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METABOLISM OF THE HISTORIC CITY

METABOLIZM MIASTA HISTORYCZNEGO

Abstract

A number of surprisingly twin processes take place both in the city and in living organisms. One should expect that progress in shaping in space should be as effective as in medicine, where a number of processes are monitored. Currently, in the era of widespread digitization, almost every aspect of the functioning of space can be the subject of thorough and continuous research – both in terms of technical infrastructure, transport, traditional and digital media, as well as social initiatives. Only valuation in the field of preserving cultural heritage and the use of appropriate methods can elude purely mathematical analyses. But are you sure? The article presents methods of modeling and monitoring the metabolism of historical tissue, which, in combination with relatively low-investment activities that use the existing, often neglected potential, can contribute to a more sustainable functioning of space. These actions, in the context of legislation aimed at restoring natural resources, seem not only necessary, but also irreversible.

Keywords: metabolism, spatial decision support system SDSS, hydrological systems, blue-green corridors

Streszczenie

Zarówno w mieście, jak i w organizmach żywych zachodzi szereg zaskakująco bliźniaczych procesów. Należałoby oczekiwać, iż postęp w kształtowaniu w przestrzeni powinien być równie efektywny, jak w medycynie, gdzie szereg procesów podlega monitorowaniu. W dobie powszechnej cyfryzacji również niemal każdy aspekt funkcjonowania przestrzeni może być przedmiotem dokładnego i ciągłego badania – zarówno w zakresie infrastruktury technicznej, transportu, mediów tradycyjnych czy cyfrowych, jak również inicjatyw społecznych. Jedynie wartościowanie w zakresie zachowania dziedzictwa kulturowego i stosowanie odpowiednich metod może wymykać się czysto matematycznym analizom. Ale czy na pewno? W artykule przedstawiono metody modelowania i monitorowania metabolizmu tkanki historycznej, które w połączeniu z relatywnie niskoinwestycyjnymi działaniami wykorzystującymi istniejący, często zaniedbany potencjał, mogą przyczynić się do bardziej zrównoważonego funkcjonowania przestrzeni. Działania te, w kontekście prawodawstwa ukierunkowanego na odbudowę zasobów przyrodniczych, wydają się nie tylko konieczne, ale również nieodwracalne.

Słowa kluczowe: metabolizm, przestrzenny system wspomagania decyzji SDSS, systemy hydrologiczne, błękitno-zielone korytarze

1. INTRODUCTION

Living organisms constantly undergo a huge number of chemical reactions, connections and processes, which since ancient times have been compared to urban metabolism. The seven life processes of living organisms, including nutrition, excretion, growth, response to stimuli, movement, respiration and reproduction, can also be directly or indirectly related to the complex system of the city. In both cases, all the processes are interrelated, and the violation of the "balanced" system translates into dysfunctions of the entire organism. For the first time, the study of urban systems in terms of metabolism was proposed in 1965 by Abel Wolman. It covered a number of processes in cities related to water supply, water and air pollution and the disposal of these pollutants[1].

Currently, due to technical progress, the problem of urban tissue metabolism is experiencing a renaissance. This interest is intensified by faster and faster IT tools and the increasing amount of available data. The digitization process, which gained momentum in the first decade of our century, affects almost every aspect of life – from technical infrastructure, through transport, traditional and digital media, to ecosystem services, civic engagement, sanitation and air quality. Research in this area covers a wide range of technological and social innovations in productivity, sustainability and viability[2]. The control of processes taking place in the city and the implementation of effective tools make our cities more and more intelligent.

Monitoring urban metabolism, in addition to the functioning of technical infrastructure, may include issues of disturbed balance and restoration of nature, including water and greenery. In principle, every investment, including in the historical tissue, should take into account the threats posed by environmental pollution, the occurrence of heat islands, water shortage or excess, loss of natural habitats or social stratification. In the European Union, one of the tools for restoring what we have destroyed will be the adoption of the Nature Restoration Law. It will be the first comprehensive act of its kind covering the entire continent, also concerning the ecosystems of historic cities.

The article indicates several elements of the historical urban fabric, the atrophy of which may lead to the dysfunction of the entire system. The presented examples of relatively low-investment activities make use of the existing, often overlooked, potential for the re-activation of the urban organism. These are interventions that use previous experience of shaping space, which can be an inspiration to improve its functioning in the future. Methods of modeling and monitoring the metabolism of historical tissue were also indicated. The stage of simulating various scenarios can contribute to the improvement of life, work and leisure not only in the historic city. The problem is illustrated by water in the historical urbanized space.

2. URBAN SYSTEMS MODELING

Research on the functioning of urban systems has long been based on mathematical models that enable smooth analysis of changes related to changing parameters of boundary conditions. The latest history of research in this field dates back to the first half of the 20th century. The research of Wassily Leontief, an American economist of Russian origin, developed in Europe since the 1920s, and from 1931 in the United States at Harvard University

[1] A. Wolman, *The metabolism of cities*, "Scientific American" 1965, vol. 213, pp. 179–190.

[2] H. Min Kim, S. Sabri, A. Kent, *Smart cities as a platform for technological and social innovation in productivity, sustainability, and livability: A conceptual framework* [in:] H. Min Kim, S. Sabri, A. Kent (eds.), *Smart Cities for Technological and Social Innovation. Case Studies, Current Trends, and Future Steps*, Academic Press, London 2021, pp. 9–28, DOI: 10.1016/B978-0-12-818886-6.00002-2.

and then at New York University, is of fundamental historical importance here[3]. This later Nobel laureate invented input-output tables. Input-output tables contain rows and columns representing the basic branches of the economy, and column-row records determine the flow of activity in money or materials. Leontief created a coherent and complete model that became an inspiration for the construction of electromechanical computing devices even before World War II. Due to the great development potential, the idea of input-output tables is still being developed and used not only in economics. The invention of the digital computer contributed to the intensification of research into human movement, transport modelling and land use. The further development of research was based on mathematical models that increasingly took into account the dynamics of change in unstable and heterogeneous cities. The ideas of urban dynamics in the theory of morphogenesis were introduced in 1975 in the book "Structural Stability and Morphogenesis" by the French mathematician René Thom[4]. The theory of morphogenesis, closer to the description of the real state, deals with dynamic systems, in particular situations where the continuous change of the control parameter leads to qualitative changes in the behavior of the system. The limitation of the implementation of earlier theories in the area of spatial planning was the availability, volatility and instability of data. In addition, the economic aspect of planning policy did not always take into account the different paradigms of architecture and urban planning. Starting in the 1970s, research has increasingly taken into account energy inputs and the energy balance (Ill. 1)[5].

The currently used tool to support more balanced decision-making in spatial planning and evaluation is the interactive spatial computer system decision support system (SDSS). The study of spatial effects is based on predictive and prescriptive (normative) models. Predictive models use statistics to analyze any kind of unknown event, regardless of when it happened or will happen. Normative models are used to determine what actions can be taken to make the best decision. Decisions modeled in SDSS support the user or groups of users in determining the decision path in the most effective way[6]. SDSS includes a decision support system (DSS) and a geographic information system (GIS). Both systems use a database management system (DBMS). DBMS is system software for managing and processing geographical databases that can be used to forecast the possible effects of decisions.

Today, one of the widespread hydrologic and hydrological modeling tools is the geographic information system GIS, which is designed to enter, store, edit, search, analyze, and output geographic data and information[7]. Digital elevation models are used to parameterize the relief and water relations. Their derivative are digital terrain models, on the basis of which a digital elevation model of the terrain is developed. Data from airborne LIDAR (Light Detection and

[3] The precursor of input-output tables is considered to be the French economist, the creator of the economic direction – physiocracy, François Quesnay, who in 1758 published the "Economic Table". The board shows the circulation of goods in the society of that time and the process of realizing a pure product.

[4] R. Thom, *Structural Stability and Morphogenesis*, W.A. Benjamin, Reading 1975.

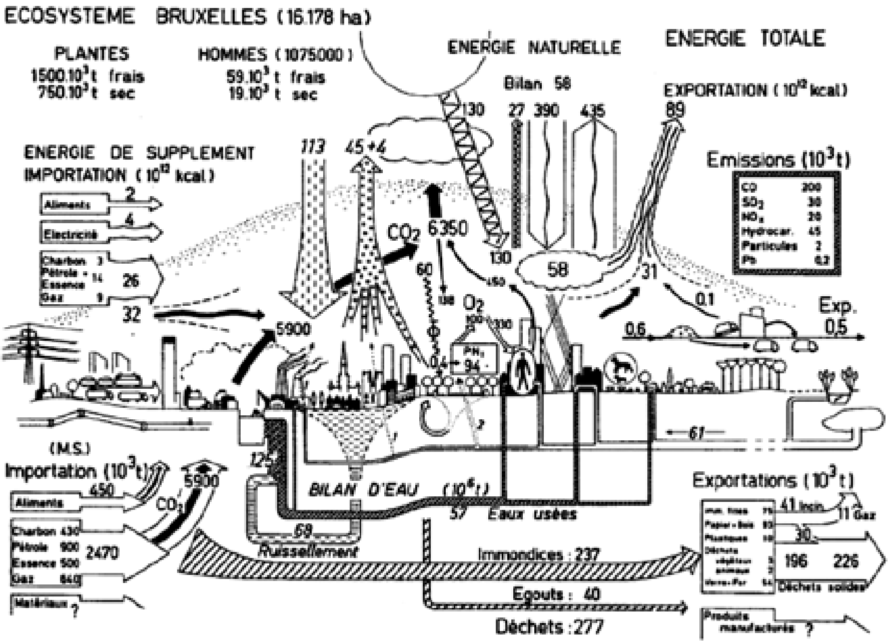
[5] P. Duvigneaud, S. Denayeyer-De*, L'Ecosystéme Urbs, in L'Ecosystéme Urbain Bruxellois* [in:] P. Duvigneaud, P. Kestemont (eds.), *Productivité biologique en Belgique. Travaux de la section belge du programme biologique international*, Duculot, Paris 1977, pp. 581–597.

[6] R. Sugumaran, J. DeGroote, *Spatial Decision Support Systems. Principles and Practices*, CRC Press, Boca Raton et al. 2011, p. 14.

[7] M.N. DeMers, *Fundamentals of geographical information systems*, John Wiley & Sons, Inc., Hoboken 2009, p. 19.

Ranging) laser scanning is used to prepare analyzes and a digital elevation model, thanks to which it is possible to build elevation models. The high quality and high resolution of the models replaces the recent tedious and costly field surveying[8].

Spatial modeling in a geographic information system (GIS) can be linked to multi criteria decision evaluation (MCE). Generating action scenarios must be preceded by defining criteria, for example, enhancing biodiversity or preserving or removing specific objects. Determination of criteria in the urban tissue should also involve local stakeholders. The next step, after the selection of appropriate indicators and variables enabling the measurement of selected criteria, is the assessment, for example, from the perspective of preserving cultural heritage, preserving biodiversity, flood protection and investment implementation costs. Then the criteria, using the MCE multi-criteria decision evaluation technique, are compared and the results are merged with the GIS. The result should be the generation of several viable scenarios, which, after comparison and evaluation, can be the basis for building a specific action strategy. The subject of integrated GIS and MCE modeling can be any component that builds an urbanized or non-urbanized space. Further progress in the field of better modeling should be sought in the growing collection of new data and new generations of physical models.



Ill. 1. The Brussels Metabolism Study on Natural Energy Balance is considered one of the groundbreaking and most comprehensive studies in urban ecology and urban metabolism, 1970, source: P. Duvigneaud, S. Denayeyer-De*, L'Ecosystéme Urbs, in L'Ecosystéme Urbain Bruxellois* [in:] *Productivité en Belgique*, P. Duvigneaud, P. Kestemont (Eds.), Traveaux de la Section Belge du Programme Biologique International, Bruxelles 1977.

[8] M. Brzezinka, *Zastosowanie GIS w modelowaniu hydrologicznym. Wybrane zagadnienia*, DATAGIS. PL Technologie Geoinformacyjne, http://www.datagis.pl/upload/original/zastosowanie-gis-w-modelowaniu-hydrologicznym.pdf (access: 20.06.2023).

Modeling using differential equations and matrix algebra to describe flows can have almost unlimited applications in spatial planning, also in historical space. It can relate to the built environment, communication, transport as well as environmental and social aspects. Action scenarios can be fundamentally different. Examples of possibilities and at the same time limitations of actions in the aspect of water system restoration are presented below. However, the mathematical description of urban metabolism may be limited. Christopher Kennedy states that "a comprehensive but simple model of urban metabolism is described by about 25 closed-form equations". He cautions, however, citing research in historical space that "urban metabolism studies, which sought to quantify all or most of the flows of materials, water, nutrients, energy and pollutants through cities, have become largely data-gathering exercises."[9]

3. WATER IN THE HISTORICAL TEXTURE OF THE CITY

An important element of the functioning of cities, as in the case of living organisms, has always been water. It may directly affect their health, land use, biodiversity, climate and flood protection. Water in the urban ecosystem, also associated with greenery, has for centuries served not only sanitary and living purposes, the functioning of crafts (mills, fulling mills), irrigation of fields or as an easily accessible extinguishing agent. It was also used for defensive purposes, constituting an additional barrier.

The connections between towns and villages and wetlands were uneasy and inseparable. Removing water from cities or marginalizing it has always had an impact on the quality of life of residents. Therefore, societies, relying on knowledge and technical possibilities, realizing the consequences of its lack or excess, tried to regulate its amount. Unfortunately, many cities over the last decades have unwisely got rid of it or are getting rid of it from circulation. The lack or scarcity of water may result in flooding during periods of intense rainfall on the one hand, or droughts on the other hand. Extreme natural phenomena result in the disturbance of biodiversity. Currently, societies are becoming more and more aware of the importance of this problem. This is reflected in more and more actions taken to keep water in the city. The range of activities may include, among others, the construction of water reservoirs and infiltration systems. Their implementation in urbanized space may involve the need to incur large financial outlays and many implementation problems. Less expensive and energy-intensive solutions can provide the experience of shaping space from the past. In many towns with previously developed hydrological systems, as a result of industrialization, motorization, negligence or ignorance, they could have been destroyed or marginalized. Restoring water reservoirs and channels that are currently devoid of water or liquidated can be an important element of water retention, as well as the reconstruction of natural habitats, including wild fauna and flora in the urban ecosystem.

An obstacle to restoring the former hydrological system may be subsequent transformations of space, which could include changes in the topography of the land or erection of new buildings and structures. Making the right remedial planning decisions requires examining

[9] C. Kennedy, *A Mathematical Description of Urban Metabolism* [in:] M.P. Weinstein, R.E. Turner (eds.), *Sustainability Science. The Emerging Paradigm and the Urban Environment*, Springer, New York et al. 2012, pp. 275–291.

the current and historical hydrological conditions, including the explanation of the circumstances of the introduced changes and the analysis of their effects on the environment, natural resources, buildings and land used. Until recently, access to only analogous geographic information significantly limited investment plans in this area. Currently, using data and digital tools, such as the spatial decision support system SDSS, it is possible to simulate hydrological and hydrotechnical changes, taking into account specific boundary conditions, both at the concept and design stage, as well as after the investment. It is therefore possible to determine potential investment costs and profits in various variants, while reducing location conflicts. Implementation of effective rules and tools to organize the space should ultimately result in the reconstruction of urbanity[10].

An example of SDSS implementation is the project "Byøkologisk 2011–2026" implemented by the Municipality of Oslo. In the 19th century, during the urban development of Oslo and the surrounding area, the water system was largely covered. The hitherto covered Hovinbekken creek was reopened as part of the project[11]. Restoration work also included reclamation and habitat creation, creation of pools and construction of settling tanks. Now, as part of this project, most of the other canals have also been restored to a more natural state, creating blue and green corridors.

Nysa is a historical city where it would be possible to implement the spatial decision support system SDSS in order to rebuild the hydrological system, which is currently not fully used. The example illustrates the complexity of the conditions that should be taken into account during the implementation of the water system repair project and potential conflicts. For hundreds of years, the city was protected by medieval and modern fortifications and the related system of hydrological devices. If it was necessary to defend the city, the system allowed the flooding of huge areas of land in a controlled manner. To this day, an extensive hydrological system has been preserved in the city park, with a system of weirs, dams and water ponds, as well as the Water Fort, which is part of the Prussian fortifications erected at the end of the 18th century. After 1945, the water level in this system, as well as in the canals flowing through the city, was lowered by about 1.5 m. The canals remain almost completely dry for part of the year. This pathological situation was consolidated by locally covering them or even erecting a service facility in them (Ill. 2). Rainwater in the city is not collected, but is discharged through the rainwater drainage system to the Nysa Kłodzka River or through a combined sewage system to the sewage treatment plant. In the face of the need for the most sustainable management of space, it is obvious that it is necessary to restore the old, proven solutions. Leaving water in the city is a key issue here. The possibilities of collecting water are enormous – in addition to raising the water level in canals and ponds, it is possible to fill empty water reservoirs forming a moat surrounding the western, southern and eastern sides of the city center with water. In this way, the city would gain natural water reservoirs. Therefore, the introduction of small retention within a medium-sized historical city is not only possible, but also necessary. At the same time, the implementation of structural changes does not have to generate excessive costs, and the implementation itself can be carried out in stages.

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[10] Z. Zuziak, *Węzły miejskości a modele przestrzenne struktur miejskich. Z notatek nt. synergii* w *urbanistycznych konstrukcjach* śródmieść, "Budownictwo i Architektura" 2018, no. 17(3), p. 109.

[11] *Prinsipper for gjenåpning av elver og bekker i Oslo*, version 1.0, September 2015, http://www.osloelveforum.org/wp-content/uploads/2017/10/Prinsipper-for-gjen%C3%A5pning-av-bekker-og-elver-i-Oslo-2015.pdf (access: 20.05.2023).

Ill. 2. a – map of Nysa from 1926, source: *Neisse. Ein Führer durch die Stadt Und ihre Geschichte*, F. Bär's Buchdruderei Neisse 1926; b – moat by the hospital, narrowed to about 1/5 of its width; c – moat surrounding the town from the south as a potential water storage area, periodically flooded with water before 1945, author's photo, 2023; d – view towards the former mill, the dashed line shows the buried canal of the mill race, on the right a service building built in the canal, in front of the former mill the canal covers a paved square with a fountain and a parking lot, author's photo, 2023.

Another extremely important effect of lowering the water level in the city may be disturbing the foundation conditions of buildings. Violation of the durability of buildings and structures erected on wooden piles may be particularly dangerous. The issue is broader and concerns many historical towns located most often on rivers and lakes and in swampy areas. Exposure of wooden piles with simultaneous access of air may result in the destruction of the piles and the entire building. Here, it is important not only to monitor the water level, but also the damaged or potentially endangered buildings.

The lowering of the groundwater level is closely related to the excessive sealing of the surface. In addition to the liquidation of greenery, which is the subject of widespread criticism not only in Poland, the construction of sealed pavements and squares excludes or significantly reduces water infiltration into the soil and the flow of groundwater. As a result, a reduction in groundwater recharge can cause urban subsidence. Examples of research in metropolises may raise legitimate concerns. The center of Mexico in the years 1910–2000, mainly due to the active drainage of the aquifer and due to the reduction of water supply, lowered by 9 meters. In contrast, part of Bangkok between 1960 and 1988 lowered by 1.6 m, or an average of 5.7 cm per year[12].

Another type of threat may be associated with damage to the drainage system, both within the historic city and the non-urbanized areas located above. Paczków is an example of a historic city where the drainage system and rainwater system were damaged. This medieval city, famous for its preserved fortifications and one of the most regular city center plans, was equipped with an efficient hydrotechnical system ensuring not only the lack of moisture in the buildings, but also a gravitational power supply system, among others, for city fountains. After 1945, the drainage system was damaged, causing, among other things, flooding of the basements of the buildings and their permanent dampness. The fountain in the market square was dismantled over time due to the lack of water supply. However, the fountain, rebuilt in 2019, is no longer powered by gravity.

There are many more examples of cities where the hydrological system has been destroyed. The logical solution to the problem may be to return to methods proven over the centuries, which may turn out to be more sustainable than many existing ones.

4. CONCLUSION

In the study of urban metabolism, it should be expected that the future development of the spatial decision support system will be focused on the construction of more complete systems, enabling a fuller use of the stochastic modeling strategy and more accurate regional disaggregation. The search for optimal solutions should be supported by the use of experience based on past experience, leading to the simultaneous solution of many problems. Sometimes, reflecting on quite recent solutions that took into account the participation of nature and the association of causes and effects of imbalance can be an effective way to solve current problems. Of course, restoring natural resources in the urban tissue will require actions that are not always accepted by users and space managers. It can generate conflicts. In recent decades, the balance in the historical fabric of cities built over centuries could be exposed to various types of threats. Some of the actions had their further consequences, which in total could be an obstacle to restoring natural, balanced relationships in the urban system. Therefore, a number of spheres of life will require redefinition. Many of the existing urban planning theories, assuming slow and sequential changes in spatial structures, have already been questioned. The description of the actual state is closer to non-linear models, taking into account the dynamics of change in unstable and heterogeneous cities.

All activities monitoring urban metabolism should be implemented in spatial planning legislation, in particular in local spatial development plans. The effectiveness of their implementation will depend on continuous pre- and post-action evaluation and enforcement of potential discrepancies.

[12] E.H. Decker et al., *Energy and material flow through the urban ecosystem*, "Annual Review of Environment and Resources" 2000, vol. 25, pp. 701–702.

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