Urban Green Spaces: An Element of a City's Balance Between the Built and Natural Environments

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Abstract. The article presents a report on the possibility of using greenery as an element of natural balance in the city. The research was carried out in 2016 and 2017 with the aid of Poznan University of Technology Faculty of Architecture students and under the guidance of the authors. The reasons for the growing environmental problems in cities and proposals for remedial measures to prevent a breakdown of the ecological balance have been suggested. In this context, a model equilibrium in the natural spatial plan of the city was proposed, based on the quantification of the basic relationships between biotic and anthropogenic components. It emphasises the need to establish a dynamic balance in the urban environment. Particular significance to ecological engineering based on the principles for adapting biocoenoses to habitat conditions was assigned. Research within this scope focuses on three primary directions: adapting natural sites to the changed environmental conditions, ecosystem protection, formation of new natural ecosystems. The presented method for defining environmental balance was used in drafting detailed designs for rebuilding the natural environment in the Poznan Metropolitan Area.

Keywords: Urban greenery · Environmental balance · Anthropogenic activity

1 The Problem

Green spaces are an important component of urban structure. They provide a setting, where built up areas are uniquely interwoven with the fabric of a society. Natural conditions, social standard and investment activities all contribute to the state of green areas in cities.

The unique character of urban green areas takes root in the "urban planning process", which generates the structure of a city through complex environmental, social, organisational and technical interrelations combined with the actions of its residents.

The very diverse forms of urban green spaces are created with varying intensity. Sometimes they owe their existence to coordinated planning activities, whilst at other times to spontaneous growth. But regardless of whether they came about as a result of

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natural phenomena or the efforts of urban planners, green spaces define the character of an urban environment.

1.1 Natural Constraints for Urban Growth

The interactions between humans and the natural environment they live in have assumed the characteristics of constraints, of a critical nature for further development of the settlement network. Nature's ability to spontaneously regenerate the intensively consumed resources has declined drastically. A deficit of natural resources is discernible in urbanised areas (which until quite recently were looked upon as an inexhaustible source of spatial development). Substances accumulate in the environment which exhibit harmful biological impact on life forms. Devastated areas, disused industrial areas and landfill sites are gradually taking up increasing swathes of land and in doing so they not only eradicate landscape qualities but also curtail settlement and recreation opportunities available to the ever growing urban populations [1].

Environmental problems attributable to the fact that more and more people are consuming increasing amounts of natural resources gave rise to serious fears for regional development perspectives. This is illustrated by Ehrlich's "ecological disaster" scenario, primarily driven by the disproportionate increase in the environmental burden resulting from population growth [7].

Carvalho considers incorrect use of technology to be behind the growing environmental problems in cities [6].

According to Maddox, the biggest conflicts with nature in developed, intensively urbanised areas do not stem from population growth, but rather incompetent use of technology [12].

Boulding points out that industrial production can be used as a measure for the loss of natural resources. The larger the economy, the more production is required to sustain it [5]. This subject is also associated with the rapid ageing of hi-tech products, energy and waste management. People are consuming increasing amounts of energy to obtain the latest models of advanced products. The planned lifetime period, which entails the destruction or disposal of an item which is still usable, has become the generally adopted means for growth, even though it is particularity harmful from the point of view of natural resource management (including spatial management) for the environment.

In this context, remedial measures to prevent a breakdown of the ecological balance have been suggested. The "spaceship earth" concept, put forward by Boulding is one of the most significant [4]. It emphasises the need to establish a dynamic balance in the environment. On a world scale this means an end to exponential growth, stabilisation of production and consumption and securing the quality of the primary natural resources. Maher emphasises that a shift from "quantity" to "quality" in spatial use will avert an ecological disaster [13]. Last assigns particular significance to ecological engineering based on the principles for adapting biocoenoses to habitat conditions [11].

Hough precisely defines the conditions which are required to ensure a decent quality of life [10].

"A Blueprint for Survival", co-authored by E. Goldsmith and D. Allen, is a text which not only spells out the general concepts for a sustainable (stabilised) ecology, but also refines plans for implementing given transition phases [8]. Based on the sustainable economics concept, the blueprint emphasises the need to appropriately orchestrate changes in spatial development management, aiming to reverse the current development directions which endanger the natural environment.

Bonenberg presents a compilation of measures and actions needed to restore the already damaged environmental balance [3].

Wenk presents an interesting approach to the environmental protection problem set [22]. The author makes no attempt at justifying the limited effectiveness of remedial measures used today and draws a conclusion that regeneration of natural environment is not possible without mankind's moral revival, especially when it comes to self-control.

Ecopsychology devotes a lot of attention to these concepts. This new discipline carries particular value, as it concerns the interpersonal dimension of health. Ecopsychology sets itself the task of defining the links between our health and well-being and the natural environment, where the primary focus is on green spaces. It is a type of a cultural personification of the bonds with nature. That new assessment of the bonds between mankind and the surroundings, has serious implications when it comes to spatial planning as it talks about individual preferences and behaviour of the residents with respect to green spaces. These preferences should be expressed through a subjective approach to the surrounding green areas, articulated by spatial policy with its interpersonal reflection in meticulous designs of green areas [2].

2 Environmental Balance in Cities

The "man - natural environment" relationship has become one of the primary factors limiting growth of urbanised areas. Human activity within these areas as well as the environment's ecological "quality" become entangled in an approximately inverse proportion. In a city centre for example, the former of the two factors is high, whilst the latter - low. On the other extreme, when we consider a location in a nature reserve, unspoilt by man, the aforementioned proportion will be inverted.

The idea to bond human activity with the environment's ecological "quality" was coined a long time ago. Architecture is one of the first disciplines, which considered the environment as an element inextricably linked with the activities of social groups as well as individuals. In the classic "De architectura libri decem", Vitruvius analysed the natural conditions for building new cities. In chapter four of Book One, he points out the impact of the climate and ways to choose a healthy site and in chapter six the effect of winds on the health of the residents. He devoted chapter six of Book Eight to testing for good water – he made a connection between the appearance of the inhabitants of a give region, the type of deposits in vessels and local vegetation with the properties of water. He presented ways for testing and avoiding harmful exhalations when digging wells [20].

References to the idea of unity between living organisms and the environment (and this includes unity between man and nature) may be found in subsequent geographical, biological and medical texts.

Whereas balance in natural ecosystems has been investigated quire thoroughly and unambiguously, the balance in artificial ecosystems still provokes discussions. Disputes primary revolve around theoretical research models and practical urban planning and architectural activities with reference to settlement areas.

In the context of nature, these are one of a number of spatially separate ecological systems found in the environment. It is emphasised that nature is a mosaic of ecosystems on different levels of succession, some already "mature" exhibiting high internal stability whilst the "younger" ones are less stable, with less species diversity and no internal balance. These are most often associated with human settlement activity.

Simmons identified four types of ecosystems which should make up a sustainable spatial system [17]:

(1) Artificial ecosystems, which include the "built-up environment" within settlements. In order to prolong their existence, these depend on various types of externally supplied energy and materials.
(2) Very productive, intensively used agricultural areas with the ability to generate high crop yields.
(3) Compromise areas, such as multiple-use forests, recreational areas, landscape parks or pastures.
(4) Mature non-agricultural ecosystems, or areas of vegetation unspoilt by man. These comprise important clusters of high biotic diversity and vital sites for gas exchange in the environment.

Odum presented a model of spatially separate types of environment needed by man. He used the given ecosystem's development stage and circulation of resources as the criteria [14].

The model encompasses the following ecological systems, grouped in accordance with the basic biological function:

(1) inanimate systems (the urban environment, urbanised areas),
(2) multi-use systems (intermediate type environment),
(3) developing systems (productive environment),
(4) mature systems (protective environment).

Maintaining an environmental balance requires an appropriative partial balance to be determined in each of the aforementioned areas.

This imposes particular requirements over the spatial planning process in order to ensure sustainable development of urbanised areas.

The theoretical description of the complex system of interactions between settlement activities and nature within those areas is still inadequate.

At first sight, such a statement may seem unjustified - is it not the case that numerous scientific disciplines have been probing the impact of mankind's economic activities on the environment? Nevertheless, the reasons for change, consequences of the negative impact of urban planning factors in nature require continuous research.

This is perhaps associated with the signification rate at which changes are taking place. Many failed, unsuccessful efforts in an urban environment, where the expected benefits where overwhelmed by the losses stand testament to the above. The reason behind such errors is most often found in the difficulty associated with drafting a reliable forecast as to the environment's reaction in urbanised areas and insufficient tried and tested methods for determining an acceptable level of anthropogenic interference. First and foremost, a lack of clearly defined criteria for an environmental balance in an urban environment should be emphasised.

3 Criteria for Environmental Balance in Cities

When talking about environmental balance in cities, one should define the balance level. It is obvious that reinstating optimal conditions for the development of mature natural biocoenoses within those areas is impossible as this would entail eradicating mankind's settlement and economic activities.

On the other hand, neither is it possible to continue the progressing degradation of natural vegetation complexes, which lead to them being entirely eliminated from an urban areas.

The desired balance level should be within the two extreme boundaries. And thus, spatial development plans should be drawn up for the green areas (vegetation) to retain their spontaneous regeneration capabilities with respect to the damage inflicted by settlement activities within territorially defined spatial units [3].

Environmental balance in a city can be described by the "man - natural environment" relationship. In order to obtain sufficiently accurate data to build a model environmental balance system within the scope of a city's spatial development plan, the basic relations between biotic and anthropogenic components were quantified. This quantification will make it possible to determine accurate proportions in terms of area and will provide guidelines as to the type of spatial development in a given areas. At the same time, it will facilitate a comparison of the implied state with the actual state, indicating spatial development directions which maintain or restore environmental balance.

The desired balance can be expressed using the following abstract, simplified notation:

$$\mathrm{NA} = \mathrm{AC}. \tag{1}$$

where:

NA - stands for the quality of the natural environment within the boundaries of the given urban spatial unit,
AC - stands for anthropogenic activity within the boundaries of the given urban spatial unit,
NA/AC = g - balance level index.

Equation (1) can also be expressed as:

$$NA/AC = 1. \tag{2}$$

When ecological balance within a given area is disrupted, then:

$$NA/AC < 1. \tag{3}$$

and z = 1 − NA/AC indicates the scale of the danger.

There is extensive discussion in literature on the subject in question as to the selection of accurate indices describing the state of the environmental balance [3]. It depends on the specific nature of the area subject to the plan, scale and scope of available reports. A comprehensive suggestion within this scope has been put forward by the Mission to Save Earth Team as part of UN Agenda 21 on Sustainable Development. The indices have been selected on the basis of 7 criteria: measurability, innovation, adequacy, comparability, usability in design applications and effectives.

The two primary ecological system components - AC and NA are made up of sets of various types of values. For example, the NA component exhibits a system of (variable) characteristics, such as: energy flows at given trophic levels, plant species diversity, food chains, biomass quantity, etc. Similarly, the AC component may be described using the number of residents and the number of employed individuals in a given area, flow of materials, energy consumption, size of investment sites, etc.

3.1 Quality Characteristics of the Natural Environment

In spatial planning, when talking about green spaces we are dealing with a community of species organised in such manner, that it exhibits specific characteristic properties, not seen in individual specimen or populations which it is made up of. The community functions as a certain whole, through mutual metabolic connections. The term "biocoenosis" is used in most ecology texts to describe all biological components of such a community (fauna, flora and soil microbes). A "biotope" refers to the specific habitat conditions encountered in a biocoenosis.

Trojan cites the following characteristics of biocoenoses [19]: characteristic species composition, species composition richness, duration in time, area and boundaries. Biocoenoses exhibit a specific trophic structure, energy flow rate and the rate at which it accumulates, as well as properties such as: capacity, stability, diversity, succession stages. Many authors use the "biocoenosis" term for large, independent ecological units, such as forests. However, accordion to some opinions, biocoenoses may span areas as little as s few square meters. Odum makes a distinction between highly organised and relatively independent "large biocoenoses" and "small biocoenoses" which, to a large extent, are dependent on neighbouring ecological systems [14]. Wang associates the areas of biocoenoses which inhabit an ecosystem with the basic administrative units [21].

A similar diversity is seen when it comes to opinions of classifying biocoenoses. Such a classification is most often based on: major structural properties, physical environment of the biosciences or functional relations. As an example, we may cite

Perelman's classification attempts [15] based on basic biogeochemical properties and classification based on functional relations [18].

The presented diversity of opinions on the areas, boundaries and classification of biocoenoses, allows one to refer to a biocoenosis as a certain abstract value - rarely is there a clear distinction between biocoenoses, they often overlap, one blends into another. This provides some justification to link the areas and boundaries of biocoenoses with basic spatial units where sustainable growth is to be ensured.

In defining the variables associated with the quality of the natural environment NA, it was assumed (constituting a simplification of a kind) that they are linked to the biocenotic balance of green areas within settlement units. Partial environmental quality assessment criteria were selected to adequately reflect the basic requirements defining the balance level as set forth at the outset. Thus, variables were selected which are decisive to the largest extent possible in terms of:

– biocoenoses regeneration ability with respect to the damage done by production activities engaged in by the ecosystem's community,
– ability to compensate for the psychological and physical stress suffered by the residents, which, amongst others, is associated with biocoenoses landscape qualities.

One of the primary criteria for assessing the regenerative ability of vegetation is its stability.

The stability principle states that the energy flowing through every closed natural system changes it until self-adjustment mechanisms permanently adapt the system to the surrounding conditions. Upon reaching stability, energy changes occur within a system in a uniform, pre-determined manner and at a defined rate. A high degree of stability is a property of developed biocoenoses, which inhabit "mature", extensive forest, meadow or aquatic ecosystems.

However, it is known that a system is only stable within certain boundaries, outside of which controlled stresses result in destabilisation. Then the biocoenosis (flora) loses its ability to restore itself to the original state. The degree of floral stability depends on the changes taking place in the abiotic environment. These changes may stabilise or destabilise a system.

(a) A biocoenosis growing under natural ecological succession conditions will result in increased stability. An analysis of a succession trajectory, or the changes and order of biotic communities from the initial biotope inhabitation until the process of changes comes to an end and the final biocoenosis stabilisation are depicted in texts by Sahney and Benton [16].
(b) A reduction to biocoenosis stability is associated with the effects of various stresses, most often caused by urban planning and mankind's economic activities. Some effects of that activity, impact the flora and constitute a powerful stimulus disturbing the self-adjustment mechanisms. The most "sensitive" species are eliminated, and we have a progressively more barren, unstable biocoenoses. The phenomenon is widely discussed in many papers [9].

A general conclusion may be drawn from such research papers, that stability can be identified as a set of (variable) properties which describe biocenotic communities.

However, it is difficult to quantify most of these variables. For example, measuring an ecosystem's primary production requires the application of laboratory methods (isotope method or CO_2 and O_2 variation analysis). In the opinion of many authors, some properties listed in the table are correlated. Therefore, it is not necessary to measure all variables to assess the biocenotic stability of green areas, but only some, those which yield most easily to measurements. For example, Odum emphasises that species richness increases as the proportion of energy expenditures for breathing to the quantity of biomass decreases [14]. It has also been demonstrated that for a larger quantity of vertical habitat zones, the rate of exchange of nutrition components between the organisms and the surroundings increases. Similarly, resistance to external disturbances is stronger in biotic communities which exhibit higher species diversity and inhabit larger areas.

That relationship has been used as a basis for new industrial and communal waste disposal concepts. These methods take advantage of opportunities to utilise decomposable contaminants by appropriately controlling their supply to a biocoenosis. These substances, if supplied in moderate quantities, may increase the overall biocoenosis productivity and constitute a valuable source of mineral food components (e.g. phosphates, nitrates, carbonates, etc.).

These examples show, that sufficiently large and diverse (in terms of species) green complexes are able to maintain stability of an artificial ecosystem which includes settlement areas.

Quality characteristics of the natural environment should be easy to quantify. This is important for practical application in spatial planning.

The following quality characteristics of the natural environment in settlement regions have been selected on the basis of the depicted analysis [3].

s_1. Species richness index.

This is considered to be one of the simplest methods for detecting and assessing environmental pollution levels. The ability to identify species suffices to determine this index.

s_2. Species evenness index.

Species evenness refers to the distribution of individuals across all the present species. If the community is not very even, then most individuals represent a single species. The remaining individuals are distributed across the remaining species. This state prevails most often when some (most resistant) species are afforded significant growth opportunities. The growth of other (more sensitive) species is held back by the impact of limiting factors (e.g. pollution).

s_3. Spatial stratification - the number of vertical habitat zones.

Spatial stratification has been determined to be between 0 and 5 (trees, shrubs, herbs, undergrowth, litter and humus).

s_4. Number of indicator species.

Indicator species are rare species and their presence (or absence) is used to infer the quality of a natural environment.

These environmental risk indices are considered to be simple to acquire and reliable. For example, lichen is a good index for atmospheric pollution due to its sensitivity to acid rain.

s_5. This biocoenosis area (determined on the basis of planimetric readings and site observations).

3.2 Characteristics of Anthropogenic Activity

The following variables have been adopted to describe the AC component [3]:

a_1 - Number of residents within an urban unit.
a_2 - Number of people employed within an urban unit.
a_3 - Size of built-up area.
a_4 - Urban unit "catchment" area.

For sites located at various distances from the centre of the settlement activity, the aforementioned a4 decreases proportionally to that distance.

a_5 - Quantity of urban unit infrastructure components.
a_6 - Material balance - quantity of materials transported to and from the urban unit.

One should note that the variables describing AC are directly related to the given location. They depict mankind's current and planned urban and economic activity levels within each identified urban unit. They are easy to determine on the basis of analyses which encompass demographic forecasts, spatial development directions, the current and planned size of built-up areas, waste management effectiveness and energy consumption forecasts.

4 Measuring Environmental Balance

In accordance with the adopted assumption, ecological balance should include areas where the residents are active on a daily basis, and thus primarily urban functional and spatial units associated with work, dwellings and recreation.

Then, the desired balance for every urban functional and spatial unit, as defined by Eq. (1), assumes the following form [3]:

$$r(a_1, a_2, a_3, a_4, a_5, a_6) = w(s_1, s_2, s_3, s_4, s_5). \quad (4)$$

where:

r, w - location multipliers, associated with the specific nature of human activities and habitat conditions (climate, water and soil) within the urban functional and spatial unit.

The following procedure has been adopted to measure NA and AC:

– determination of partial indices for each area subject to the research on the basis of statistical data, planimetric readings and site visits,

- calculation of normalised values for the aforementioned indices by placing raw values of each index on an identical normalised scale (0/100),
- determination of a rank for each index; here given indices were compared using paired significance method
- calculation of NA and AC values as an arithmetic mean of the normalised and weighted partial indices values.

The presented method for defining environmental balance was used in drafting detailed designs for rebuilding the natural environment in the Poznan Metropolitan Area. The research area was divided into 344 functional and spatial units. AC and NA values were calculated for these areas which were then recorded on a city map. By linking areas where the aforementioned indices had similar values, "contour maps" were obtained depicting the level of anthropogenic activity (AC) and natural environment quality level (NA). Analogously, AC/NA were also marked on a city map, facilitating an identification of sites where environmental balance is most disrupted.

124 areas most at risk were identified on the basis thereof, and actions aiming to restore balance were suggested. The expected positive results stem from project suggestions entailing reinstating local environmental balance. And thus:

- in 15 functional and spatial units a reduction of local vehicle traffic was suggested in favour of safe pedestrian and bicycle access,
- in 3 functional and spatial units establishing water reservoirs (ponds) was recommended at sites which are currently home to abandoned substandard industrial and warehousing developments,
- in 45 functional and spatial units green corridors were recommended which comprise a cohesive ecological network interlaced with residential estates,
- in 16 functional and spatial units dense green belts were recommended on both sides of major trunk roads,
- in 30 functional and spatial units encompassing existing urban parks, enriching the greenery species mix was recommended,
- in 13 functional and spatial units, establishment of "city farms" was recommended to produce food for the local residents,
- in 2 functional and spatial units, establishment of extensive biocenotic communities was recommended, to filter municipal waste water and to compost organic wastes.

5 Conclusion

The "man - natural environment" relationship has become one of the primary factors when it comes to urban quality of life. Green areas are an important environmental balance component.

The suggested method for determining environmental balance in an urban setting provides significant support for the designs and planning procedure. The conclusions yielded by environmental balance analysis define the role and place of green areas in a city, the scope of necessary investments, how green spaces should be managed and the associated costs. In that context, green areas are an indispensable element of the "new urban planning culture" in urban design.

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