

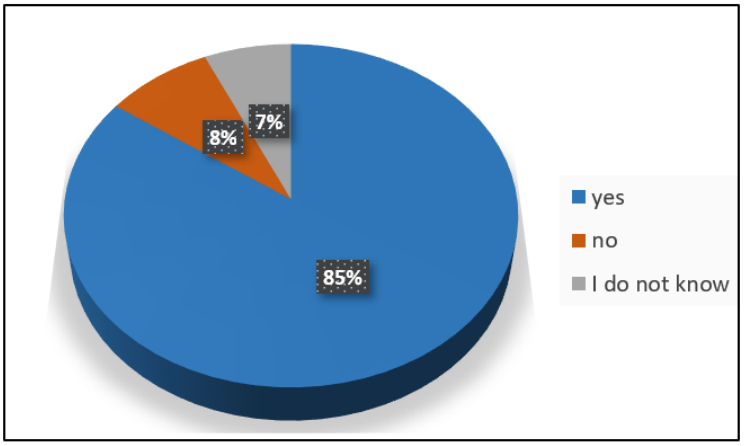

Fig. 1. Responses of survey participants to the question 'Do city sounds matter to you?' [own work].

The next question was 'Would you like to change (eliminate, improve, boost) the sounds you hear in your city?'. The question was aimed at determining the subjective feelings of residents regarding the sounds in their urban environment. Almost 70% of the respondents declared a willingness to change city sounds - 36% of which answered 'definitely yes', and 33% decided that they would like to change 'maybe only some of them'. One-fourth of the respondents were unable to express an unequivocal answer to this question. Only 6% of the surveyed city residents expressed a lack of willingness to make any changes in terms of sounds in their city (see Fig. 2). It can therefore be concluded that the topic of eliminating, improving and boosting urban sounds is worth exploring. The obtained results constitute an important premise for directing further research.

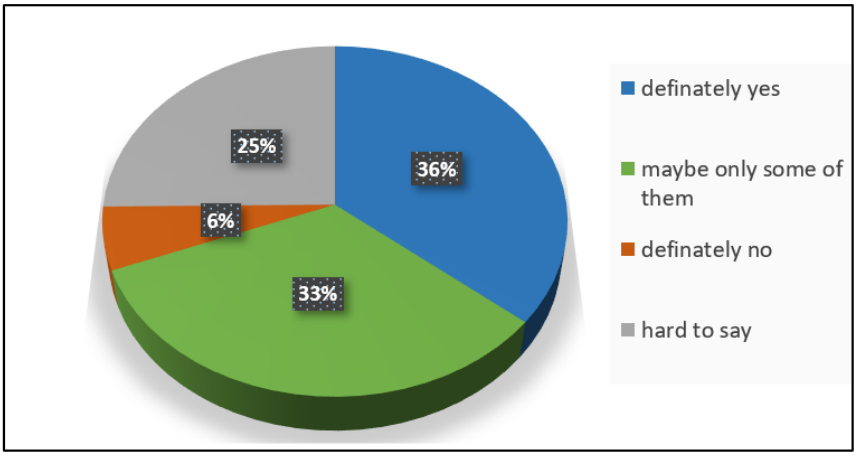

Fig. 2. Responses of the survey participants to the question 'Would you like to change (eliminate, improve, boost) the sounds you hear in your city?'. [own work].

The questions were only addressed to city residents, which is consistent with the assumption that the research is exploratory in nature. Their aim is to provide some knowledge about the current state of the research issues, to estimate the need for research and to set directions for further research projects. The research team plans to direct further research on acoustics of urban space to Smart Cities.
An important part of the research was to learn about the opinions of city residents on the necessity or possibility of eliminating or boosting sounds that are particularly important and shape the emotional values of the study participants. At the same time, the respondents were asked to indicate what the elimination or boosting measures would consist of and what their purpose would be. Over 500 people participating in the

survey made their views known freely in this regard. Their qualitative analysis allowed for assigning statements to five main categories: (a) transport, primarily including road transport; (b) industrial, road and construction works, repairs; (c) animals; (c) people; (e) others, including the environment. Fig. 3 shows the percentage share of individual topic categories within the statements. The largest number, i.e. 300 opinions, related to the issue of traffic, mainly car traffic, and also rail, tram and, occasionally, air traffic. An important part was also the issue of sounds generated by people (66 opinions). Among the statements, a recurring problem of undesirable sounds related to the broadly understood industry (21 opinions), and to a lesser extent to animals (9 opinions), was also distinguished. Another category was also defined, within which opinions of a general nature were classified (84 opinions).

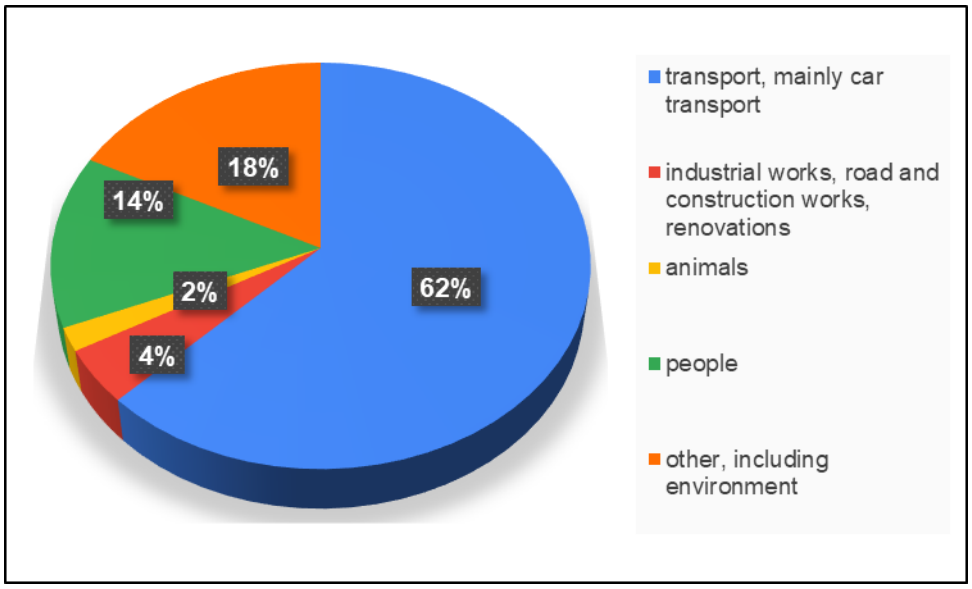

Fig. 3. Topic categories of respondents' statements regarding the possibility of eliminating or boosting sounds in the city [own work].

At a later stage of the cognitive process, a single statement was assigned to one of the three options characterising the respondent's intentions, i.e. (option 1) the statement indicated changes in the boost or reduction of city sounds; (option 2) the statement indicated the goal to be achieved in relation to the discussed subject of the statement; (option 3), the statement indicated both the changes and the purpose of their implementation. Fig. 4 shows the result of such an arrangement. The fewest statements concerned the third option, i.e. the indication of possible changes in the acoustics of the city and the purpose that these changes could cause.

Taking into account the problems most frequently indicated by respondents with regard to the negative impact of city sounds on the residents, the problem of noise resulting from traffic, especially car traffic, should be emphasised. In this regard, there have been numerous statements referring to night traffic, such as emergency vehicles driving with flashing lights and sirens, motorcycles and trucks. Possible changes that, according to the respondents, would reduce the nuisance, would consist in limiting vehicle traffic, especially at night, and above all improving road infrastructure. Also indicated was a necessity to introduce soundproofing measures, both of a technical nature, such as noise barriers including natural ones, such as extending green areas and, most importantly, planting trees.

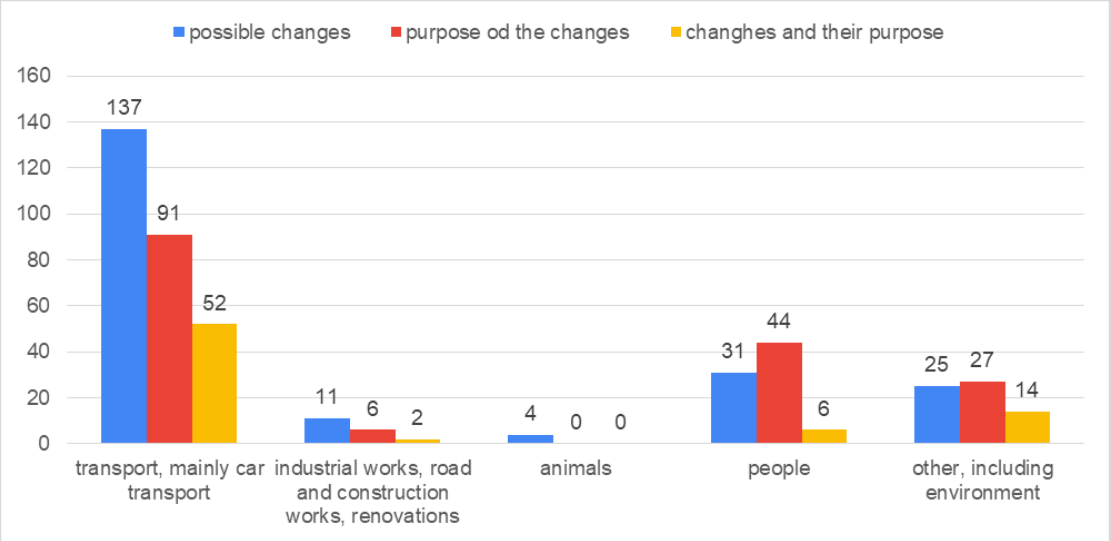

Fig. 4. Topic categories of respondents' statements regarding the possibility of eliminating or boosting sounds in the city [own work].

The qualitative analysis of the statements also showed a negative attitude of the residents to certain sounds, the so-called everyday life. These are sounds generated by people in or living in the neighbourhood. In terms of statements, such issues as: quarrels and loud conversations between neighbours, the vicinity of restaurants and wedding venues, as well as noise generated by playing children. At the same time, the need to increase the number of playgrounds was indicated, as well as to carefully locate them in the urban space and at an appropriate distance from residential buildings. Few opinions were negative about the sounds made by animals, mainly birds (gulls) and dogs. On the other hand, there have been many negative statements about industrial noise from plants, but also from earthworks, construction and renovation works.
Among the most frequently suggested intentions of residents defining the general attitude to improving the city's acoustic climate, which can also be treated as a summary of these considerations, the following postulate should be mentioned: silencing the sounds of society and boosting the sounds of nature.

4 Preliminary studies of the opinions of the administration of large Polish cities on the creation and use of strategic noise maps

Research conducted in the 1990s showed that the state of the acoustic climate is disastrous. According to the results of these studies, 100-120 million residents of the then European Union were exposed to noise levels exceeding the relevant standards [18]. Recognition of the noise disturbance status led to the development of many programme documents, which made up the so-called 'Perspective noise policy'. The presented principles became the basis for the development of a legal act in the form of Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise [13]. This directive was intended to define a common approach to avoiding, preventing or reducing the harmful effects of exposure to noise, including annoyance, on the basis of established priorities. According to them, in Art. 5 of the above-mentioned document, standardised environmental noise assessment indicators were introduced for all EU countries, which were to be used in the preparation of strategic acoustic maps and noise protection programmes. The indicators, then implemented in the legislation of individual EU member states, are: L_{DWN} - long-term average sound level A for all days, evenings and nights during the year, and L_N - long-term average sound level A for all nights of the year.
As part of the arrangements adopted in [13], calculation methods have been defined for the preparation of acoustic maps for specific groups of noise sources: industrial, aviation, road and rail noise. The acoustic

maps prepared according to the above-mentioned guidelines by local governments of cities were to primarily serve the needs of preparing various types of programmes aimed at reducing noise. The analysis of the results obtained in the 1st-4th round of acoustic mapping showed some ambiguities from the beginning [13]. They resulted from the provisions of the directive regarding the measurement and calculation methods used in the creation of Strategic Noise Maps. In Poland, as part of the 1st-4th round of acoustic mapping, maps were prepared using the calculation methods recommended in the directive, but with no full compliance with national law. Moreover, it was found that different methods of determining the number of people exposed to excessive noise in buildings were a significant reason for the differences in the obtained calculation values. As a consequence, noise maps from the first round of mapping turned out to be incomparable, not only did they not give the possibility to obtain comparable information on the actual exposure of residents to excessive noise in the entire EU, but even in one Member State.

In 2008, the European Commission started working towards the elaboration and development of a methodological framework for a project entitled 'Common noise assessment methods in Europe', led by the European Research Centre. The result of this work was the Directive [14] adopted in 2015, defining common noise assessment methods, known under the acronym CNOSSOS-EU. These methods are effective from 1 January 2019 and will be used in the fourth mapping round in 2022. The provisions of this directive were introduced into Polish legislation in 2019 in the form of an act [19]. In 2020, the EU Directive [15] was published, which indicates the harmful effects of noise in the environment and the method of its assessment, i.e. ischaemic heart disease, significant nuisance and significant sleep disturbance. It should be noted that the presented impact assessment only relates to the sources of traffic noise. Interesting research on the application of noise nuisance assessment methods, taking into account the auditory sensations in the environment caused by various noise sources, is presented in [20].

Strategic noise maps have been implemented in Poland since 2007 and updated every five years. Cities (over 250 thousand residents) already have 3 editions of such maps, while cities with more than 100,000 residents - 2 editions. It is worth posing the question: what benefits for city residents resulted from activities related to the preparation of a strategic noise map and the development of noise protection programmes on their basis?

The research team of the Department of Production Engineering of the Silesian University of Technology conducted a study in the period May - July 2021, in which 32 of the largest cities in Poland participated (between all the 36 cities in Poland obliged by law to create and to exploit the strategic acoustic maps). Questions asked to Municipal Offices concerned - in general terms - activities related to the creation and use of strategic noise maps and noise protection programmes. The obtained answers show that the implemented acoustic maps were the basis for the development of Environmental Protection Programmes against Noise and for taking into account acoustic conditions in spatial development plans.

The analysis of the collected responses shows that with the successive editions of the maps, the number of implemented solutions to reduce excessive noise increased. In the years 2007-2012, most cities limited themselves to implementing ‘classic’ solutions such as: noise barriers, speed bumps, vehicle speed limits and issuing decisions to industrial plant owners to reduce noise emissions. In the years 2013-2017 and later, a wider spectrum of anti-noise solutions began to be used, in the form of: changes in traffic organisation, quiet road surfaces, vibration isolation of rail tracks, grinding and lubrication of rails, planting of insulating greenery. The priority was to limit the traffic of private cars in city centres and replace it with bicycles, scooters and properly functioning public transport. The proposed solutions are described in more detail in [21].

The received responses clearly show an increase in the number of residents' complaints about noise in the analysed period of 2013-2021, but the use of map information by residents and investors remains very limited. It seems that this increase was not so much caused by the deterioration of the acoustic climate [23], but by the growing awareness of the quality of life of society and the desire to improve acoustic comfort. Nevertheless, this ‘acoustic awareness’ of the residents of Polish cities still leaves much to be desired. Most of the reported complaints of residents concerned road and industrial noise, including noise from small business establishments, car washes, air-conditioning and cooling equipment at shops, etc. After analysing in detail the complaints of residents in the cities studied, it should be stated that the residents also complained about the acoustic nuisance caused by the impact of specific noise sources. These complaints concerned,

inter alia, noise from playgrounds and sports fields, noise generated from car races organised at night, the noise of church bells, or noise generated by persons at al fresco dining establishments.
An important conclusion from the conducted research is the statement that the acoustic map gives residents and decision-makers the opportunity to obtain information on the average noise level in a given place of the agglomeration, permissible levels and size of the possible exceedance of these values, and this possibility is not only used by residents, but also investors, architects and planners (e.g. when buying a flat, house or planning an investment). Therefore, it seems interesting and at the same time necessary to supplement the noise map with an information layer, allowing for recording and listening to the sounds of urban space - inseparably related to a specific location.
There are known solutions consisting in recording sound signals in the environment and their realistic reproduction in laboratory conditions, which are in line with the research on the soundscape [22]. Such solutions not only allow the registration of unique sounds, but also the reproduction of various spatial sound phenomena. Modern aural techniques allow for the location of selected sounds in registered spaces, sound simulation of acoustic effects with the use of, for example, noise barriers.
The research team of the Department of Production Engineering has started conceptual works both on the identification of the sound impressions of the residents and related expectations, as well as on the creation of the sound layer of the city. The main goal of the undertaken research is to develop a method of creating and using a digital map layer containing data on the acoustic quality (acoustic comfort) of selected urban spaces. It will be achieved by developing:

- means and methods of acquiring, processing and recording information about 'city sounds' that can be used in the structure of noise maps, based on GIS class systems,
- a method of assessing the degree of acoustic nuisance of sound sources and appropriate indicators, taking into account aspects of subjective perception of sound,
- a method of assessing the acoustic quality (comfort) of urban spaces and appropriate indicators,
- a method on how to share information about the sound component of urban spaces in urban spaces with interested entities (stakeholders).

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5 Conclusions

The preliminary research results presented above show that the area of issues related to the acoustic component of urban space still has many unresolved problems worth undertaking research. The authors of this study are convinced that the key premise for making decisions regarding the acoustics of smart urban space should be the effective recognition of the needs and expectations of residents [23]. The basic goal of creating a smart urban space must be to improve the quality of life of the residents of this space, also in their subjective opinion. Therefore, residents should be asked about their expectations, needs and concerns. Such an assessment should cover the widest possible spectrum of residents, including various age groups (children, seniors) or people with various disabilities. On the other hand, Smart technologies offer a wide spectrum of possibilities of shaping the quality (comfort) of life for residents.
The presence of sounds in the 'Smart city' implies the need to undertake research work and implement the results of such research in practice. These may be research on sounds preferred and difficult to accept by various groups of residents (also in relation to the time of day / night), research on the impact of sounds on concentration or distraction, e.g. pedestrians on the streets where 'quiet' (electric) vehicles move about, studies of people's individual reactions to sounds.
The declared goal is to improve the quality of life in the city, but so far such quality has not been satisfactorily defined.
In the search for such a definition, we can, for example, refer to a situation in which every resident of a smart urban space is provided with personal comfort, tailored to their preferences. For example, they would like to enjoy themselves by listening to their preferred music. It is possible to consider using both 'Silent Disco' solutions [24, 25], based on equipping each participant of the event (party) with their own headset. Another possibility is the use of solutions in the field of the so-called active agents [11].

Another problem to consider is the subjectivism of perception and response to sounds. The question remains open: what is pleasant and what is a nuisance for a specific recipient? A dual reaction to sounds is clearly illustrated when using a helpline, that we are 'third in line' and while waiting, we listen 'over and over' to an objectively pleasant musical theme. Playing children can be seen as a sign of peace, joy and a family symbol, but also as a source of noise.
Perhaps, the considerations on Smart City sounds should also include the use of techniques such as music therapy or research on the influence of music on the mood of individuals and groups, and thus specific 'Smart City music'?

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