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Technical Notes

ARCHITECTURAL AND ENVIRONMENTAL ACOUSTICS AS AN ASPECT OF SUSTAINABLE DEVELOPMENT

Motto: *"Noise is an environmental pollution characterized by a multitude of sources, present in all ecosystems of the biosphere,"*
National Environment Protection Council – 1984 r.

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Sustainability, among other global and local issues, embraces also problems connected with protection against noise and vibration. In this context architectural acoustics and environmental acoustics should be considered as a part of the sustainable development policy. It refers to the environment and land management as well as to the whole building sector. Proper acoustic conditions prevailing in the external environment and in the interior of a building are not only a question of a comfort or quality but the real problem of creating healthy and active society. One of the most important point is the possibility of proper assessment, in acoustic terms, of an environment and proper assessment of land areas designated for specific use. The paper presents an attempt at systemising of the acoustical issues within the sustainability frame. The parameters and factors which should be taken into consideration while preparing principles of environmental noise management considered as an aspect of sustainable development are discussed.

Keywords: noise, vibration, sustainable development, environment protection, assessment methods.

1. Definitions (prepared for the purpose of the paper)

Environment – all natural elements, including elements transformed as the result of human activities, especially: land surface, natural resources, water, air, living organisms (humans, animals and vegetation), and landscape. More information on the environment is provided in Fig. 1. The following elements should be distinguished:

- Outdoor environment (natural and urbanized).
- Indoor environment (residential, occupational, public utility and recreation facilities).

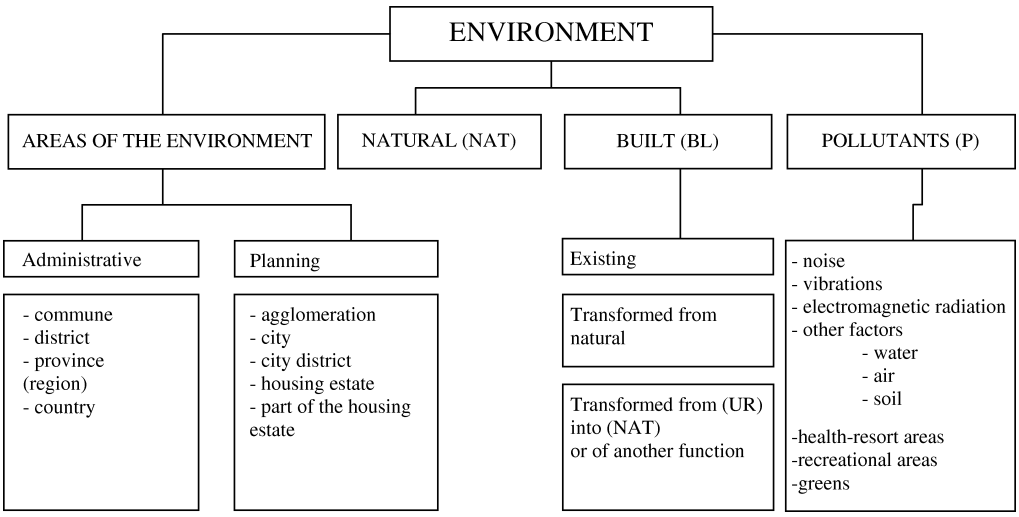


Fig. 1. Systematic approach to the pollutant, environmental protection and resources management factors according to the sustainable development principles.

Environment protection consists in undertaking actions or forgoing harmful activities, which enables restoring natural balance, embracing in particular:

- Rational shaping of the environment and managing its resources according to the principles of sustainable development.
- Preventing environmental pollution, restoring proper state of the natural elements.

Pollution – emission or immission that is harmful to human health or the environment, causes losses in property, lowers the esthetic value of landscape or collides with other proper use of the environment.

Acoustic climate of the outdoor environment – complex acoustic phenomena that occur in outdoor environment caused by the sources of noise and vibration located within the environment and/or outside it, defined using appropriate acoustic indicators taking into consideration time, frequency and space.

Acoustic climate of the internal environment – complex acoustic phenomena that occur in indoor environment caused by the sources of noise and vibrations located within the internal environment and/or outside it, defined using appropriate acoustic indicators taking into consideration time, frequency and space.

Sustainable development – social and economic development, in which the integration of economic, political and social activities takes place, whilst maintaining natural balance and stability of basic natural processes in order to guarantee the possibility of meeting the crucial needs of individual communities or citizens, of both the current ad future generations.

The Environment protection law states that the protection of environment consists in rational shaping of the environment and managing its resources according to the sustainable development principles.

2. Architectural acoustics

Architectural acoustics covers a field of science and research that, according to the settlement of PAN (Polish Academy of Sciences), embraces five branches of acoustics (see Fig. 2), i.e.:

- Urban acoustics.
- Room Acoustics.
- Building acoustics.
- Noise generated by installation and building equipment.
- Industrial noise problems,

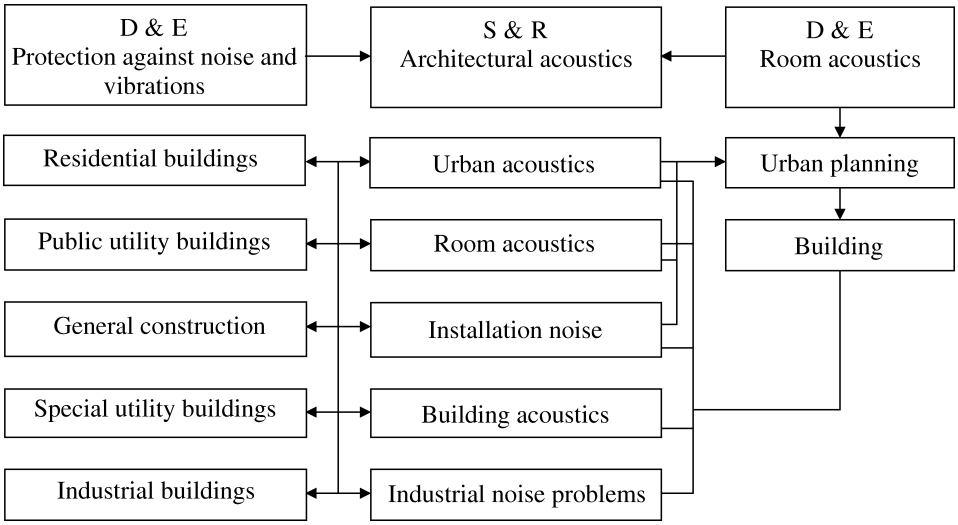


Fig. 2. Systematic approach to the architectural acoustics and environmental acoustics according to [1].

Scientific and research works conducted in these five areas are aimed at defining the practical principles for designing and implementation (D&I) of methods of protection against noise and vibration for buildings and their surroundings, including areas such as parks, recreation sites, health centres, etc. located in urban areas. Despite the fact that the research works concerning this group of issues were already started in Poland between 1965-75 and the fact that there was a special group of experts working within the Economic Commission for Europe (ECE), whose purpose was to develop a comprehensive research program, after completing the initial research scheme further studies on international level were stopped. Only the publishing of the Green Paper on the future noise policy of The European Community gave these problems a proper importance and lead to the development of an EC Directive [6].

Based on the results of research on acoustics and urban planning it is possible to promote groups of indicators designed for assessment of acoustic climate of an area (city, region or the whole country), and the indicators determining the level of exposure of population inhabiting these areas to noise and vibration exceeding values set down

by legal regulations. These indicators can be used in analytical works for the assessment of efficiency of specific solutions from the viewpoint of sustainable development, and also for the assessment of the effects of urban areas revitalization.

3. Environmental acoustics

Environmental acoustics, according to the opinion of specialists, embraces 7 branches, i.e.:

- Sources of noise and vibration in the environment (outdoor and indoor).
- Spatial planning in terms of vibro-acoustic protection needs.
- Noise and vibration protection measures in the environment.
- Methods of environmental noise assessment.
- Sustainable development as a factor shaping the acoustic climate.
- Legal requirements.
- Technical and organizational measures.

While solving problems existing in the area of architectural and environmental acoustics, defining legal requirements (directives, regulations, acts, standards, etc.) and also defining technical and organizational measures that influence creation of acoustic climate in the environment, is of crucial importance. The technical and organizational measures are usually described in instructions and guidelines developed and issued by professional institutions and research centers.

Basic factors that influence the acoustic climate in the environment are shown in Table 1. Progress of research works in the area of environmental acoustics enables the

Table 1. Factors shaping the quality of acoustic climate in the environment according to [2].

		Methods to be applied	Actions
1	Mitigation of noise and vibration by modernization	Modernization and modification of sources	Using modernized solutions and measures of noise reduction (e.g. enclosures, barriers and casings).
2	Applying proper rules of spatial planning	Proper location of noise sources and areas which should be protected	Development of underground infrastructure. Proper location of noise sources and protected facilities.
3	Using means of protection against noise and vibration	Enclosing noisy facilities and sources; Enclosing protected facilities; Vibro-insulation.	Proper layout, partitions structure, enclosures, vibro-insulation.
4	Applying legal and organizational measures	Traffic control, work-time control, limitations, restrictions, screening sources and protected facilities.	Traffic control, including its intensity and composition. Controlling the operation time of noisy facilities. Screening sources and protected facilities.

development of acoustic indicators designed for the purpose of sustainable development, i.e.:

- Indicators defining the pollution of environment with noise and vibration coming from particular sources of noise (road and railway traffic, aircraft, water traffic, communal and industrial noise) and, on the complex level, for selected areas (e.g. urban areas, strips along motorways, cities, regions or entire country).
- On the basis of revised Instruction ITB No. 310 issued by Building Research Institute (ITB) or EU documents it is possible to create other indicators for the needs of spatial planning [6] or for the purpose of revitalization of degraded areas by changing their intended use. Developing acoustic indicators for investment areas assessment for cadastral purposes [3] would be one of the important tasks. Tables 4 and 5 show possible examples of methods for creating such indicators.

4. Shaping of the environment and resources management

Discussing issues of environmental protection against noise needs a systematic approach, therefore, the following elements should be considered:

- The natural environment and the environment transformed by human activity i.e. so-called built environment. In an urbanized environment such areas as communes, districts, regions, provinces and entire country can be distinguished, also areas within cities, housing estates, city districts, etc.
- existing urbanized environment,
- transformed environment, planned in natural or urbanized areas,
- revitalized environment (cleaned from pollution),
- pollutants such as noise and vibration, or air, water and soil pollutants,
- polluted area, part of the terrain, housing estate, recreation site, water or agricultural area, etc.

Principal elements of environment are shown in Fig. 1. In some cases the possibility of providing conditions equal or better than existing in natural environment should be considered; in other cases it is necessary to reduce the environmental pollution to the lowest possible level. In such a case undertaking of actions will be decided upon the available financial resources.

Depending on the type of environment (natural, built, existing or transformed) both the approach and the effects may be different. Methods of approach towards thermal and acoustic issues are described in [1]. It should be emphasized, however, that among presentations at scientific conferences, in Poland and abroad, dedicated to sustainable development problems, there is an alarming gap when it comes to issues related to protection against noise. Table 1 shows the basic activities that should be undertaken in order to shape a proper acoustic climate in the environment [2]. There are a number of factors that justify systematic analyses of acoustic climate of the environment every few years, e.g. changes of noise and vibration sources over certain period of time due to technological progress, changes in the tendencies in spatial planning that cause excessive densification of city development areas at the expense of greenery, parks and

other recreation sites. Detailed analysis of these issues is presented in [3], where, in the conclusion, the necessity of developing acoustic classification of investment areas depending on the level of intruding noise is indicated. Acoustic class of the area would influence its price and allow for a more exact and clearer assessment of its suitability for intended use. The following factors should be taken into consideration when working on development of such a classification:

- Intended use of the area.
- The level of inconvenience depending on the type of noise source (road, railway, aircraft, industry).
- Relations between different assessment indicators, taking into consideration the prevailing period of use of the given area during the whole day or week.
- Requirements related to the indoor noise level.
- Relation between the acoustic conditions prevailing indoors and external noise level (with closed and open windows).
- Actual possibilities of constructing external walls providing adequately high acoustic insulation, taking into account problems of proper ventilation.

5. Introducing the environmental and architectural acoustics into the process of sustainable development

Environmental and architectural acoustics integrates problems of housing, inhabitants' exposure, and environmental protection against noise and vibration. Numerous scientific and research works conducted in Poland in the field of acoustics are strongly related to the concept of sustainable development. Despite this fact it is rarely taken into consideration in the implementation of sustainability principles by specialists form other research fields like ecologists, urban planners, transportation systems designers, or environmental impact assessment specialists. Also other experts and decision-makers tend to neglect noise issues. This is probably related to the distribution of funds; it is easier to omit the entire subject than to take it into consideration. The results of such an attitude are negative.

Attached list of references [1–21] specifies selected publications that can be useful when examining problems related to introduction of environmental and architectural acoustics into research projects, taking into consideration the sustainable development principles. Long-term and comprehensive activities planned in the field of protection against noise for Europe are specified in [5].

6. Sustainable development indicators inspired by Agenda 21 [1]

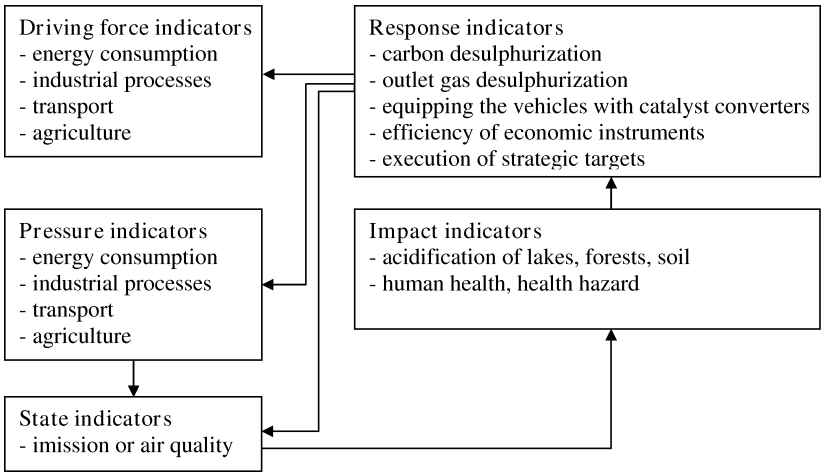
The methods of implementation of sustainable development indicators on local and regional level are supposed to consist in technical and information technology integration and also in cooperation of sustainable development indicators with other modules of Regional Data Base (BDR).

It was assumed that the expected restructuring of BDR through the creation of sustainable development indicators module will make it possible to extend the scope of statistical information delivered to Eurostat. The assessment systems presented in [14] (see Tables 2 and 3) do not take into consideration the indicators describing acoustic climate and the needs for protection against noise, both in spatial planning, construction sector, industry and other sectors of the economy.

Table 2. Sustainable development indicators (PSR) according to [12].

Pressure indicators	State indicators	Reaction indicators
In a form of de-stimulator: • Emission of gas pollutants from particularly noxious plants (per km^2); • Emission of dust pollutants from particularly noxious factories (per km^2); • Emission of carbon oxide and methane (per km^2); • Share of dust pollutants stopped or neutralized in installations for reducing emission of dust pollutants (in %); • Share of gas pollutants stopped or neutralized in installations for reducing general emission of dust pollutants (in %).	***In a form of stimulator:*** • Quality of atmospheric air – concentration of SO_2, NOx and dusts, for example the number of days during which the allowable emission was not exceeded; • Percentage of inhabitants satisfied or very satisfied with the environment quality (in %). ***In a form of de-stimulator:*** Imission of pollutants: SO_2, NOx and dusts • Percentage of inhabitants dissatisfied with the environment quality (in %);	***In a form of stimulator:*** • Investment expenditures for atmospheric air and climate protection per capita; • Share of investment expenditures for preventing pollution in general expenditures for atmospheric air protection; • Share of generally-accessible greenery and greenery within housing estates; • Expenditures for energy savings per capita, in PLN per person.

Table 3. Sustainable development indicators in the DPIRS system, according to [12].



The concept of sustainable development indicators, inspired by Agenda 21, was created in 1990's [14]. This concept can also be used when developing indicators describing acoustic phenomena in the environment, building industry and spatial planning, which was examined in a study presented at the OSA/04 Conference in Gdańsk [1]. Following [14] we should consider two groups of indicators:

a) Indicators built according to the principle "from the problem to the solution" – using PSR indicators (P – pressure / reason; S – state; R – response), where:
   - The pressure indicators (P) – show the main sources of environmental hazard;
   - State indicators (S) have environmental character; they estimate the quality of environment by quantifying the partial qualities of individual components as the quality of human life, which constitutes the superior goal;
   - Indicators of response (R) to environmental phenomena express in a coherent way the comprehensive action of local authorities, financial institutions, local communities, etc. Table 2 shows example of analysis based on such indicators related to air quality assessment.

b) System DPSIR (Driving Force – Pressure – State – Impact – Response). This system constitutes the main direction of methodical research in OECD (Organization for Economic Co-operation and Development) and in the European Union. This group of indicators is based on the "decoupling indicators" concept and incorporates the main indicators of driving force (D) and Pressure (P), because they can change over a shorter period of time than State (S) indicators and can be influenced by activities related to environmental policy. Table 3 shows examples of DPSIR system indicators for assessing the state (S) – emission or air quality [1].

7. Selected problems of environmental and architectural acoustics in the context of sustainable development

Research works on sustainable development in building industry were undertaken at the Building Research Institute in middle 1990s. However, the acoustic issues were discussed only to a limited extent [18]. In the following years, a number of papers which examined the acoustic issues more extensively have been published [2–4, 7, 8, 14, 18, 19]. Environmental and architectural acoustic issues have been introduced to the sustainable development concept in a more comprehensive way in 2004 [1]. The list of references specifies the most important Polish and foreign works that had principal importance for the development of sustainable development issues in building industry and spatial planning. The actual achievements of acousticians in this field, in Poland and abroad, are more extensive, and this allows us to hope that architects, urban planners and ecologists will also recognize these achievements.

Four basic groups of research fields, the realization of which is significant for the studies concerning sustainable development can be distinguished:

- approving and certification of noise and vibration sources designed for use in natural and built environment and mitigation of noise and harmful vibration from

these sources through changing their construction and application of means of protection against noise and vibration,
- creating acoustic climate of communes, regions, provinces, the entire country and protection of these areas against noise and vibrations, in connection with spatial planning of built areas (transportation routes and facilities, commercial and industrial facilities and others),
- working on proper acoustic quality of materials, products, systems and facilities in the construction industry by research, proper designing and approval and certification process, production quality assessment, assessment of acoustic performance of completed building works,
- shaping the indoor acoustic climate of housing development, public and industrial buildings, vibro-acoustic protection against internal noise and vibrations and also noise and vibrations penetrating from outside.

8. Environmental and architectural acoustics, assessment and indicators

Urban acoustics, outdoor environment acoustics, is closely connected with spatial management and involves problems related to elimination or mitigation of noise and vibration generated by sources located in urbanized environment that penetrate into areas or buildings. This is achieved through proper location of buildings and facilities that are the sources of noise, proper location of areas and buildings which should be protected against noise and location of facilities and areas which are not sensitive to noise and vibration.

The urban acoustics embraces research works on sound and vibration distribution in open spaces and partially developed areas such as streets, squares, tunnels, but also assessment of the effectiveness of screening and attenuation by various urban elements,

Table 4. Example of PSR analysis concerning the pollution of commune, region or entire country with noise exceeding the values specified by regulations, according to [1].

PSR acoustic indicators		
P – pressure	S – state	R – response
Pollution of the area with different types of noise: • road traffic, • railway traffic, • aircraft, • industrial, • municipal, • other.	Quality of acoustic climate of built environment: • commune, • region, • country. % of area polluted with excessive noise, % of population exposed to excessive noise (WZK, LZS, TZH).	Restricting the suitability of an area for building development of: • healthcare and recreation, • housing estates, • public utility buildings. Increase of costs of noise impact mitigation. Increase of costs of area revitalization.
Auxiliary materials: ITB Instruction No. 310.		

such as greenery, embankments, industrial facilities, flyovers, buildings, acoustic barriers and other elements.

The environmental acoustics covers investigations on the effect of different sources of noise like road traffic, railway, aircraft, water and public transportation, industrial sources and other sources of noise located in natural and built environment. Urban acoustics also deals with the influence of the layout of traffic lines and industrial facilities from the viewpoint of their effect on the environment and humans.

The noise mapping of agglomerations, noise protection elements and measures of building protection against noise are specific problems of the environmental acoustics [6, 7]. Analytical studies researching the influence of different factors onto acoustic quality of the environment can use the PSR assessment method (examples: shown in Tables 4 and 5) or DPIRS system (example shown in Table 6).

Table 5. Example of PSR analysis concerning the pollution of an area with road traffic noise (motorway, speedway), according to [1].

PSR acoustic indicators		
P – pressure	S – state	R – response
Pollution Motorway: • traffic intensity, • number of traffic lanes, • percentage of heavy vehicles, • width of insulation zone, • other protection means, • increase of costs.	Climate quality: • exceeding levels specified by standards, • noise penetration range, • area polluted with noise. STATE ASSESSMENT • objective (measurements), • subjective (surveys).	Mitigation: • moving the road away from the areas protected against noise, • using noise protection measures, • elimination of the motorway from the area.
Auxiliary materials: ITB Instruction No. 310.		

Table 6. Example of DPIRS indicative analysis concerning the number of inhabitants and % of area exposed to excessive noise, according to [1].

ACOUSTIC INDICATORS DPSIR				
D – driving force	P – pressure	I – influence	R – response	S – state
• road traffic, • material solutions for the road, • road surroundings, • number of lines of traffic, • width of traffic lane, • traffic composition.	Sound level – A L_{Aeq} L_{DWN} other	• impact of noise on health (health hazard), • terrain value, suitability for specific purposes.	• technical solutions for vehicles, • creating insulation zones, • diversification of building development, • using means of acoustic protection.	Noise imission and increase of pollution of the area TZH % • increase of the percentage of population exposed to noise LZH %.
Auxiliary materials: ITB Instruction No. 310.				

9. Acoustic quality indicators for construction elements, materials, products and building interiors

Indicators of acoustic quality for construction elements, products or entire buildings can be developed on the basis of approval and certification tests results. There is a possibility of developing, for analytical purposes of sustainable development in building industry, indicators for designed buildings or housing estate and then comparing them with indicators of completed housing, taking into consideration costs, which can be helpful when assessing building industry, taking into account the sustainability principles. Due to the lack of reliable methods for assessing life cycle of construction materials and products it is more complicated to take into consideration the influence of recycling construction materials used for the purpose of noise protection and room acoustics. Indicators of the acoustical quality of building interiors can be worked out based on methods presented by AGH [17].

10. Conclusions

The discussion presented in this study shows the following:

- There is a possibility of introducing the environmental and architectural acoustics into the analyses of the effect of spatial planning and building development, executed according to the sustainable development principles, which would make these analyses more comprehensive.
- There are possibilities of using both Polish and European legal documents concerning the acoustic climate in the environment and the acoustic quality of housing and public development for this purpose.
- Poland has a sufficient scientific and designing potential for developing appropriate research works aimed to achieve this goals.
- The main problem related to starting the research works and the works related to the introduction of environmental and architectural acoustics into sustainable development analyses, assessments in spatial planning, proper assessment of transportation, industry and in construction sector, is the lack of financial resources, which results from underestimating acoustic questions by ecologists, urban planners, transport and industry experts.

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