VILNIUS UNIVERSITY

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METHODOLOGY OF QUANTITATIVE ASSESSMENT OF LANDSCAPE TECHNOGENEITY
(CASE OF LARGEST LITHUANIA CITIES)

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VILNIAUS UNIVERSITETAS

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INTRODUCTION

The relevance of the study

In the context of landscape development, humans as an expansive, ecologically plastic and especially destructive species have been aggressively affecting the various elements of natural spheres transforming them and filling the space with new technogenic objects. For a few decades, researchers have been discussing the issue as to how the traces of human activity should be qualified in the context of natural environment or whether the anthropogenically created environment and its objects should be regarded as a part of the nature (Comer, 1997) or a foreign body in the natural environment, i.e. an expression of something artificial and unnatural (Hunter, 1996; Machado, 2003; Angermeier, 2000). The present study upholds the latter view. The choice of this position is based on the ability of humans to consciously perceive the outcomes and extent of their activity and causality of related processes what, incidentally, distinguishes them among other species of biological organisms. For this reason, along with the biosphere, i.e. animate natural sphere, the anthroposphere, referring to humanity with its social, cultural and economic environments, and the outcome of human activity technosphere, the whole of manmade technical devices, constructions and modified natural objects, are distinguished (Balandin, 1978; 1982; Rozanov,1987; 1998; Kavaliauskas, 2011; Kavaliauskas, Veteikis, 2004; Veteikis, 2002; Jankauskaitė; Veteikis, 2005a; 2009; 2012). The elements of the technosphere – the objects of various degree of artificiality or anthropogenic transformation – are unevenly distributed in and produce different impacts on the landscape. For this reason, in different spheres – such as landscape management and planning, conservation of natural territories and assessment of the state of geosystems and ecosystems – the development of methods and indices for determining the naturalness or artificiality of territories and their practical application have not lost its relevance and importance.

Nevertheless, there exist a great lot of methods for assessment of artificiality/technogeneity or, conversely, naturalness of landscape. A distinct qualitative preponderance has been gained by bioecological and biological studies. Naturalness/artificiality in the studies of this kind often is only one of the conservation values and only very few studies present precise assessment methods and indices (Macdado, 2003). In some cases, only the theoretical premises for problem solution are mentioned (Anderson, 1991; Angermeier, 2000). Still other studies confine to qualitative assessment alone. Species composition of vegetation, incidence of invasive and indigenous species, potentially natural vegetation, degree of cultivation, etc. are only a part of qualitative indices of naturalness (Ellenberg, 1979; Blume, Sukopp, 1976; Grant, 1995; Edarra,1997 Jalas, 1995; Kovarik, 1999; Sukopp, Hejný, Kovarik, 1990). For unknown reasons, the quantitative evaluation is avoided. Among one of rare examples J. L. Ferma-Almanda‘s indices of naturalness can be mentioned (kilometres, number of roads or buildings per unit area of territories, territory under mature vegetation, area of conserved territories)(Ferman-Almanda, 2001).

The given examples of evaluation of naturalness show a rather narrow range of possibilities to apply these methods. The employed indices are effective for evaluation of little anthropogenically affected territories with dominant components of animate nature. Whereas for determining abstractedly the degrees of naturalness or artificiality of anthropogenic territories or technogenic objects these indices are of little help.

Landscape geographers and architects in their research follow different approaches. Naturalness often is analysed through the perceptual prism (Ode, fry, 2009; Tveit, Ode, 2006; Palmer, 2004, Lamb, Purcell, 1990) and respondent survey methods are used for analysis of landscapes of different structural composition and anthropogenisation degree. The perceptual approach is based on subjectivity as it depends on the researcher's or respondent's opinion. The present study is important and relevant as an attempt to solve the issue of maximal objectivity in determining the artificiality degree using quantitative indices and methods.

Objectives and tasks

The strategic objective of this study is to develop a methodology for quantitative assessment of the degree of technogeneity of landscape. The main aim is to reveal the spatial distribution patterns of embodied energy as of an indicator of landscape technogeneity.

Tasks:

1. To analyse the research trends of energy purposefully targeted at technogenic deformations of environment;
2. To develop a conception of embodied energy in the context of technogenic landscape research;
3. To develop a system of indices for evaluation of the degree of technogeneity of landscape through the amount of embodied energy;
4. To determine the specific distribution patterns of the indices used for assessment of landscape technogeneity degree;
5. To regionalise the landscape technogeneity degree in the reference territories;
6. To show the possibilities for practical and theoretical application of the developed methodology.

Research object

So far, the developed methods have not been employed for assessment of structurally most complex and technogenically transformed types of anthropogenic landscape such as urban landscape. Undoubtedly, in the urban environment few if any natural elements have survived. Yet there remains an open issue as to the degree of artificiality of newly developed or modified landscape elements, extent of changes in the transformed human living environment, and territorial distribution patterns of artificiality. The objective of the dissertation in a broad sense is: modern landscape embracing components of different degrees of anthropogenisation and technogenisation. In a narrow sense, the research object embraces technogenic landscape and its technogenically affected components.

Scientific novelty of the study

1. A geographical conception of embodied energy as indicator of landscape technogeneity was developed.
2. Spatial data of surface scanning by remote sensing technology (LIDAR) were used for landscape technogeneity analysis – determination of morphometric parameters of technogenic elements.
3. A digital database of spatial parameters of buildings in the largest Lithuanian cities was created.

4. Methods for evaluation of landscape technogeneity degree – embodied energy – were developed.

5. Specialised typological regioning was performed for: territorial distribution of morphometric and material properties of technogenic components in the largest Lithuanian cities, distribution of technogenic material and territorial artificiality, and urban landscape technogeneity.

6. Territorial distribution patterns of the technogenic structure of urban landscape were determined.

Applicability

The practical and theoretical possibilities of the methodology developed during the present study are demonstrated through its application examples. The embodied energy is one of the constituents of energetic organisation of technogenic landscape structure and could be taken as a basis for distinguishing technoenergetic territorial complexes (energotopes). Objective determination of landscape technogeneity degree is one of the steps towards evaluation of environment optimality. The qualitative and quantitative properties of technomaterial in technourbosystems (analysed in detail in the present study) could be of service for investigation of the metabolism of urboecosystems. The practical use of the study is feasible in the fields of economic activity planning and landscape management.

Maintained propositions

1. Multilevel indices' system is required to perform landscape technogeneity investigation and embodied energy evaluation.
2. Amount of landscape's embodied energy depends from matter artificiality and technogenic matter quantity in area.
3. The greatest amount of embodied energy is accumulated in central- historic, highest building density city parts.
4. Different and peculiar spatial structure of landscape technogeneity is typical for analyzed city areas.

Approbation of research results

The research results have been published in 3 articles including 2 in the scientific journal "Annales Geographicae" and one in the peer reviewed international conference issue „Теоретичні, регіональні, прикладні напрями розвитку антропогенної географії та геології : матеріали треть".

Two presentations were made at scientific conferences: Young Researchers' Conference "Biofuture: perspectives of natural and life sciences" (Vilnius, 2001); international conference of anthropogenic geography „Теоретичні, регіональні, прикладні напрями розвитку антропогенної географії та геології" (Kryvij Ryg, 2011).

Extent and structure

The thesis includes the main chapters: introduction, review of research, methodology, research results, conculsions, list of literature resources as recommended by Regulation No. VI-4 of the Research Council of Lithuania. The thesis analysed 131 literature sources and includes 32 maps, 75 diagrams and other illustrations, 7 tables.

1. OVERVIEW OF RESEARCHES OF ENERGY INVOLVED IN LANDSCAPE TECHNOGENISATION/ANTHROPOGENISATION PROCESSES

The issue of landscape anthropogenisation became an object of geographical research at the end of the 19th–the beginning of the 20th century (Marš, 1866; Dokučiajev, 1899; Sauer, 1925; Berg, 1931). Since then, the human impacts on nature and natural landscape have become an issue of increasing concern. In this context, an important place is occupied by investigations of transformed technogenic energy in the landscape anthropogenisation processes.

In the landscape geography science, certain trends of investigation into mastered energy can be distinguished. They are linked with conceptions of spherical and systemic perceptions of environment.

Spherical-philosophical approaches to technogenic energy

V.I. Vernadsky is the originator of spherical-philosophical approach which is widespread in the circles of Russian landscape geography school. In his works, the resercher extensively described the biosphere as a global ecological system integrating all living beings. This author also referred to the issue of the energy of the members living material (biological life)-biosphere. Basing on the idea of animate nature evolution, he formulated the concept of noosphere, which emerged from the biosphere in the process of evolution of organisms. Vernadsky was among the first researchers who promoted the idea of cognition as immaterial form of energy. In this way, he laid the foundations for further investigations of energy as landscape transformation motor (Vernadski, 2004).

The idea of noosphere also was propagated by Vernadski's contemporaries E. Le Roy and T. De Chardin from France. Le Roy (1927) understood noosphere as a new geological phenomenon in our planet where humans transform their living environment by means of the force of labour and mind (Le Roy, 1927). In T. De Chardin's works, the noosphere is "the sphere of human thought" created by human cognition and force of mind (de Chardin, 1964, 1965). Though the conception of the noosphere has not received serious consideration when Vernadski was still alive, in the course of time it has been gaining popularity in the works of many authors (Grigorjev, 1966, 1970; Balandin, 1982; Gumiliov, 2001; Annenkov, 1989; Vedenin, 1990; Glazovsij, 1988; 1989; Girionok, 1987; Moisseev, 1990; Bondariov, 1997; Burovskij, 2010). Yet the energetic shell of human sphere, energetic aura and human transformed energy flows in the noosphere are mentioned and discussed not in all mentioned works or only passingly overviewed. F. I. Girionok (Girionok, 1987) believed that human beings interact with the geographical environment through biomaterial and anthropoenergetic channels, which are closely interrelated. Moreover, according to this author human activity is concentrated not only on maintenance of the "living" but also of the "inorganic" bodies. Speaking about the inorganic body of humanity, the author had in mind the products of human activity – technosphere.

N. Moisejev (1990) identified the development level of humanity with the degree of mastering energy in human everyday life. The mastered energy sources and the rate of mastering were equated by him with the natural processes such as floods, volcanism and hurricanes.

L. N. Gumilev (2001) believed that the energetic impulses of the biosphere are conveyed to society through discrete individuals or even through ethnoses whereas the mastering of gegeochemical energy described by Vernadski represents the relationships between man and environment. Gumilev spoke about a mysterious kind of energy from the cosmos which is able to affect the stereotypes of human behaviour. He defined this mystified energy absorbed by individuals and ethnoses as pasionarity. A. M. Burovskij (2010), based on Vernadski's conception of the noosphere and Gumilev's ideas of cultural evolution and pasionarity, developed a science of anthropoecosophy where anthropogeosphere-earth sphere is the main object of investigation. The anthroposphere is transformed by cognitive material, i.e. humans in a broad sense and society – its energy. The issue of cultural energy also occupies an important place in the science of anthropoecosophy. Investigating into the ecological state of cultures, he raised the problem of quantitative evaluation of the ecological state of environment. The author indicated the energy or labour necessary for creation of production or performing processes as one of the key criteria for quantitative evaluation of the ecological state of environment (Burovskij, 2010). He (2010) also pointed out the feature common for all cultures: to store, .i.e. accumulate energy in material things.

L. L. Rozanov was originator of geotechnomorphology science. In his works, speaking about geotechnomorphogenesis, technolithomorphohenic sphere and technogenic relief formation, Rozanov also emphasised the importance of human influence, ruled by material and energy, on formation of the technosphere and, in general, the face of the human living environment. Rozanov mentioned technogenic energy as one of the key relief-forming forces (Rozanov, 1989, 2001).

Generalising we may state that in the works of the mentioned and many other authors the emphasis on investigations of technogenic energy flows is rather weak. Yet, since the 5-ties–6-ties of the 20th century, landscape geographers have been pointing out that energetic links of landscape are no less important than the material or even the informative links.

Geosystemic investigations of technogenic energy

The emergence of geosystem theory in geography opened vast vista for the studies of landscape complexes and their system links. Yet in practice most of them only encompassed geophysical analysis of the links of natural complexes including natural energy. Meanwhile, energy studies of anthropogenic landscape usually confined to general theoretical definitions of the structure of anthropogenic/technogenic systems.

In one of his articles, A. J. Retejum with co-authors (1972) touched upon the subject of technogenic energy. Analysing the relationships between nature, technologies and social products they worked out their classification based on the relationships with the environment and distinguished two types of geotechnosystems: production and service. Production systems are subdivided into extraction and processing. The production systems extracting materials are a baseline for material-energy flows. The processing systems transform the extracted material to procure energy. The latter include smelting works, factories producing fertilisers, etc. The service technosystems are classified by the mentioned authors into active and passive ones. The active systems affect the environment through energy and material transmission. The environmental loads of the analysed technosystems are characterised in a few aspects depending on their type. Some systems simply assimilate the solar energy, transform it into heat energy and return it to the atmosphere. In other cases, the energy exchange is related with functioning ensured by fuel expenditures.

In one of his many articles, German classic landscape geographer E. Neef discusses the relation of technology with the landscape. In Neef's opinion (1969), due to close links between material and energy, systems can be regarded as energy structures. He suggests analysing these structures and their processes using energy methods taking into consideration the energy distribution patterns. Speaking about geotechnical metabolism, he mentions energy transformations in the process of human activity. The transformed energy is fixated in material structures and is extracted during anthropogenic processes. Energy is one of the constituents of Neef's landscape energy potential equation.

In 1956, H. E. Thomas wrote about the use of models of energy and material flow for evaluation of the degree of assimilation of the earth surface (Thomas, 1956).

Ecosystemic investigations of technogenic energy

The ecosystemic concept is concentrated on the studies of the habitats and living space of organisms including humans. According to Z. Naveho (1996), the total human ecosystem theory is the methodological core of landscape ecology. The theory was developed in the 60-ties by F. E. Egler. The main idea of the total human ecosystem (THE) is that humans and their living environment in nature comprise an integrated space which should be investigated as the highest hierarchic rank of ecosystems (Naveh, Lieberman, 1996; Egler, 1970). In the THE, man is the cornerstone which is able to influence the quality and processes of his living environment. Thus speaking about the THE, it is relevant to touch upon the issue of energy, material and information flows. Z. Naveh (1996) dealt with this issue in his later works. According to him, the technogenic and intensively exploited agroindustrial landscapes completely depend on the fossil fuel energy. They have lost the systemic properties such as renewal or organisation of own structure (1998). Naveh distinguished ecotopes according to energy, material and information outflows from bio- and technoecosystems. In his model, natural bioecosystems, existing due to solar energy, and urban and rural technosystems, supported by fossil fuel, are distinguished. An intermediate link could be distinguished: bioecosystems supported both by solar and fossil fuel energy (Naveh, 1980; 1998).

Z. Naveh drew his ideas from the works of many followers of landscape ecology. In his book "Landscape Ecology" he overviews the works of many researchers who analysed the issues of the relationships of ecosystems and main energetic relationships. H. Ellenberg's (1973) functional classification of ecosystems may serve as an example. The highest rank (mega-) ecosystems were classified by him into natural and close to natural, which mainly depend on solar radiation, and artificial urbanised industrial ecosystems, which exist due to fossil fuel and, of recently, due to nuclear energy (Ellenberg, 1973).

Naveho (1996) in his "Landscape ecology" also discusses A. Toffler's futuristic book "The third wave' (1980) in which the author speaks about the cyclic development character of the whole of society and its activity products – technosphere. In Toffler's opinion, the humanity is living in the third post-industrial revolutionary stage of social evolution "information age" which followed the second development stage "industrial revolution". Toffler emphasises the dependence of society, irrespective of the development stage, on energy, which together with production and distribution systems is a part of the technosphere. Depending on the cycle of society development, people master the advancing tools of energy production and transformation in this way mastering new kinds of energy over and over. Therefore, according to Toffler (1980), the mastering level of energy shows the degree of cultural development (Naveh, Lieberman 1996, Toffler, 1980).

In 1965, a book about energy geography was published by American researcher L. Linton. Linton spoke about the necessity to create measure units for such processes as capital, population, technical information, water, etc. flows, which would allow their representation as energy transmission similar to ecosystem relations. Linton assumed that energy and its measuring units, thermal units (calories) and watts, could become an integrating axis of the branches for natural and human geography (Linton, 1965).

In his early works, H. T. Odum promoted an idea that natural and economic social ecosystems can be studied in one common aspect – through energetic prism (1971, 2007). He formulated the notion of "emergy". Emergy is amount of energy of one kind necessary for transformation of material or state of material. Based on this notion, H. T. Odum explains the dominance of some cultures or social orders (2001). In one of his last works, he classified ecosystem elements according to their functional properties, i.e. energy sources, producers, users and accumulators. Basing on the laws of physics, the author points out that any system may transform energy, i.e. accomplish work. Heat energy is the lowest rank energy produced as a by-product in the processes of transformation. Use of material in the process of formation of the internal and external structures and releasing energy is one of the major properties of systems. Systems also are characterised by energy transformation in the process of self-organisation.

An important place in Odum's works is occupied by the hierarchy scale of energy where during transformation processes smaller amounts of energy are transmitted towards the top and the kind and quality of energy also change. The notions "transformation ratio" and "quality of energy" were replaced by another Odum's notion "energy transformity". In its essence, this term means emergy necessary for production of a unit of other kind of energy.

Shu- Li Huang – a representative of Chinese landscape science – investigated the dependence of urbanised landscape spatial expansion on energy flows (2001). Huang used energy and energy transformity values as a methodological basis for energy flow analysis. Huang used energy and emergy transformity dimensions. The conception of energy transformation for production of goods or services was employed by this author for analysis and spatial visualisation of ecosystems and economic processes (Huang, 1997, 1998a, 2001, 2007). In general, the conception of *emergy* has been widely used by south-east Asian, Chinese in particular, landscape geographers. Z. F. Cai with co-authors (2009) applied spatial energetic analysis based on "energy calculations" for urbanised agglomeration regions of Peking, Tianjin and Tangshan. Another team of Chinese scientists applied energy calculations for evaluation of ecological planning and improvement of resources and natural environment for economic purposes (Chen, Chen. Zou...., 2009). In their article, they give energy based energetic indices conveying the thermodynamic loads in systems during their transformation and the proportion of the renewable energy sources and necessary resources for projected object which express the economic value of processes.

Many other similar examples of Asian landscape science representatives, who analysed urbanised landscape ecosystems based on the emergy conception, can be given (Li, Zhu, 2011; Zang, Jang, 2011; Yang, Chen, 2009; Liu, Yang, 2009).

R. H. Herendeen analysed the pluses and minuses of emergy, environmental energy calculations and evaluation of systems. In his opinion, the "vertical scale" including producers, their suppliers, suppliers of the latter, etc. is the optimal way to determine the amount of energy necessary for producing goods. In Herendeen's system energy flow model energy is evaluated through the intensity of through-flows of the system (e.g., kcal/day).

J. L. Hau and Bakshi (2004) spoke up for advantages of emergy conception against economic methods of ecosystem flow evaluation. They pointed out that emergy conception is an objective way to determine the value of human and natural labour without basing on subjective expert opinions.

There exist many more methods for technogenic energy evaluation in human living environment which could be applied for system analysis. The exergy calculation methods (Balocco, Papeschi, 2004; Ertesvag, 2001), widespread in engineering sciences and based on the second thermodynamic law can be given as an example. Exergy stands for maximal amount of mechanical labour which theoretically can be produced by one energy unit (Ertesvag, 2001).

Investigations of technogenic energy by Lithuanian geographers

In Lithuania, the anthropogenic landscape has been studied in variable aspects (Kavoliutė, 1996, 1998, 2000, 2002; Ribokas, 2000; Ribokas, Aidukonytė, 1998; Basalykas, 1979, 1977; Kavaliauskas, 1976, 2000; Veteikis, 2000, 2002, 2003, 2005a, 2005b, 2008; Veteikis, Jankauskaitė, 2009; Veteikis, Kavaliauskas, 2004; Milius, 1974, 1979; Godienė, 1999, 2000, 2001). Nevertheless, the targeted investigations of technogenic energy are in the embryo state.

In P. Kavaliauskas' works, the technogenic energy has not been investigated directly. Yet they include the conception of technosphere implying a "territorially differentiated human environment whose elements, though remaining a part of natural material, may exist in their relationship system only due to human effort and left for themselves they gradually disintegrate" (Kavaliauskas, 1976).

D. Veteikis (2003, 2005a, 2005b) has more extensively studied the issue of technogenic energy. In his technomass calculation methodics, along with the indices of artificiality of materials and technogenic resistance he distinguished the ergotechnical index of amount of labour (Veteikis, 2005a). The ergotechnical index is defined as usefully spent amount of labour for installation of transformed or artificial objects. This index does not encompass the amount of technogenic energy necessary for production of materials for objects and their transportation to the mounting area. Ergotechnical index encompasses the usefully consumed amount of labour, i.e. amount of potential and kinetic energy used for installation or transformation of anthropogenic or anthropogenised formations in the environment.

In the collective article L. Jukna and D. Veteikis (2010) introduce artificiality classification of the elements of the earth crust according to the character of consumed energy (Jukna, Veteikis, 2010). The classification is based on CORINE classification of elements in the land cover. It should be extended and complemented for broader landscape energy studies.

2. METHODS

Conception of the embodied energy in the elements of technogenic landscapes

The definition of technogenic energy is directly related with the conception of embodied energy. Therefore, this notion should be detailed.

The technogenic energy should encompass the human purposefully used energy in the process of landscape technogenisation. The technogenisation itself in this case is perceived as creation and installation of technogenic objects or transformation of natural ones.

The landscape elements are a kind of energy storages in which depending on their morphometric and morphological properties a certain amount of energy is conserved. The term ***embodied energy*** is applied to this kind of energy. The term has emerged in engineering and technical literature and is used by engineers and architects as a measuring unit for "environmental friendliness" and economy of building materials (Milne, Rardon, 2003; Venkatarama Reddy, 2003, 2010; Dixit, Fernandez-Solis, 2010, 2012; Jiao, Lloyd, Wakes, 2012). The embodied energy (EE) refers to various forms of energy used in the process of emergence of objects in a landscape. Yet there is no common conception defining the formation stages of technogenic objects to be included into this process. The present study tends to the approach that EE is the energy used for production, including extraction, transportation and installation of construction materials (Reddy, Jagadich, 2003). Nevertheless, while evaluating the technogeneity of a landscape the transportation energy calculations should be excluded. Firstly, the technogenic landscape is a dynamic system developing in time and space and the age of its elements often may differ. This means that it is almost impossible to determine the place from which at certain time building materials were transported. Secondly, the covered distance by building materials does not make them more technogenic. Therefore, in the landscape geography studies the **energy embodied in technogenic objects** should be regarded as a sum of stages of extraction of raw materials and production and installation of buildings materials in a landscape and their energy or, in other words, a sum of ergotechnical (amount of labour used for installation in a landscape) and material artificiality (amount of energy necessary for production of object material) indices.

Research methods

The cognition of energy embodied in a landscape as a phenomenon is an important step towards the subsequent analytical section the realisation of which is impossible without distinguishing indices and without a relevant set of geographical data.

The present work is based not only on analysis of literary sources but also of empirical cognition of the world, i.e. GIS data analysis, which allowed determining the parameters of landscape elements necessary for evaluations of ergotechnicity and embodied energy and, based on the distinguished indices, the degree of landscape technogeneity, compiling thematic maps and performing territorial regioning.

GIS analysis can be divided into stages of technical work:

1. Data creation stage;
2. Mapping stage;

3. Data analysis stage;

4. Presentation of results.

Data creation stage

Evaluation of embodied energy and landscape technogeneity requires a digital spatial database containing information about morphological and morphometrical properties of technogenic objects. In Lithuania, there is no complete database of this type. Therefore, the necessary data about the elements of technogenic landscapes have been obtained by means of GIS software. The algorithm of database creation can be split into two parts:

1. Determining morphometric properties of technogenic elements;
2. Determining material properties of technogenic elements;

For determining the spatial properties of buildings LIDAR data was used. They were processes with ArcGis, ArcMap 10.1, ArcWiew 3 software versions which allowed calculating the area of building foundation and, what is most important, the height of buildings.

The height of buildings was established in two stages (Fig. 1):

1. Determining mean value of Z coordinate of the roofs of buildings;
2. Determining mean value of Z coordinate of foundation levels.

The LIDAR data allow determining only the parameters of visually seen parts of building above the ground. The depth of basements and foundations remained undetermined.

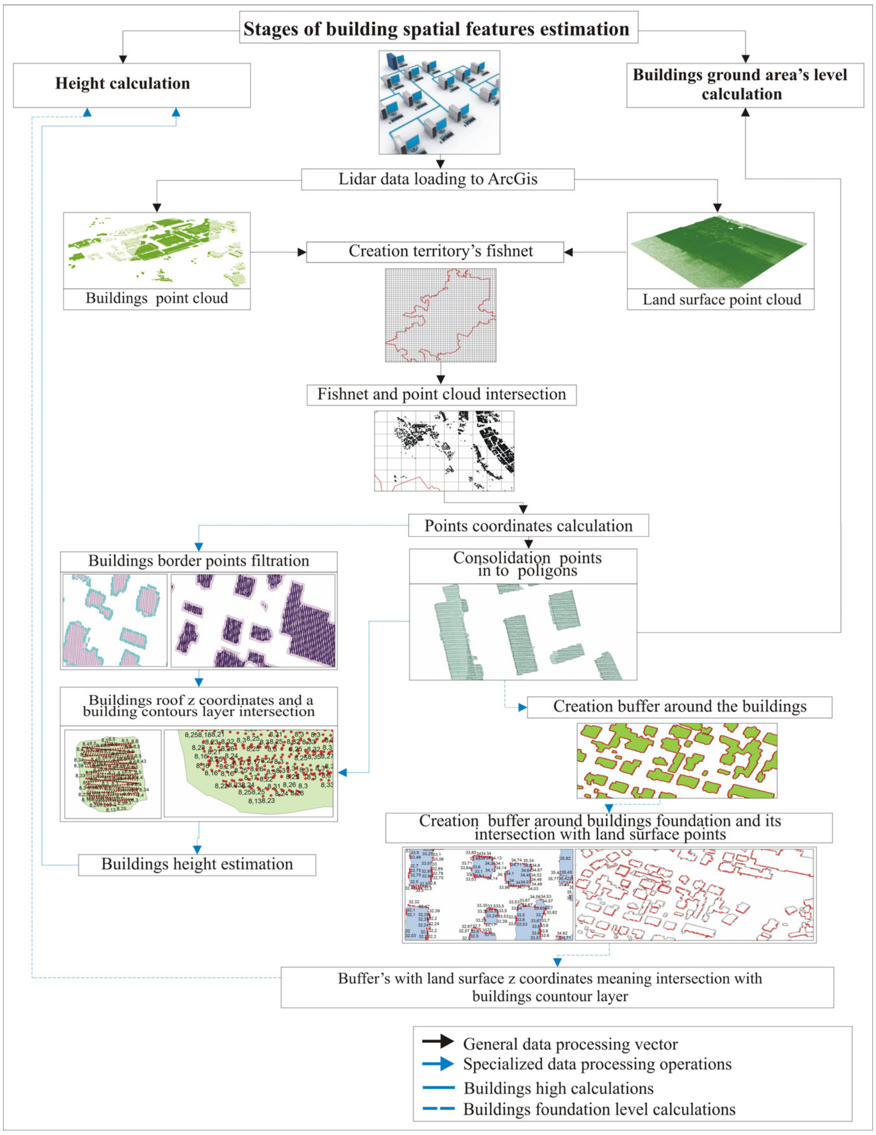


Fig. 1. Algorithm of determining the spatial parameters of buildings

The lengths and widths of city streets and roads were established using GDB 10 digital database (Nacionalinė žemės tarnyba, 2009). Yet this database includes only the widths of parts of main streets. The widths of narrower utility streets were determined following the Construction Technical Regulation of the Republic of Lithuania (Statybos techninių reikalavimų..., 1999).

For determining the amount of embodied energy in the technogenic landscape structure, the data about the material composition of objects also is necessary. The present study is confined to analysis of construction material used in the outer walls of the buildings. These data were obtained from the Lithuanian Centre of Registers. The database of the Centre does not include data about the materials of buildings distinguished during LIDAR data processing. For this reason, superposition of this database with digital layers of spatial parameters of buildings left the material structure of some objects undetermined. Interpolation of the data about the unknown material structures within the range of the data about the defined constructions was chosen as a solution. The interpolation was conducted taking into account a few indices: spatial parameters of constructions (height and foundation width) and materials of neighbouring constructions defined in the database of the Centre of Registers. For determining the materials of undefined buildings the probability theory was employed and on its basis the following assumption was made:

The material of undefined object will be identical /equal with the mode – value that appears most often in the neighbouring objects of the same parameters (height and foundation width) and with identified material.

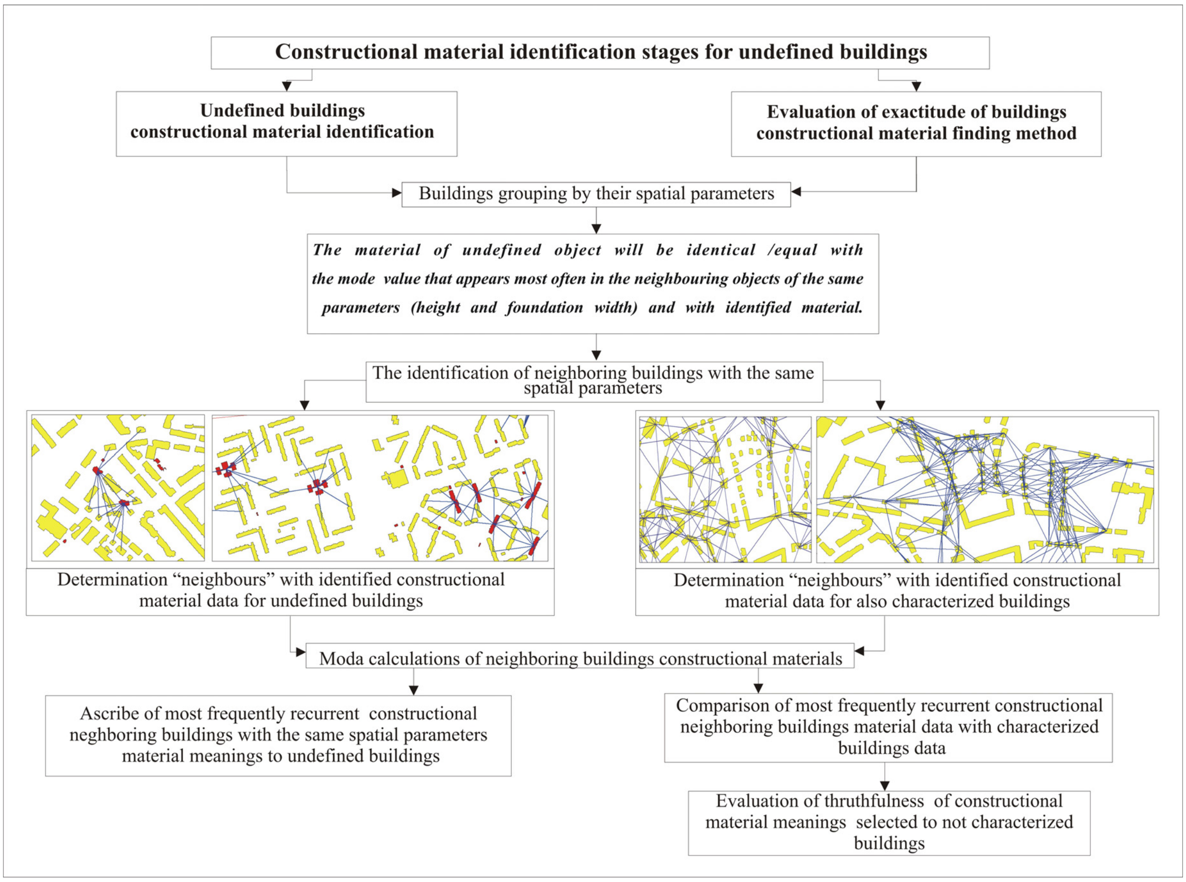


Fig 2. Algorithm of determining the construction materials in undefined buildings

Following this assumption, all buildings were grouped according to the height and foundation width. The total of 12 groups was distinguished. Further identification of construction material of undefined buildings was performed using ArcView 3.1 program. For each member of groups 8 neighbours with identified construction material were determined (Fig. 2). The data of the material structure of determined neighbours were stored in a separate database. Their mode was calculated using Microsoft Excel and later tied in with the data of undefined buildings applying to them the most probable value of construction material.

The probability of correctness of applied values was validated using the above described method for identification of neighbouring construction material. The mode for eight nearest neighbours of the same height and foundation width and identified construction material was calculated. The calculated mode values of neighbouring buildings were then compared with the material composition obtained from the Centre of Registers. The evaluated correctness of interpolation and identification of material allowed further analysis of the index of embodied energy.

Preliminary mapping stage

During the compilation of GIS database, a digital database of the buildings in the largest Lithuanian cities was created including morphometric and construction material data for each object. Through manipulations with the obtained database using GIS program the data were visualised and mapped. The technomorphological structure of landscape elements in the cities under consideration was determined. Maps of spatial differentiation of the network of buildings and streets, heights of building and construction materials were compiled and served as a basis for calculations of the main indices and for territorial regioning.

Data analysis included the interpretation of data (raster images, maps) obtained during the preliminary mapping. Data analysis and qualitative evaluation when the set of available data is highly variegated is a rather complicated process. Territorial regioning of geographical spatial data, i.e. grouping spatial data into territorial formations according to the analysed properties, is an optimal solution. The spatial data about buildings and streets/roads of cities (for grid and networks of the areas of construction materials) obtained during the preliminary mapping were typologically regioned:

- Regioning of heights of buildings
- Regioning of spatial differentiation of buildings
- Regioning of spatial differentiation of roads/streets

An individual regioning of construction material of technogenic objects also was performed.

A qualitatively new information was obtained: the boundaries of the areas of morphometric and material properties served as a basis for further analysis, distinguishing the types of ergotechnicity and artificiality of territory material and localising the areas in city territories. Analysis of embodied energy (technogeneity of landscape) was performed through superposition and summing of the ergotechnic and material artificiality values after territorial regioning of this phenomenon.

Presentation of results

The compilation of geographical database demanded extensive technical work. Its visual expression is: various thematic maps (typological and individual regioning) and statistical information (tables and diagrams). The results of logical analysis are given in structural and methodological schemes.

System of indices

Technogenic landscape elements are represented by material bodies. Their properties are described by various qualitative (morphological) and quantitative (morphometric) parameters. The complete analysis of landscape elements should be based on the both groups of indices.

Morphometric indices stand for object properties expressed in figures and mathematical units: width, length, height, mass, and volume. These geometrical properties of objects are important in the lowest investigation level including individualisation of discrete technogenic objects. The higher investigation level includes distinguishing the indices of height (of buildings) and area under buildings which serve as a basis for finding out the spatial distribution patterns of technogenic elements. It should be pointed out that these indices are auxiliary in evaluation of the main technogeneity measure – embodied energy. Determining the values of auxiliary indices allows establishing the values of the constituents of embodied energy – ergotechnicity and technogeneity.

Morphological indices. Technogenic objects have properties which can be expressed in nominal values. Material composition is one of such properties. This index is important for qualitative investigation of landscape structures. Determining of the material composition of objects is one of the most important stages in evaluation of landscape technogeneity both on the levels of auxiliary and partial indices (fig. 3).

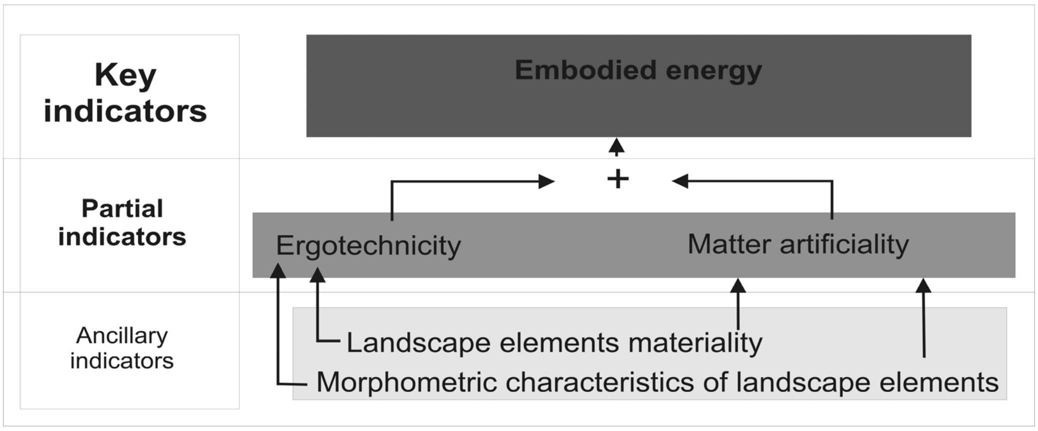


Fig. 3. System of indices for landscape technogeneity evaluation

Evaluation of energy embodied in technogenic landscape elements

The embodied energy incorporates different forms of energy used for extraction of raw materials, production of construction materials and installation of technogenic objects in a landscape. The two technoelement creation stages have two common indices describing the embodied energy:

- Index of artificiality (technogeneity) of material;
- Ergotechnical index.

Index of artificiality (factitiousness) of material is applied to the energy necessary for extraction of raw materials and production of construction materials. For determining the artificiality index it is first of all necessary to know the potential energy expenditures for extraction of valuable minerals (raw materials) and kinetic energy (if the extraction is performed from a flat surface) expenditures for carrying them from the place of extraction. It is also necessary to take into account the expenditures of fuel and energy consumed by mechanisms. Calculation of kinetic energy necessary for transportation to construction material production site is very complicated, as mentioned in the section EE, and not relevant for the present work.

The process of production of building/construction materials may include various forms of energy depending on the properties of materials and production technologies: electricity, thermal and mechanical energy, or, sometimes, chemical reaction energy.

Direct evaluation of energy incorporated in building materials is especially complicated and time-consumptive. It requires knowledge of material mechanics, chemistry and physics. Calculations of this kind and compilation of databases are conducted by teams of scientists. Besides, this is the field of engineering technical sciences. The present study was oriented toward spatial distribution of technoelements with different properties and its causality therefore it used the database of energy embodied in building materials created at the Technological University of Bath (Hammond, Jones, 2008).

The table below gives the values of energy embodied in the main construction materials of landscape technoelements.

Table 1. Amount of energy embodied in the construction materials of landscape technogenic elements

Material	Embodied energy Mj/kg	Embodied energy Mj/m^3
Reinforced concrete	0,95*0,26 Mj 25kg/m^3	2128 Mj/m^3+ 612,9Mj= 2749,9
Silicate blocks	0,85	212,5
wood	8,5	4335
Steel	24,4	191540
Bricks	3	6000
Glass	15	37500
Asphalt	2,6	5980
Pathway cover	1,24	2778
Gravel	0,11	246

The used database contains indices of energy embodied in seven kinds/products of timber. In the present study, the overall value of EE for timber was chosen. In the case with bricks, the overall value of EE for production of clay bricks was chosen. For metal constructions, the steal EE index was used. Steal was chosen because it is used for garages which are dominant among metal constructions and considerably outnumber the objects with constructions made of aluminium or other metal. The EE index for ferroconcrete also includes the index of metal fortification.

Ergotechnical index is applied to concrete labour used for installation of objects in a landscape. In the case of buildings, it applies to expenditures of potential energy for lifting building materials and kinetic energy for transportation of material at certain distances (length of roads). Theoretically, this index also should include the energy expenditures by mechanisms employed for construction of objects yet in practice it is impossible to determine the types of technologies and mechanisms and their state at the time of use which also predetermines the energy consumption value.

The main step in the process of ergotechnical index calculation is the stage of determining the technomass. This stage requires data on morphometric and morphological indices. In the present study, the technomass was determined for object surface structures: walls of buildings (including roof area) and asphalt or breakstone cover of roads.

Principles of regioning landscape technogeneity

Territorial division of landscape technogeneity or energy embodied in the technogenic landscape is a multi-stage complex process requiring many steps at different levels of technogenic landscape analysis. Fig. 4. illustrates the main steps of complete analysis: territorial evaluation and regioning of auxiliary, partial and main indices.

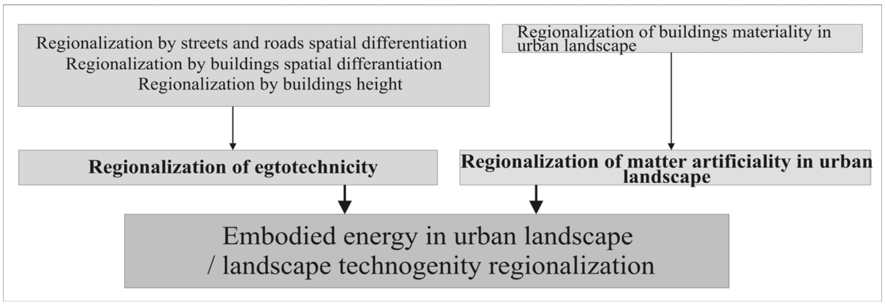


Fig. 4. Stages of regioning of landscape technogeneity

<u>Principles of typological regioning of spatial differentiation of buildings</u>. For analysis of spatial differentiation of buildings in urban territories the area under buildings is an important index. Grid method (box method) was chosen for analysis of this phenomenon. Our territories were divided into 100 m^2 grids within which the ratio the construction foundation area and surface area/total grid area was calculated. For every grid, percentage of the territory under buildings was determined. The obtained grid mosaic allowed distinguishing territorial areas with different types of spatial differentiation of buildings.

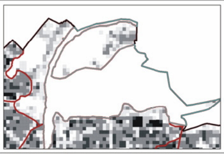
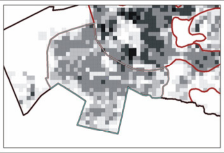
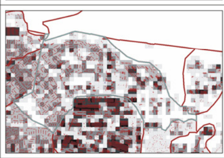
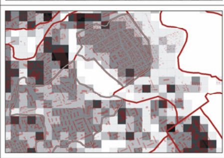
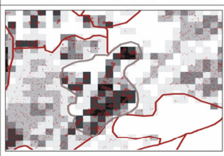
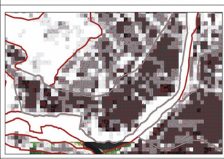
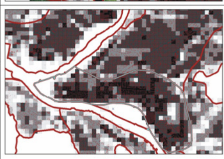
Types of spatial differentiation of buildings	View of etalon area's grid layer	Ortofotoviews of etalon area	Description
Unbuilt area			Prevails grids with unbuilt area
Low density, fragmentic territorial composition			Low density built up area, with single and rare groups of buildings. Grids with unbuilt area and very low or low built level prevails
Low density, consolidated territorial composition			Areas builded with small evenly spreaded buildings. Very low or low building density grids prevails
Medium density, fragmentic territorial composition			Area with unevenly spreaded buildings. Different ground area buildings from individual to apartment houses can be found.There can also be massive industrial buildings. All types of building density grids mixes in this class of area
Medium density, consolidated territorial composition			Medium building density grids prevails, area evenly builded
High density, fragmentic territorial composition			Unevenly, massive buildings builded area. Unbuilt, medium, high and very high density grids prevails
High density, consolidated territorial composition			Densely, evenly builded area. Buildings ground area can vary widely. Territory can also be characterized by high density grids
Very high density, consolidated territorial composition			Evenly and very densely builded area. High and very high building density grids prevails

Fig. 5. Types of spatial differentiation of buildings

The boundaries of typological area were drawn according to the properties of the mosaic of objects: number of dominant grids among different intensity of built up grids and integrity of the areas under buildings.

Principles of typological regioning of spatial differentiation of road/street cover. The regioning included typifying of territorial differentiation of city roads, streets and railroads contained in GDB 10 digital database. City grid (10 m^2) network lies at the basis of typifying (Fig. 6).

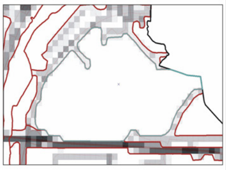
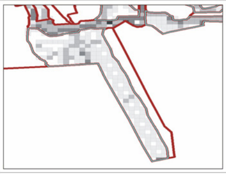
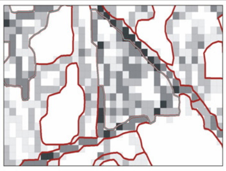
Types of spatial differentiation of streets/ roads	View of etalon area grids layer	Ortofotoviews of etalon area	Description
Areas without street/ road cover			Prevails grids with no road cover inside
Low street density, fragmentic territorial composition			Area with fragmentally distributed ancillary and attendant street net. Prevails grids with no road cover or very low and low road cover
Low street density, consolidated territorial composition			Streets are evenly spreaded. Prevails ancillary and attended street net, very low and low street/ road cover grids
Medium street density, fragmentic territorial composition			Attendant streets tipe prevails. There also may be segments of main roads in area. Territories includes grids with no road cover, very low, low and medium street density. Single high density girds can be found
Medium street density, consolidated territorial composition			Evenly spreaded, high density, attendant street net, where prevails grids with medium quantity of road cover. Single high and low density grids can be found
High street density, fragmentic territorial composition			In territory, main and fast traffic roads limits low street density areas or areas without road/ street land cover. Prevails grids without road cover, high or very high, in some cases medium quantity of road cover
High street density, consolidated territorial composition			Areas includes main traffic nodes and axes. Prevails main and fast traffic roads. Grids has high and very high road/ street cover quantity values.

Fig. 6. Types of spatial differentiation of streets

Principles of typological differentiation of spatial vertical distribution of buildings in cities. The typifying of areas distinguished based on the grid mosaic was carried out according to the dominant average building height calculated for each grid. In cities, three vertical spatial differentiation types were distinguished, which were subdivided into sub-types according to the number of dominant heights:

1. Low buildings: a) one-storey buildings, b) two-storey buildings;

2. High buildings: a) three-storey buildings, b) 4-5-storey buildings, c) 5-9-storey buildings, d) skyscrapers.

3. Buildings of mixed height.

Principles of regioning of technogenic materials of cities. The index of embodied energy was calculated for city roads and buildings. For this reason theoretically, both groups of elements should be taken into consideration identifying the construction material of technogenic elements and distinguishing the characteristic territorial types of materials and territorial areas. However, city roads, as distinct from buildings, are not characterised by material diversity. Therefore, the study is confined to typological regioning of buildings material and individual regioning of cities at a higher level.

Regioning of technogenic materials on the lowest hierarchic level (rank of localities corresponding with different size squares of buildings) was performed according to qualitative property – dominant construction material of buildings.

The following types of localities were distinguished:

1. Homogeneous – with dominant one type of material which within the area exceeded 66 % of the total area under buildings (brick, wooden, metal, ferroconcrete, glass, silicate block buildings).
2. Binary – with dominant two types of construction material accounting for 33 % and more (up to 50 %) each of the total area under buildings (brick-concrete, brick-wooden, brick-metal, etc. buildings).
3. Heterogeneous – mixed, with dominant three and more types (up to 6 %) of construction materials.

The taxonomic units of higher rank – neighbourhoods, were distinguished according to the compositional structure of material and spatial differentiation of territorial units. Depending on the variations of the chosen properties, four types of neighbourhoods were distinguished:

1. Homogeneous fragmented – neighbourhoods with dominant one construction material and fragmented territory.
2. Heterogeneous (high diversity) fragmented – small neighbourhoods with high material diversity and fragmented territory.
3. Homogeneous integral – large evenly built up neighbourhoods with one construction material.
4. Heterogeneous integral – small evenly built up neighbourhoods with one construction material.

For generalisation of spatial distribution patterns, optimisation and simplification of further spatial analysis of obtained data, the mosaic of typological neighbourhoods was grouped and united into higher rank taxonomic units – sub-regions. The sub-regions were given individual numbers andtitles.

Principles of typifying ergotechnicity of cities

The ergotechnical index encompasses the studied morphometric parameters of technogenic landscape elements and transfers the obtained data to higher investigation level. The index conveys the specific features of spatial concentration of technomass irrespective of its form or origin.

Territorial regioning of ergotechnic (amount of labour) index is based on grid network within which amount of labour spent on installation of objects was calculated.

The area boundaries were drawn according to the quantitative property – amount of technomass (very high (4), high (3), average (2), and low levels (1) of technomass) and patterns of its spatial differentiation (Dispersed (1) and consolidated

(2) distribution). The performed actions allowed defining the distinguished areas according to the amount of technomass in them. Yet the character of the technomass dispersed in the typological regions remains uncertain. The following solution was chosen: ergotechnical areas were superimposed with typological regions of auxiliary indices (spatial differentiation of roads and buildings and vertical differentiation of buildings) and typified – types of dominant partial indices in ergotechnical areas were determined. Distinguishing of types revealed the qualitative and quantitative aspects of different technogenci elements' distribution within areas (Table 2).

The titles of the obtained typological types of technomorphological properties of ergotechnical areas are composed of three parts. For convenience of further analysis, the titles were abbreviated using a coding system. Numbers 1, 2 and 3 stand for the density of road/street network (sparse, medium, and dense). Number 4 stands for a territory without streets in the road density coding system. Number 5 means the same in the category of density of buildings. Number 4 in the latter category indicates very high density of buildings. In the vertical distribution column 1 stands for low buildings, 2 for high buildings, 3 for mixed type of buildings and 4 for a territory without buildings.

Table 2. Types of technomorphological properties of ergotechnical areas

Type	**Street density**				**Building density**					**Vertical distribution of buildings**			
	1	2	3	4	1	2	3	4	5	1	2	3	4
K1-P1-A3	+	-	-	-	+	-	-	-	-	-	-	+	-
K3-P3-A1	-	-	+	-	-	-	+	-	-	+	-	-	-

Regioning principles of territorial index of artificiality (technogeneity) of material

The territorial distribution of technogenic material is very uneven. This predetermines the distribution patterns of artificiality of material present in the territory (level of technogeneity). The artificiality of material in a territory depends on the material artificiality index and on the amount of material in the territory. The presented maps give the values of territorial artificiality within grids. The material artificiality index was calculated for each grid. The grid mosaic lies at the basis for distinguishing the types of material artificiality areas. Areas of:

1. extremely low
2. low
3. medium,
4. high
5. extremely high level of artificiality

6 Areas of mixed distribution of territorial artificiality:

  a. mixed, low-medium
  b. mixed, medium-high.

In their methods and application, the principles of landscape technogeneity regioning are comparable with the process of ergotechnicity regioning. The boundaries of landscape technogeneity areas were drawn based on the quantitative principle – according to the amount of energy embodied in the grids. The amount of the embodied energy was determined by summing up the grid values of ergotechnical and material artificiality indices.

Based on the amount of embodied energy, it is possible to preliminary define the technogeneity degree of a territory, yet this definition does not fully reveal the properties of technogenic areas. There remains an open question as to the precise amount of technomass concentrated in the distinguished area and the degree of artificiality of concentrated material. For this reason, the techogenic areas are superimposed with the boundaries of the areas of partial indices what allows classifying the distinguished areas according the manifestation of technomorphological properties (amount of technomaterial and degree of its artificiality in a territory (Table 3).

Table 3. Types of technogeneity areas according to technomorphological properties

Types of ergotechnicity (E) / Types of matter artificiality (D)		1.1	1.2	1.3	2.1	2.2	2.3	2.4
1		E11-D1	E12-D1	E13-D1	E21-D1	E22-D1	E23-D1	E24-D1
2		E11-D2	E12-D2	E13-D2	E21-D2	E22-D2	E23-D2	E24-D2
3		E11-D3	E12-D3	E13-D3	E21-D3	E22-D3	E23-D3	E24-D3
4		E11-D4	E12-D4	E13-D4	E21-D4	E22-D4	E23-D4	E24-D4
5		E11-D5	E12-D5	E13-D5	E21-D5	E22-D5	E23-D5	E24-D5
6	1	E11-D61	E12-D61	E13-D61	E21-D61	E22-D61	E23-D61	E24-D61
	2	E11-D62	E12-D62	E13-D62	E21-D62	E22-D62	E23-D62	E24-D62

The distinguished and indexed areas were classified according to the degree of technogeneity. The degree of technogeneity was determined by calculating the mean amount of embodied energy per 1 m^2 in the distinguished areas.

The following types of landscape technogeneity were distinguished:

1. Relatively natural (< 10 Mj/m^2);
2. Very slightly technogenically transformed (10.1- 30 Mj/ m^2);
3. Slightly technogenically transformed (30.1- 90 Mj/ m^2);
4. Averagely technogenically transformed (90.1-270 Mj/m^2);
5. Technogenically transformed (270.1- 810 Mj/m^2);
6. Technogenic (>810.1 Mj/m^2).

The distinguished 6 types not only differ in the average amount of embodied energy in the areas per 1 m^2 but also in technomorphological properties.

The presented classification of technogeneity areas according to the degree of technogenisation does not encompass such anthropogenised landscape elements as grasslands, cultivated lands, etc. The anthropogenisation constituent is excluded because analysis of technogeneity/artificiality includes only determining the degree of artificiality of technogenic elements (roads, buildings). The elements without technogenic material were not taken into consideration due to lack of data and specific character of the reference territory (however, the methodology could be applied to analysis of anthropogenised/anthropogenic elements as well).

3. RESULTS

3.1. Spatial distribution patterns of morphometric parameters of technogenic elements

Specific spatial differentiation of city streets

Generalising the specific differentiation of the road and street cover in cities it should be pointed out that the area occupied by types of street surface cover in the investigated cities differs. The largest open territories are characteristic of Klaipėda and

Šiauliai. In these cities, rather big areas are occupied by natural landscape elements (in Šiauliai the Rėkyva Lake and in Klaipėda the Curonian Lagoon). Kaunas in this respect stands behind Šiauliai; the part of Kauno Marios water reservoir, Neris and Nemunas rivers, and Kleboniškės forest included within the city boundaries occupy a smaller area than the Rėkyva Lake and grasslands (in the environs of Zokniai airfield) of Šiauliai. Vilnius has comparatively few larger areas without streets (9.7 %). Yet Vilnius outbalances other cities in the network of unevenly distributed streets. This type of territories is dominant in the city. In other Lithuanian cities the portion of this type of network is considerably smaller. The sparse fragmented network of streets exceeds 25 % of the city area only in Šiauliai. In Kaunas it accounts for 20 %. In general, the mentioned two types of territories and sparse even network of roads/streets occupy the larger part of the city area exceeding 60 % of the territory (in Šiauliai, the territories of the mentioned types account for 80 % of the territory). Kaunas is an exception as in this city the averagely dense network of streets is more widespread than in other cities. Yet the type of uneven fragmented distribution of streets is dominant. The area of average even distribution is considerably smaller. In other cities, the variations of the areas of average fragmented and even distribution are negligible and range between 7.8 and 12 % and between 6.5 and 10.3 %. The areas of intensive dense network of streets in the cities are rarest. The dense fragmented type occupies an especially small territory. The largest areas of this type are in Klaipėda and Kaunas (>3 %). The type of dense even spatial differentiation of street cover exceeds 6 % only in Kaunas (Fig. 7).

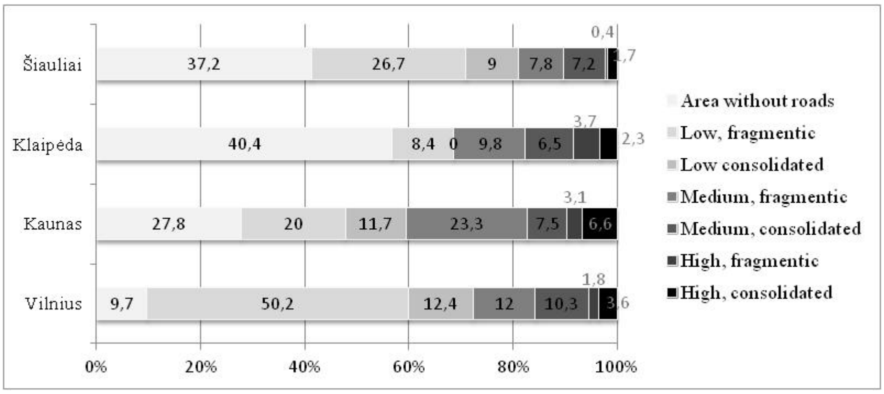


Fig. 7. Portion of the area occupied by the types of spatial differentiation of streets (%)

The performed analysis showed that Šiauliai has the smallest area of street cover. This is predetermined by dominance of the sparsely built up territories or territories without streets. Kaunas has the densest network of streets. In Kaunas, the types of average and dense street networks occupy a greater part of the territory than in other cities. Vilnius and Kaunas in this context occupy an intermediate position. In Klaipėda, there are many territories without street cover (elements with high degree of naturalness), whereas in Vilnius the natural lanscape elements are dissected by technogenic street cover (Fig. 8). Speaking about the territorial distribution of the mentioned types, it should be pointed out that street cover of even distribution is most common for the “new” private neighbourhoods (what is related with the specific planning of these territories) and garden communities. In the areas of this type, the network of average street density is most typical ((Pirmoji Melnragė in Klaipėda, part of Medelynas eldership in Šiauliai, Balsiai and Riešė in Vilnius).

Speaking about the historical cores of cities, no clear trend can be distinguished. In these areas, the street networks are characterised by even and uneven distribution and average or high building up intensity. The industrial areas of cities typically have uneven street cover distribution (the intensity of street network depends on concrete circumstances: branches of industry and size of objects served by streets/roads).

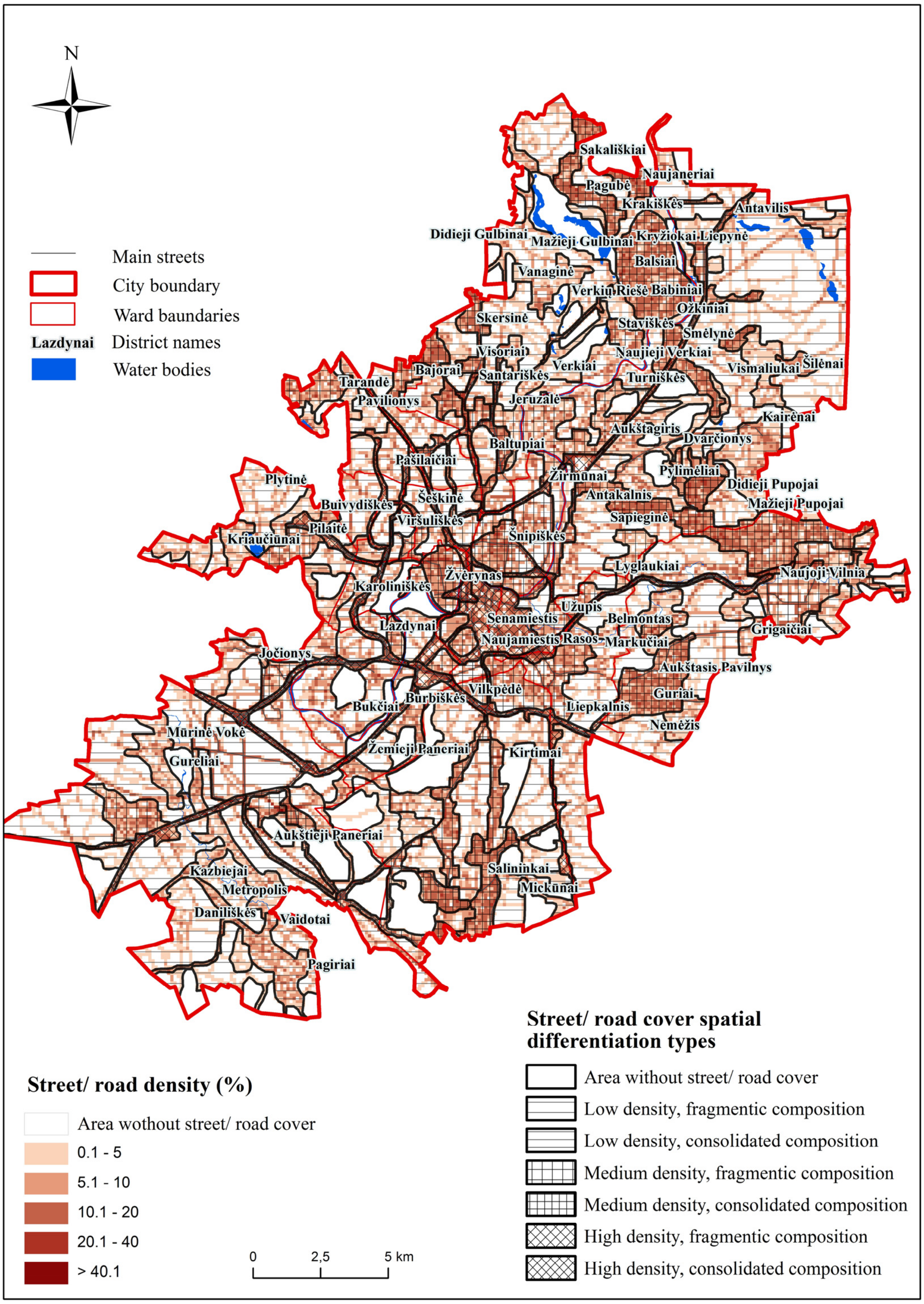


Fig. 8. Distribution of spatial differentiation types of streets (case of Vilnius)

The territorial units of natural landscapes such as forests, forest parks, parks, and meadows usually have fragmented low density street networks. The Soviet residential neighbourhoods are distinguished by uneven distribution of the street network which usually is of low density and sometimes of average density (Dainava neighbourhood in Kaunas, Gytariai in Šiauliai, Vingis and Žardininkai in Klaipėda, Šeškinė, Jaruzalė, etc. in Vilnius).

Specific spatial differentiation patterns of urban areas under buildings

The old parts of cities, i.e. their historical parts are most densely built up. The high density of buildings is responsible for dominance of their even spatial distribution in the territories.

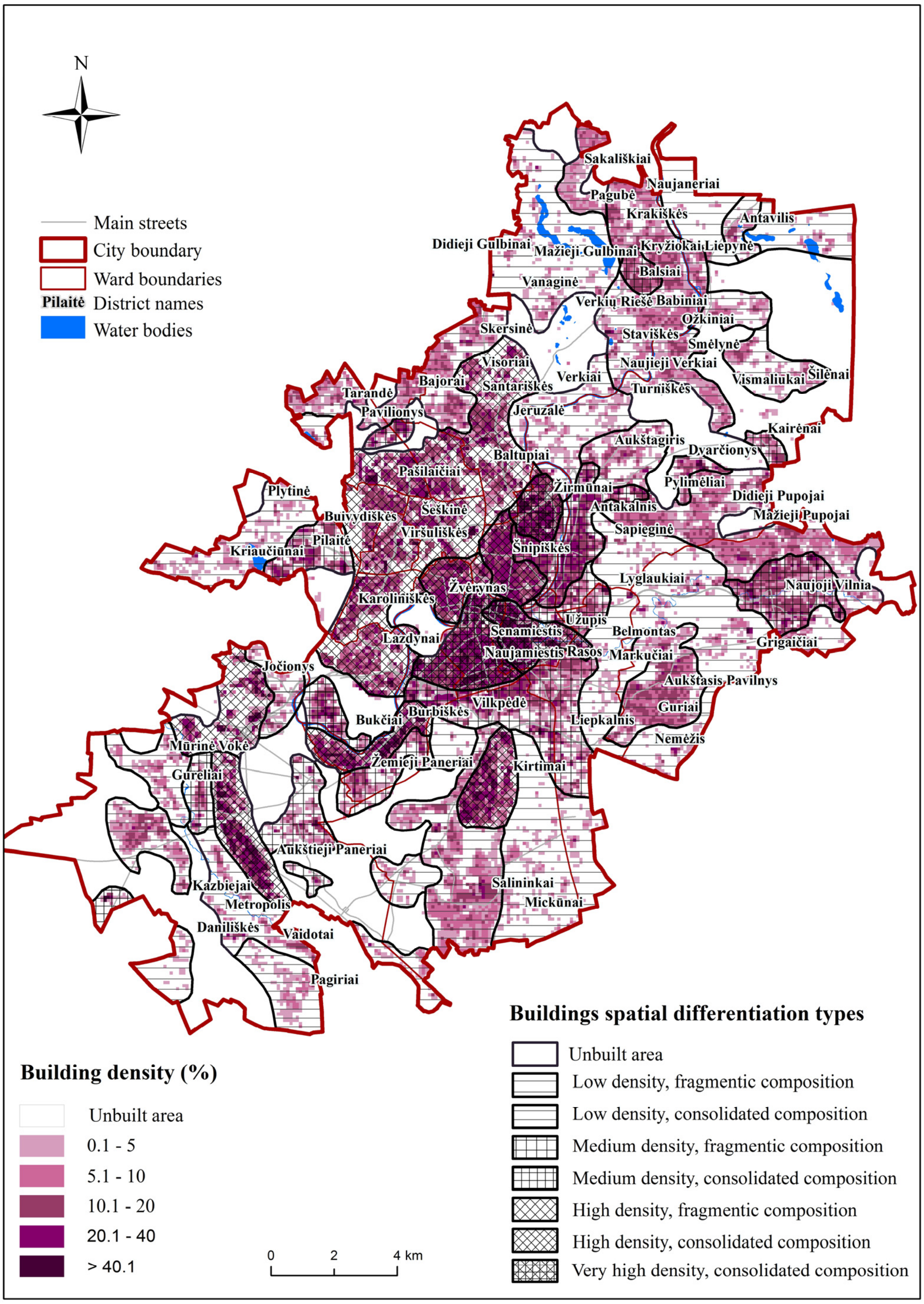


Fig. 9. Distribution pattern of spatial differentiation types of buildings (case of Vilnius)

Even distribution of buildings, if only of lower intensity, also is characteristic of the territories of private residences: garden communities, old settlements included into city area with dominant low houses and new settlements which as a result of city expansion have been recently included into the city territory. These new neighbourhoods usually are situated in the peripheral parts of cities. Dense, averagely dense and uneven distributions of buildings are common for the Soviet neighbourhoods of blocks of flats and for industrial territories. The peripheral parts of cities are predominated by unevenly and sparsely built up areas (Fig. 9). Speaking about the area occupied by spatial differentiation types and their distribution, the most common and occupying the largest area is sparse and uneven type of building up. Klaipėda and Vilnius stand out for abundance of the territories of this type. They are fewer in Kaunas and Šiauliai. The numbers of areas without buildings are comparable. The number of open areas is noticeably higher in Šiauliai where, as mentioned above, a large territory is occupied by natural landscape elements. Vilnius is distinguished for the sparse yet even spatial differentiation of buildings. This type is rarest in Klaipėda. In Šiauliai and Kaunas, this type of spatial differentiation occupies almost equal areas (Fig. 10).

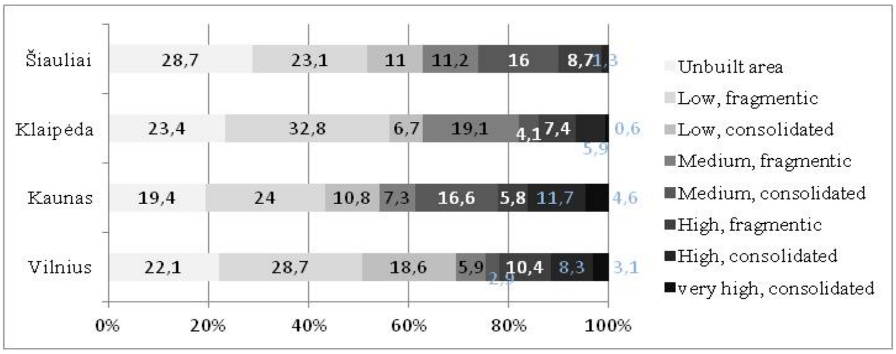


Fig. 10. Area occupied by types of spatial differentiation of buildings in cities (%)

In the last two cities, the medium density and evenly built up, consolidated type areas are more common than elsewhere. The number of areas of this type is noticeably fewer in Klaipėda and Vilnius. However, in Klaipėda the medium densely and evenly (consolidated) built up areas are outbalanced by the type of medium density fragmented built up areas. In comparison with other cities, this type occupies the largest area in Klaipėda. The distribution of intensively built up areas varies in different cities. They occupy the largest territory in Vilnius. Among the distinguished areas, intensive (high density level) fragmented and uneven spatial differentiation of buildings is the dominant type. It is followed by less intensive even type. Meanwhile, the very intensively built up (very high building density) areas (in the city centre) account for 3.1 % of the territory. Comparing with other cities, in Vilnius the index is rather high. In this aspect, Vilnius only is outmatched by Kaunas where very high building density areas account for 4.6 %. The densely built up areas in Kaunas are almost equal to the ones in Vilnius. The only difference is that High even rather than fragmented high density level type is dominant in Kaunas. The intensively built up areas in both cities account for 20 % of the territory. This index in Klaipėda is lower. The total area of intensively built up territories accounts for less than 15 %. In Šiauliai, this index is even smaller: 10 %. Šiauliai does not have very high building density level areas at all (Fig. 10).

Specific distribution patterns of vertical differentiation of buildings

The vertical distribution of buildings in cities is obviously related with the development aspects of the historical parts of cities and with their functional parts. For historical centres of cities (old cities), multi-storey (3–5 storeys) buildings are common. In the neighbouring historical parts of the cities (old neoghbourhoods – Žvėrynas and part of Antakalnis – in Vilnius, Vilijampolė in Kaunas, etc.) the height of buildings varies. The type of mixed vertical distribution is distinguished. The mixed type also is characteristic of industrial areas (Vilkpėdė in Vilnius, part of Petrašiūnai eldership in Kaunas, etc.). Territories of this type usually are situated further from the central area. The peripheral parts of cities are predominated by low buildings (private residences)((Panemunė in Kaunas, Giruliai, Plytinė, Danė neighbourhoods in Klaipėda, Daniliškės, Pagiriai etc. in Vilnius).

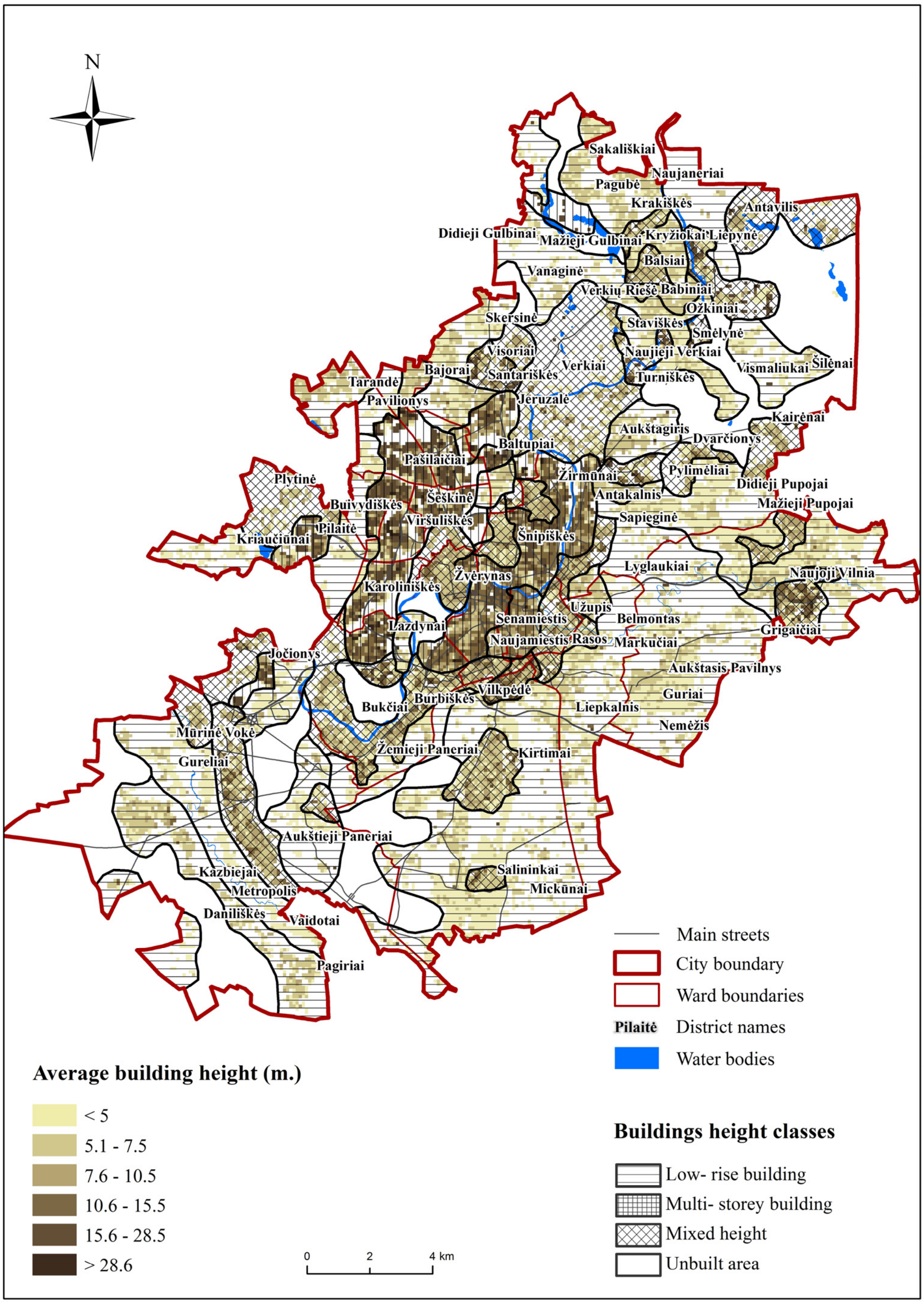


Fig.11. Distribution of vertical differentiation of buildings (case of Vilnius)

The neighbourhoods of blocks of flats built in the Soviet years are distinguished for high buildings (Karoliniškės, Lazdynai, Viršuliškės in Vilnius, Žardininkai and Vingis in Klaipėda, Gytariai and Dainiai in Šiauliai, etc.). Though high buildings are not rare in the industrial territories, e.g. Burbiškės and Vilkpėdė in Vilnius (chimneys, elevators, etc.) they do not form integral complexes (Fig. 11).

The territories of different types of vertical distribution are rather variable in different cities. Šiauliai may be called a city of low buildings. More than 80 % of built up zones include areas with dominant 1–2-storey houses. In other cities, the proportions are more equal.

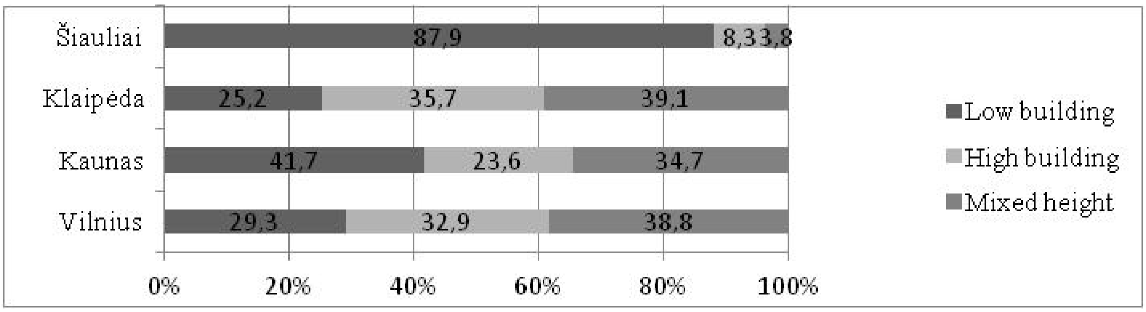


Fig. 12. Area (%) occupied by types of vertical differentiation of buildings

A larger area of low buildings and a smaller area of high buildings is characteristic of Kaunas. In Vilnius and Klaipėda, the situation is similar: the larger part of the territory is occupied by high buildings and >25 % by low buildings. Territories of mixed vertical differentiation (except in Šiauliai) are rather evenly distributed. They account for 30–40 %.

3.2. Spatial distribution pattern of material differentiation of technogenic elements in cities

Analysis of construction material in cities allowed distinguishing the dominant materials and comparing cities in the aspect of construction material.

Bricks are the dominant construction material of largest cities. The area of brick buildings occupies the larger part of built up territories. In Šiauliai and Klaipėda, the area under brick buildings exceeds 60 %. In Vilnius, it is considerably smaller – 40.7 % – yet in the general context it still outbalances the areas under buildings of other construction material (Fig. 13). Concrete and ferroconcrete buildings occupy a considerable part of city space. The area of such territories varies from 9.6 % in Vilnius to 12.2 % in Šliauliai. Reinforced concrete is the dominant material in the Soviet neighbourhoods of blocks of flats (Viršuliškės, Lazdynai, Šeškinė, Jųstiniškės, etc. in Vilnius). This type of constructionmaterial also is common in the industrial territories. The areas under metal constructions are less frequent in the analysed cities. Šiauliai and Klaipėda are distinguished by larger such areas – 4.7 % of city territory. Their percent in Vilnius and Kaunas is smaller.

The situation with the distribution of wooden houses is rather interesting. In the largest cities Vilnius and Kaunas, the area of this type of construction material is largest. In Šiauliai it is smaller and in Klaipėda especially small – hardly 0.8 % of the city territory. This can be explained by specific Samogitian architectural features. In this region, objects of clay architecture are more common than in other Lithuanian regions.

It is natural that in Klaipėda the largest area is occupied by brick (clays bricks) houses (Fig. 13). The areas under buildings of other homogeneous (glass, silicate bricks) construction materials only account for the tenths and hundredths parts of city territory and produce no noticeable influence on the general balance of construction materials. Areas with combinations of two construction materials are more common. Combinations of brick and wooden houses are the dominant type. In Kaunas, the area with the combined construction materials accounts even for 13.3 %. In other cities, the distribution of this type of construction materials is similar. Only in Klaipėda, the wooden-brick areas are noticeably rarer (2.1 %). Still smaller area (4.1 %) is occupied by brick-concrete buildings. Bricks and silicate blocks are most common construction material in the new neighbourhoods which occupy noticeable parts of Vilnius and Klaipėda territories (7 and 4.6 %).

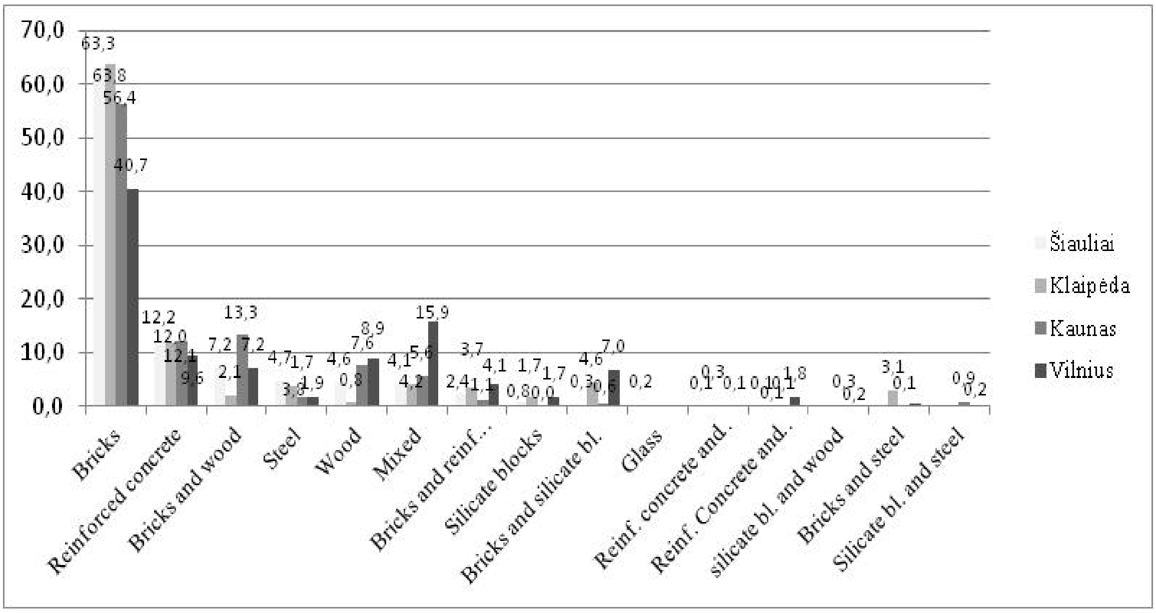


Fig. 13. Area (%) occupied by dominant types of construction material

In other cities, the area under buildings of combined construction material only accounts for 0.6 % of the city territory. There are more types of combinations of construction materialsbut they are considerably less common and sometimes only occur in isolated areas (Fig. 13). The territorial areas with dominant mixed construction material were distinguished. These areas are most common in industrial, storage and plant territories. The largest area of this type was determined in Vilnius (15.9 %). In other cities, the number of such territories is smaller as is the areas (4–6 %).

The analysed types of construction material in city spaces are very unevenly distributed. Yet the compiled maps show certain patterns of territorial distribution of types (Fig. 14). Firstly, the differentiation of areas with dominant brick constructions is evident. The historical centres of all cities are solely of this type. Due to architectural features and building up pattern, the neighbouring old parts of cities are dominated by binary brick-wood areas. Among this type of areas we can mention: Žvėrynas and part of Šnipiškės in Vilniusa and Šančiai and southern part of Žaliakalnis in Kaunas. In Klaipėda, due to the mentioned historical circumstances, binary construction material areas almost are absent. In Šiauliai, wooden-brick taxonomic rank areas can be found in the Žaliūkai neighbourhood south of the city centre.

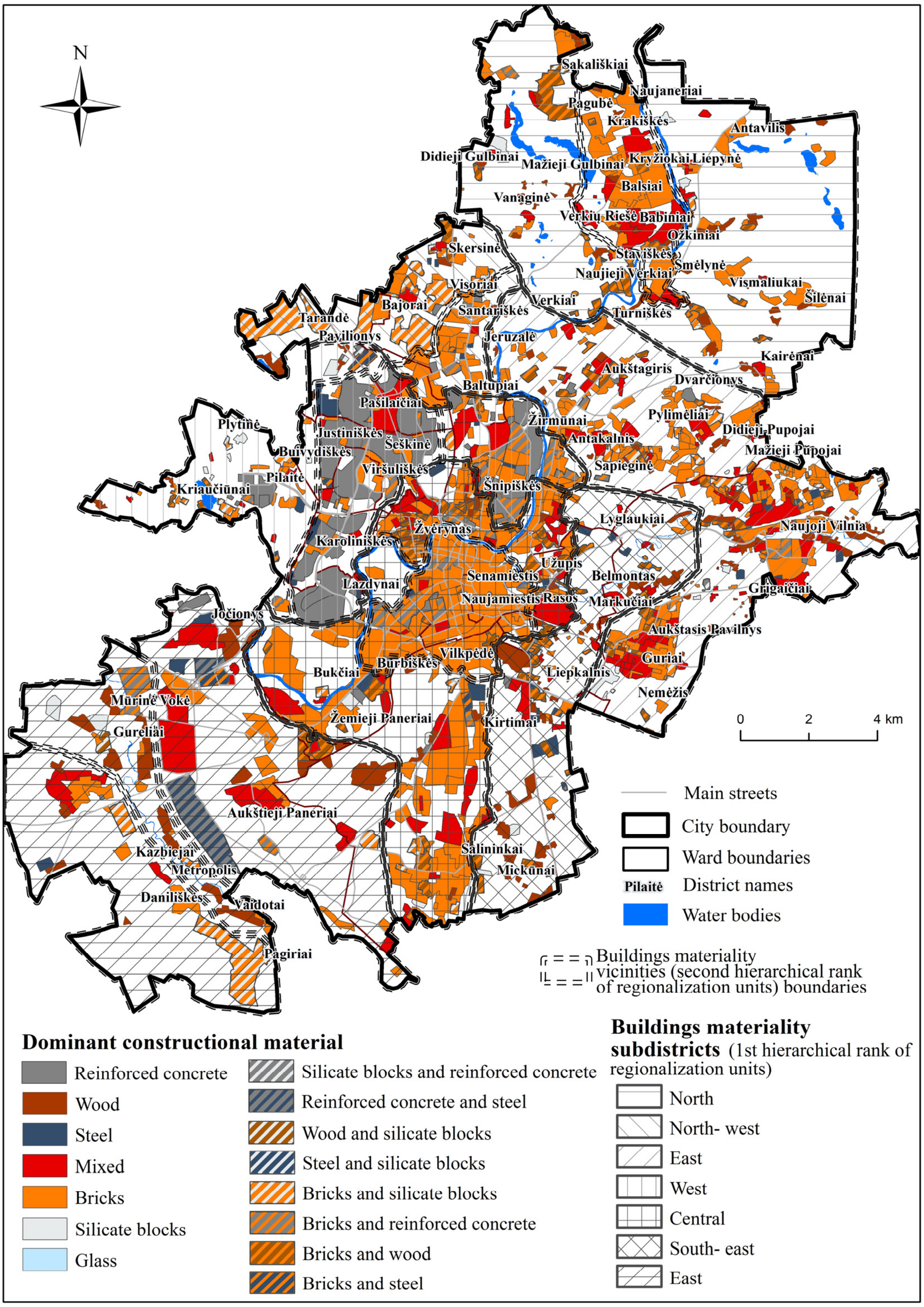


Fig.14. Distribution of technogenic construction materials (case of Vilnius)

Territories with reinforced concrete buildings represent the heritage of the Soviet years. This material is especially widespread in the neighbourhoods of multi-storey blocks of flats (towers). These neighbourhoods are situated further from city centres, i.e. usually behind the historical parts of cities with the mentioned binary construction material. The territorial distribution of metal constructions is not as easily determined. Areas with metal constructions are common in the industrial city zones where other materials with large amount of embodied energy or their combinations (reinforced concrete, concrete-metal, etc.) also are common. Metal construction areas sometimes occur near the residential zones of cities, especially near the Soviet residential towers. The areas of this type include complexes of garages built in the Soviet years (Fig. 14).

In general, the diversity of construction materials increases moving from the city centre. In the peripheral zones, areas of silicate block buildings, buildings of mixed construction materials and areas of binary construction materials are more common than areas of brick buildings. They are typical of newly built or reconstructed urban settlements (Fig. 14).

3.3. Spatial distribution patterns of ergotechnicity of cities

The degree of material concentration in a landcsape is a direct and one of the two indicators of landscape technogeneity. The evaluation of ergotechnical index performed in the present work allows determining the specific distribution patterns of technogenic material.

City spaces include technogenic elements with different parameters. In the higher taxonomic rank of territories, this means that different ergotechnicity types are characterised by different structural, i.e. technomorphological, properties of composing objects.

The highest concentrations of technogenic material have been accumulated in the historical centres of cities where consolidated areas of technomass concentrations are dominant. These areas are distinguished for maximally expressed set of technomorphological properties. The dominant indices are: K3-P4-A2 (dense network of streets, very densely built up areas, high buildings) in Vilnius and K23-P4-A2 (averagely dense and dense network of streets, very densely built up areas, high buildings) in Klaipėda and Kaunas. The historical city centre of Šiauliai has not survived (during World War II, it was completely demolished) therefore the amount of technogenic material in Šiauliai is smaller and without maximum of technogenic material (Fig. 15). Isolated consolidated areas of especially high concentration occur in the industrial territories of the largest cities where especially large buildings are dominant (Dubysa neighbourhood in Klaipėda, Petrašiūnai area in Kaunas, Bukčiai area in Vilnius, industrial area in the Medelynas neighbourhood of Šiauliai). Large amounts of technogenic materials have been determined in the transport junctions (Fig. 15).

The type of consolidated territories of high degree of ergotechnicity encompasses a far broader diversity of technomorphological properties. It includes densely built up yet with low buildings or buildings of mixed vertical differentiation old residential neighbourhoods (Šančiai in Kaunas, Žvėrynas, Šnipiškės, etc. in Vilnius) and Soviet neighbourhoods of multi-storey blocks of flats and average built up density (Gytariai, Lieporiai and Dainiai in Šiauliai, Baltija and Poilsis neighbourhoods in Klaipėda, Lazdynai, Viršuliškės, Šeškinė, etc. in Vilnius). The network of streets in this type of areas varies from sparse to dense (Fig. 15).

The new private residential neighbourhoods emerging in the territories of former garden communities, garden communities and some urban settlements common for peripheral parts of cities are consolidated areas of average ergotechnicity level (Balsiai, Kryžiokai and Pylimėliai in Vilnius, Taurakalnis and Danė in Klaipėda, Gubernija etc. in Šiauliaia). These areas usually have street network of average density and average or sparse network of low or mixed vertical differentiation buildings.

Smaller industrial objects also are included into this type of areas. They differ only in the sparse network of streets and mixed vertical differentiation of buildings.

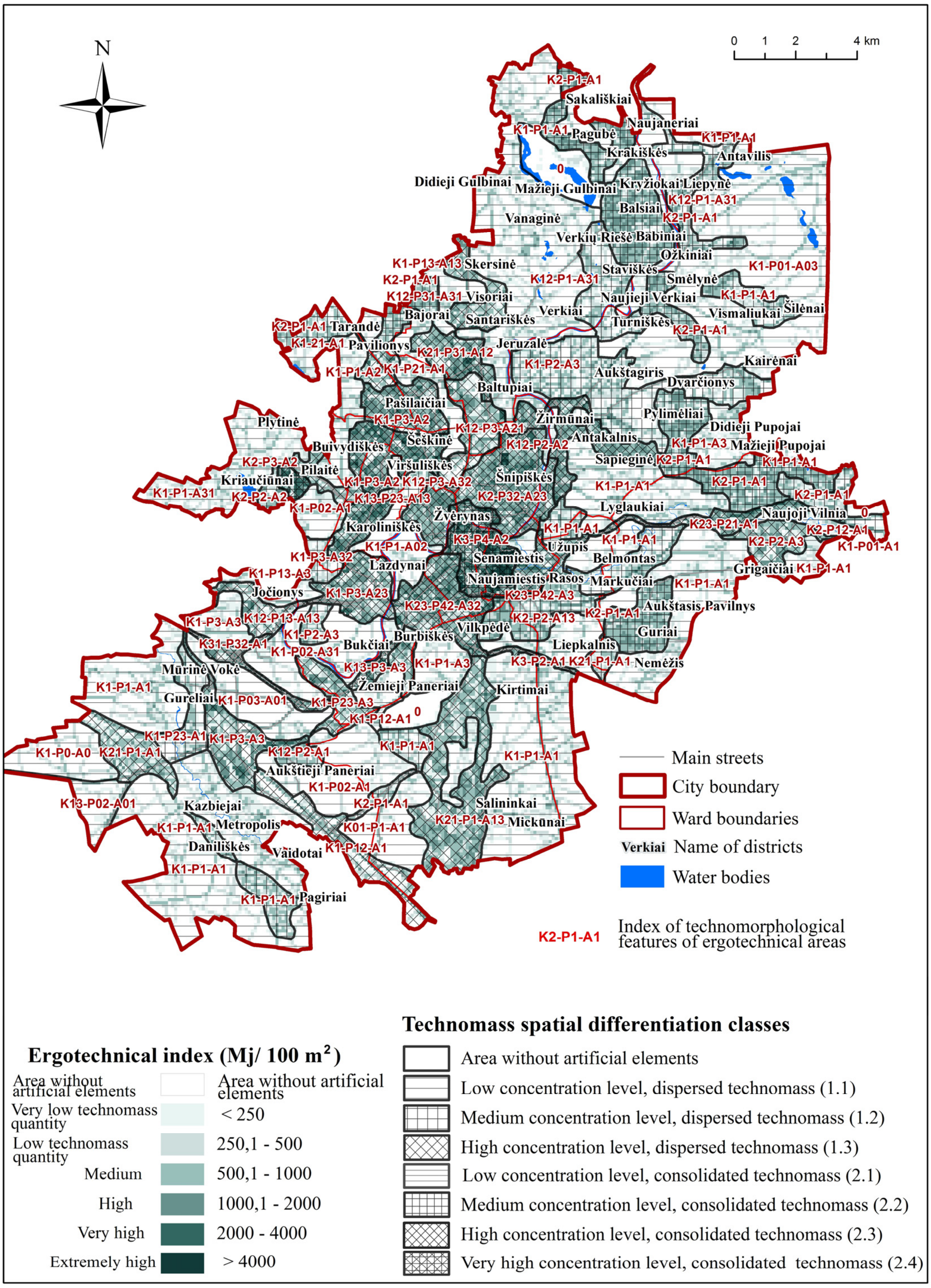


Fig. 15. Distribution of ergotechnicity (case of Vilnius)

Low ergotechnicity level consolidated areas are a rare type in cities. One of such territories was distinguished in the southern part of Klaipėda. This type has a set of K1-P1-A1 properties. The type of areas of high ergotechnicity level and dispersed distribution also is rare. These areas usually are situated near large transport junctions and in the industrial zones of cities. The index of technomorphological properties in these areas varies depending on the functional destination. The industrial zones are characterised by dense built up pattern and sparse network of streets (K1-P3-A3) whereas transport junctions are characterised by opposite structural features (K-23-P1-A13).

According to the values of ergotechnical index, the residential neighbourhoods with average density pattern of low buildings (Guriai, Aukštasis Pavilnis and Aukštagiris in Vilnius, privated residential areas in the Panemunė eldership and gardens in Kaunas) are included into the type of average concentration and dispersed distribution. This type includes some average building density industrial territories (Kaunas neighbourhood in Klaipėda).

The average concentration and dispersed distribution of technomaterial type is dominant in the peripheral areas of cities. The characteristic features of this type are: sparse network of streets, sparse distribution of buildings and open territories.

3.4. Theoretical model of technosystem evolution based on the distribution pattern of ergotechnicity level

Regioning performed in the course of evaluation of spatial distribution of ergotechnic index allowed analysing the spatial distribution of technogenic material in cities, generalising the actual situation and determining the territorial distribution patterns of technomass. It was observed that the distribution patterns of technomass (types of ergotechnicity) can be explained through the evolution model of city structures (technosystems) formation. This model can be applied for analysis of the stages of technogenisation and anthropogenisation not only in urban landscapes but in landscapes in general (Fig. 16). The model allows generalising the obtained results of ergotechnicity dispersion analysis and comparing the studied territories.

The beginning and further evolution of technogenic and technogenised systems are related with the outside anthropogenic impulse (work accomplished in the natural environment), which in the natural system is materialised as a technogenic, anthropogenic or partly anthropogenised object (house, road, cultivated field, etc.). The appearance of isolated material objects is regarded as stage I – *embryo stage of techno/anthropo systems*. It should be noted that objects may be of double character – pointed-areal or linear. Their origin may predetermine the trends of further evolution. The embryo stage is characterised by distribution of isolated technogenic objects or their groups in natural or relatively natural territories.

The isolated technogenic objects or their small groups may be affected (though not necessarily) by the outside and inside impulses which stimulate the qualitative and quantitative development of technogenic material. The qualitative development manifests through consolidation of technoobjects, i.e. through formation of the core. The quantitative development manifests through territorial dispansion of technogenic objects. In the case of linear objects – streets, roads – the initial formation of network takes place which is followed by its consolidation and gradual yet still not massive accretion of roads with pointed-areal (depending on the scale) objects. *Stage II can be defined as aggregation stage* or stage of cohesion of elements. The territorial formations attributed to the cores and axes developing in this stage are classified as types of average and low ergotechnicity level with uneven or even technomass spatial differentiation when the peripheries and open areas between axes are filled up by natural or relatively natural territories.

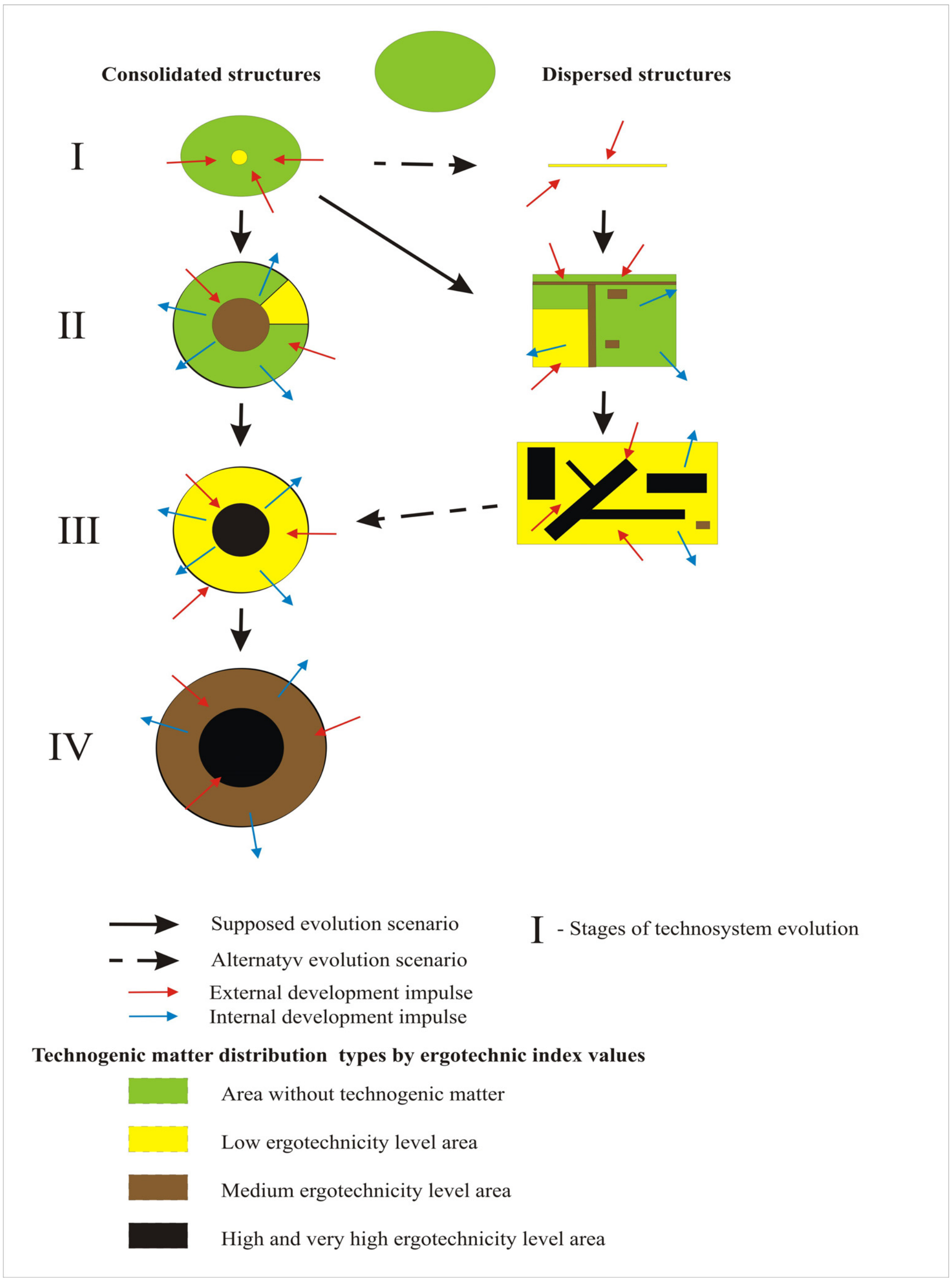


Fig. 16. Model of technourbosystms' evolution

Stage III can be defined as consolidation (strengthening) *stage*. The central core of the system develops qualitatively and quantitatively: consolidates and expands. In the centre, consolidated ergotechnicity types with average and high concentration levels occur. The linear structures develop towards consolidation and widening. The function of the main axis is performed by areas of high ergotechnicity level and dispersed distribution. The periphery, the aureoles and open areas, are occupied by areas of lower technomass concentration degree: disperse of low and average technomaterial concentration. This stage for the axial structures is the highest/final. Yet among the possible alternative scenarios of further evolution is their transformation into an area of node/core type. This scenario is possible when the open areas (zones of lower ergotechnicity rank) are intensively built up, i.e. filled up by technomaterial.

The last *stage IV of technosystem evolution can be defined as climax stage*. It is a comparatively stable stage of evolution marked by large mass, in this case technomass, stable structure and slow or absent accretion of material. At this stage, the core of the system reaches the highest degree of ergotechnicity or technomass concentration. The internal development of the core becomes impossible. The core itself is marked by a strong gravitational force which is responsible for formation of aureole of high ergotechnicity.

Theoretically, one more scenario of the climax stage is possible when the accumulation of technomass reaches the highest degree of concentration in a territory whereas the development of the core and its aureole is inhibited by large barriers; ususally of natural origin (bodies of water, deserts, other complexes). In this case, the core accumulates the maximal amount of technomaterial whereas the related aureole (periphery) does not develop due to limiting factors.

Fig. 16 presents a theoretical model of certain possible variations of aureole, core and axes under actual conditions. The existence of areas with a few cores also is possible in some cases. This situation can be regarded as a transitional intermediate stage, when the area merges into a qualitatively higher rank, or simply as a stage of quantitative growth of the core.

Spatial distribution patterns of technogenic material based on the model of technourbosystems' evolution

In the model, the urban territories are typified according to the evolution stages of technosystems based on ergotechnicity areas. Two technomaterial dispersion scenarios and 4 main evolution stages of systems are distinguished. The distinguished areas allow generalising the spatial distribution patterns of ergotechnicity.

Firstly the distribution of the systems in the climax stage meets the eye. The formations of this type, as a rule embrace the central parts of cities. The historical centres, the old town and the highest concentration of artificial material, act as the cores of the technosystems. The high ergotechnicity degree in these territorial complexes creates gravitation force responsible for formation of aureole – densely built up residential territories. In the reference cities, they usually are represented by the historical parts – old residential neighbourhoods and Soviet residential neighbourhoods of blocks of flats (in Vilnius Žvėrynas, Šnipiškės, Žirmūnai, Karoliniškės, Viršuliškės, Justiniškės, Šeškinė, and Fabijoniškės, in Kaunas Žaliakalnis, Kalniečiai, Eiguliai, Dainava, and Gričupis, in Klaipėd the core of the IVth stage complex is surrounded by Birutė, Baltkalnė, Joniškė, Vėtrungė, Mažoji and Didžioji Vitė, Bomelio Vitė, Fishing port, Baltija, recreation, Žardininkai, Alksnytė, Varpai, Laukininkai, Vingis, Debrecenas, and Pempininkai neighbourhoods)(Fig. 17).

Šiauliai does not have any area of especially high ergotechnicity degree. The central part of the city stands out as a high core type structure – IIIA. The existence of city centre of this stage can be explained by the fact that during World War II the historical city centre (core) was completely demolished. The new central structure was developed in the years of Soviet power. In the Šiauliai case, the core of the territorial complex is marked by a high degree of ergotechnicity. The aureole embraces the residential parts of the city with smaller amounts of technomaterial. It can be boted that in the northern part of the city, a new structural sub-core (area of high technomass concentration) is developing.

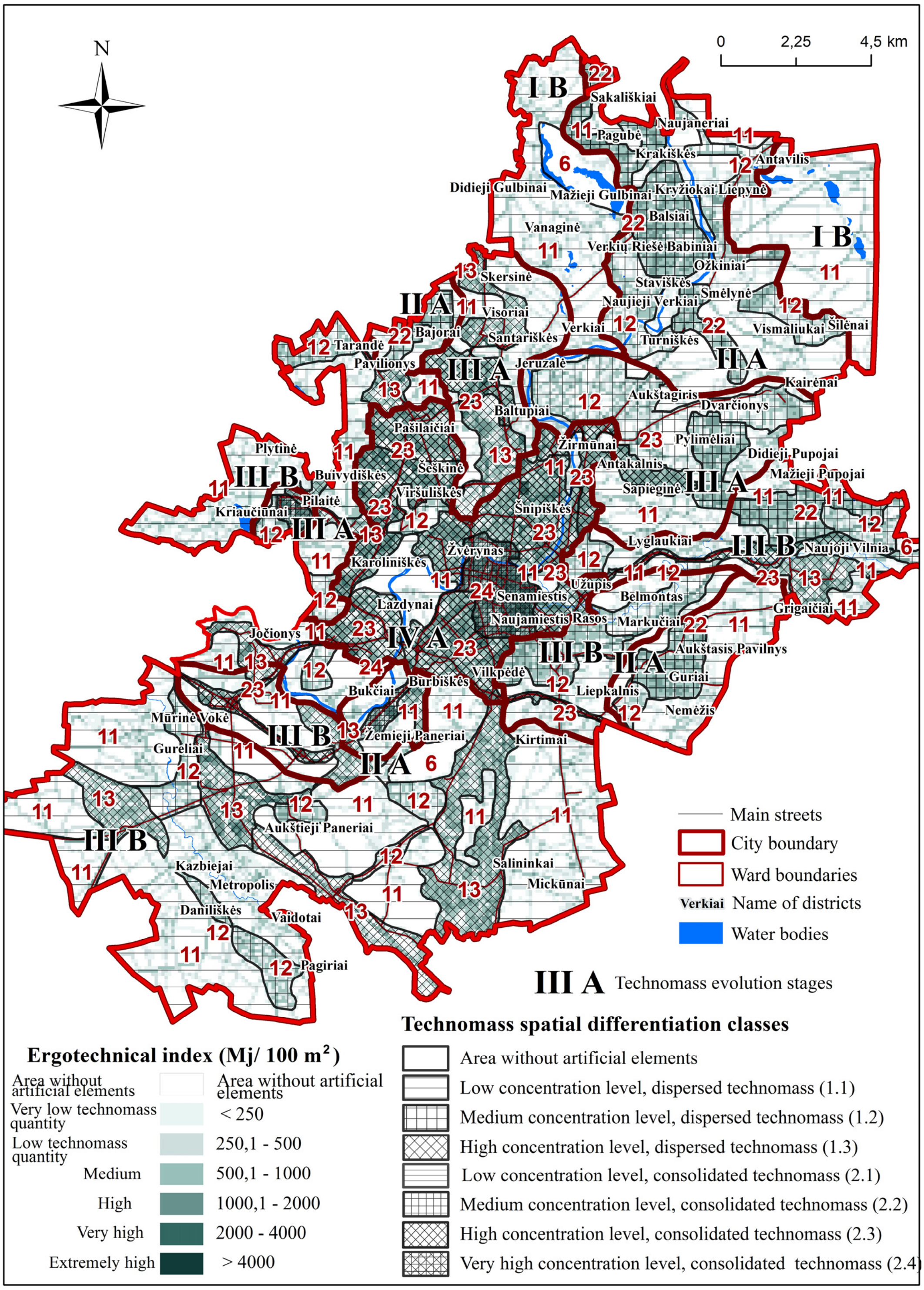


Fig. 17. Urban technosystem evolution stages (case of Vilnius)

The city zones of climax stage are surrounded by areas of the IIID consolidation phase comprising a sort of ring of lower ergotechnicity degree. The ring structure may vary between IIIA and IIIB structures. Sometimes, they may be surrounded by areas of lower (IId) evolution stage.

The cores of the first core-type structures are composed of private residential areas, sometimes the territories of Soviet blocks of flats (In Kaunas Smėliai and Milkonys neighbourhoods, In Šiauliai Dainiai neighbourhood), and territories of large industrial complexes (Petrašiūnai neighbourhood in Kaunas). The aureoles of core areas are composed of lower ergotechnicity rank territories (with smalle amounts of technomass) and marked by uneven technomass distribution. The periphery is represented by a network of roads and streets (of low and average technomass concentration ranks; dispersed) to which in the course of time sparse groups of buildings, designed for serving the central part of core structure, have adhered. In some cases, the the areas of this type are crossed by big streets and transport junctions. Yet the elements of this kind do not form noticeable assemblages and do not develop into core structures. On the other hand, the dispersed areas around the cores of high degree of technogenic material concentration (with the well expressed function of transport corridor) in the course of further technogenisation may be assimilated (merged with) by gravitation force of the core.

The IId type dispersed territories without distinct core structure in the aureoles of areas of consolidation stage include transport junctions (axes); streets of main and high-speed traffic).The industrial areas characterised by scattered territorial distribution also are included in this type (Lipkiai farmstead neighbourhood in Klaipėda is a good example illustrating this kind of situation – industrial territory crossed by a railway).

The width of the ring consolidation zones around the IVth stage climax zones is variable. Its parameters (width, area) may vary depending on the historical evolution and natural conditions. The whole southern part of Vilnius is classified as a IIB type of structure. In this part, the zones of consolidation phase extend to the city boundaries. Industrial neighbourhoods and isolated settlements (without large assemblages of technomaterial) where open areas are occupied by zones of low ergotechnicity (amount of technomaterial) are dominant. A similar situation can be observed on the left bank of Nemunas (Freda, Julijanava and Linksmadvaris neighbourhoods) in Kaunas. True, the functional purpose of this territory is slightly different (residential territory is dominant; zones of industrial function are fewer).

The areas of the IId stage of evolution usually occupy peripheral areas of cities. In some cases (Fig. 17), these territories verge with the climax zones (Kleboniškis forest area in the northern part of Kaunas, the western edge of the central part of Klaipėda, Paupys and Sendvaris neighbourhoods in Kaunas) or form the second ring of lower ergotechnicity rank (the northern part of Vilnius, the bigger parts of Antakalnis and Verkiai elderships of Vilnius, Šilainiai eldership of Kaunas, the north-eastern edge of Kaunas – Palemonas, the whole north-eastern part of Šiauliai). As in the case of consolidation phase, depending on the territorial distribution of typological areas of ergotechnicity, two morphological variations of the areas of this stage are possible. We have in mind the core and dispersed structures. The central part of the core structure is composed of the former and present territories of garden communities and their technogenic material, settlement, and villages included into the city territory in the last few decades. This is illustrated by aggregation stage area in the northern part of Vilnius. It is composed of a few cores of average technogenic material concentration: Ožkiniai, Balsiai, Kryžiokai, Pagubė, Naujaneriai, and Skališkės. Almost the whole territory of the Panemunės eldership in Kaunas belongs to this type. The residential zone of Taurakalnis neighbourhood in the north-eastern edge of Klaipėda comprises the core of the structure of the stage under consideration. In Šiauliai, such territories are characteristic of Rėkyva eldership and its garden communities.

In general, there are almost no areas in city territories which have not been affected by technogenic transformation. Even the natural landscape elements, such as bodies of water and forests, have been transformed. For this reason, the embryos of the Ist stage were not distinguished.

3.5. Spatial distribution patterns of urban material artificiality

The territorial artificiality index applies to technomass artificiality degree, i.e. amount of embodied energy. It depends on the amount and properties of construction material. It is natural that small though very artificial objects (e.g. metal garages) do not stand out for their artificiality in the general context of accumulated technomaterial in large territories (environs, sub-regions). An on the contrary, the areas of high concentration of technomaterial but smaller degree of artificiality distinctly stand out for artificiality in the territories with lower material concentration (Fig. 18).

Generalising the distribution patterns of artificiality index in urban areas, the old historical parts of cities must be distinguished. From the point of view of quantitative technomass distribution, these parts include the areas of highest technomass concentrations. The boundaries of the extremely high ergotechnicity areas partly coincide with the boundaries of very high ergotechnicity areas. The type of high ergotechnicity areas is dominant in the old neighbourhoods and historical parts of cities (in Vilnius: Naujamiestis, Žvėrynas, Šnipiškės, part of Žirmūnai, Antakalnis). The performed analysis showed that the ergotechnicity degree of these city zones is predetermined by a large amount of technomass though the diversity of construction materials in them is poor (brick constructions are dominant). The Soviet ferroconcrete neighbourhoods of blocks of flats also stand out in the general context (In Vilnius Viršuliškės, Šeškinė, Lazdynai, in Kaunas the northern parts of Vilijampolėand Žaliakalnis, in Klaipėda Žardininkai, in Šiauliai Gytariai, etc.). Due to their specific layout and technomass distribution (the blocks of flats are arranged at certain distances from each other, there are playing grounds between them, meadows and other areas without technomass; this layout is very contrasting from the point of view teachnomass distribution), these areas are characterised by mixed (6.1 and 6.2) degree of territorial artificiality, which, as pointed out, is predetermined by distribution patterns of technomass rather than artificiality and compositional diversity of construction material. The mixed (low-average artificiality) types sometimes embrace neighbourhoods with rather dense layout of private residential houses. The diversity of construction materials in such neighbourhoods is slightly higher than in the blocks of flats (brick constructions are dominant but the groups of wooden or mixed construction houses are also common) but construction materials of extremely high ergotechnicity are rare. Nevertheless, the density of buildings and the amount of technomaterial in the territory distinguish these zones among the surrounding territories (low and very low ergotechnicity areas).

The discussed type of territorial ergotechnicity (mixed and commonly average-high) also includes industrial territories (plant complexes, storage areas) which in the context of artificiality index stand out for their specific structure. Due to variable functions of buildings, the material composition and spatial parameters of objects within complexes also vary. Sometimes there occur huge buildings of especially high ergotechnicity (metal constructions). This type includes the territories which area characterised by uneven distribution of technogenic material and mixed, sometimes high, ergotechnicity degree.

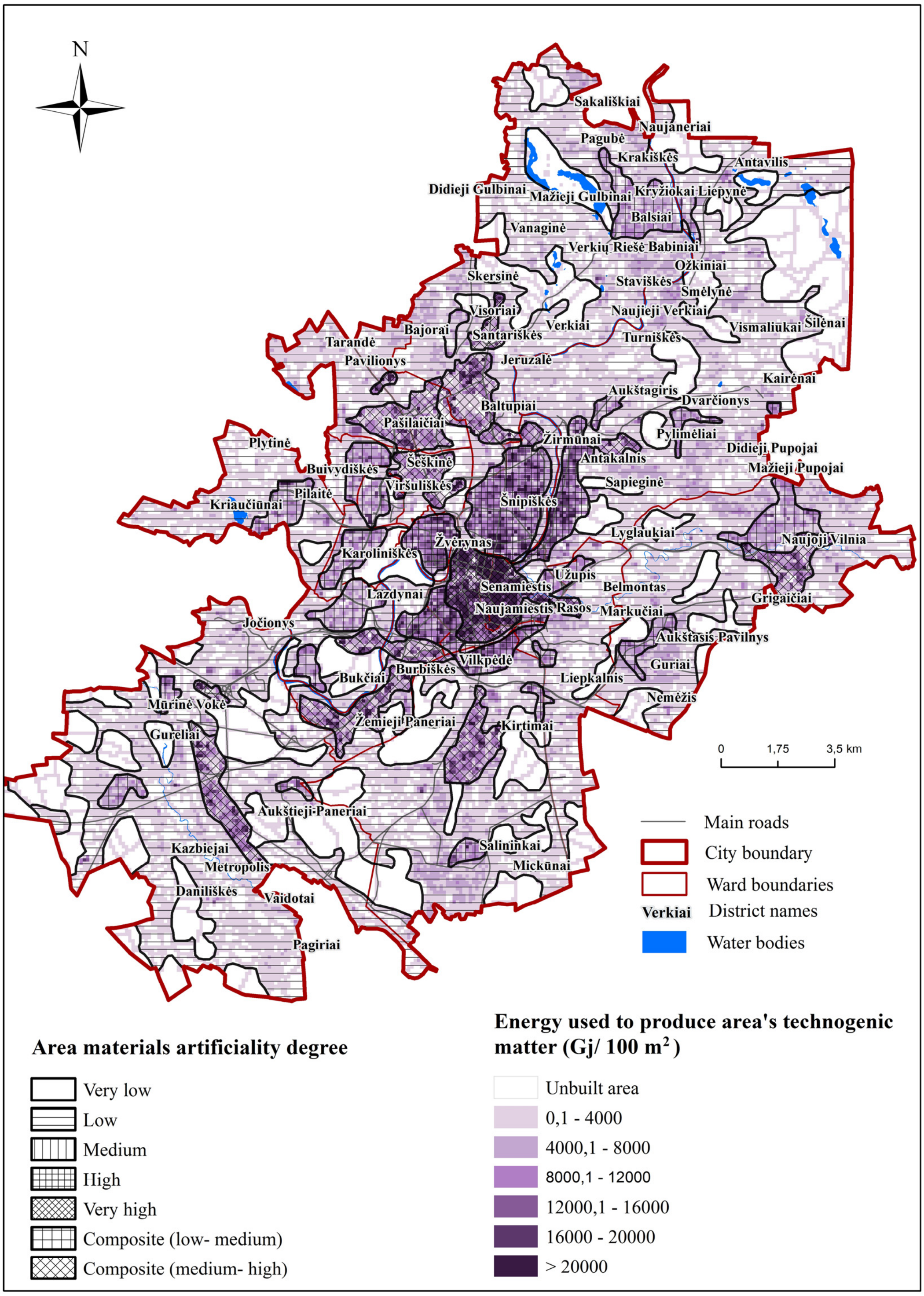


Fig. 18. Territorial distribution of artificiality of construction material (case of Vilnius)

In general, the distinguished typological areas of average, high, extremely high and mixed ergotechnicity are distributed in zones of high and extremely high technomass concentration. The territorial aspects of technomass distribution may vary yet in general these territories are distinguished for high volume of technogenic material what cannot be said about the territories of low ergotechnicity. The latter are characterised by a dense network of roads and streets. The amount of energy in the street and road cover has nothing on the amount of energy in the congeries of buildings. Though the surface occupied by road cover in cities is rather large the pavement layers are comparatively thin as distinct from buildings which have a considerably larger technomass. This circumstance eventually affects the total ergotechnicity index of territories.

3.6. Territorial distribution patterns of technogeneity of cities

For further determining the specific patterns of urbanised territories it is necessary to generalise the results of above described technogeneity analysis and compare the structural properties, distribution and spread of technogeneity types. Fig. 19 illustrates the total extent of technogenisation.

Comparison of determined values of the indices of ergotechnicity and territorial distribution of technogenic material showed that production of technogenic materials require considerably greater energy resources that their installation in the environment (Figs 17 and 18). For this reason, the boundaries distinguished after summing up of these two indices of embodied energy and territorial regioning of landscape technogeneity almost completely coincide with the boundaries of territorial ergotechnicity zones. However in the qualitative aspect and aspect of technogenisation degree they acquire different values.

The type of technogenic landscape occupies the relatively largest area in Šiauliai and Kaunas. By the way, a considerable part of the territory of these cities also is occupied by technogenic areas with somewhat smaller amount of embodied energy. Kaunas and Šiauliai outweigh the other two cities in the amount and ergogenicity of technogenic material, In Vilnius, the technogenic and technogenised landscapes occupy the smallest part of the territory (18.2 %) if compared with other cities.

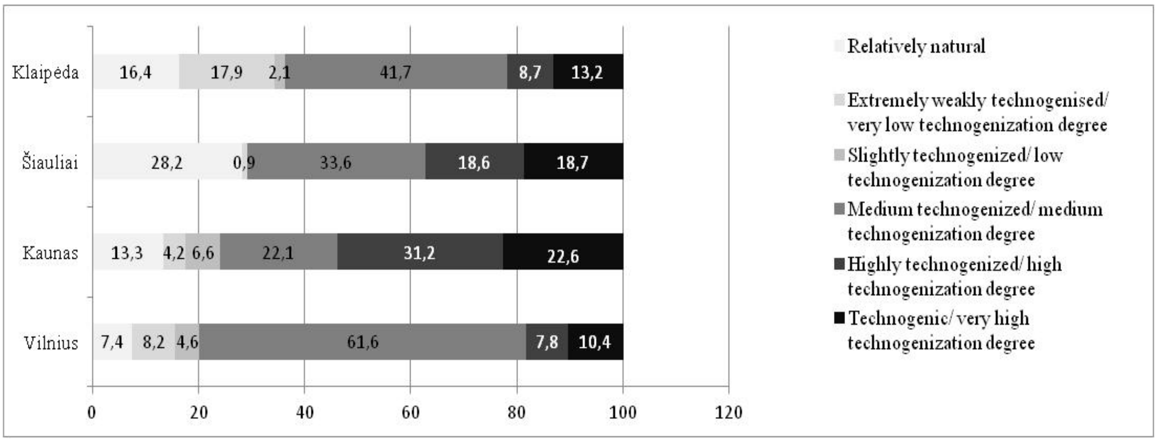


Fig. 19. Area occupied by types of technogenisation degree (%)

Nevertheless in the general city context, Vilnius is distinguished for abundance of average technogenisation territories. Their area exceeds 60 %. In Klaipėda, this type of landscape also occupies a big portion of the territory. Meanwhile Kaunas and Šiauliai, distinguished by high technogeneity zones, stand behind in this respect. Incidentally, the variations of the portion occupied by technogenised landscape in the studied cities are most noticeable (Fig. 19).

The slightly technogenised landscape type is the rarest in urban areas. In Kaunas, this type of landscape occupies somewhat less than 7 %. In other cities, this percent is considerably smaller. In Šiauliai, the type of weakly technogenised landscape was not determined altogether. The situation with extremely weakly technogenised landscape is similar. Klaipėda stands out in this respect as extremely weakly technogenised and natural elements exceed 30 % of the territory (Fig. 19).

The situation is different in Šiauliai where extremely weakly technogenised landscape only accounts for 0.9 % of the territory. However, in comparison with other cities, Šiauliai has rather many natural elements of landscape (lakes, meadows). Kaunas and Vilnius are considerably poorer in extremely weakly technogenised and relatively natural areas than Klaipėda and Šiauliai (Fig. 19).

Generalising the structural composition of technogeneity types we can state that due to abundance of areas with large amounts of embodied energy (technogenised and technogenic types) the Kaunas landscape may be regarded as most strogly technogenically affected. This is proved by the map of technogenisation degree (Fig. 26) and section of city axis illustrating the variations of embodied energy and spatial distribution of technogenisation types. In the Kaunas case, the average amount of embodied energy (EE) outweighs the values of other cities (Fig. 20). The Kaunas territory is comparatively compact and includes many peaks of technogenisation (exceeding the mean values), i.e. different rank technogenisation cores. According to the diversity of technogenisation types and average amount of EE, the Vilnius landscape stands behind Kaunas and other cities. Thus, in comparison with other cities, its territory is least technogenically affected. The structure itself is uneven and fragmented (Fig. 21). There are many technogeneity minimums (natural or weakly technogenised territories) densely distributed within the areas with higher amount of EE. Šiauliai and Klaipėda do not fit in any category of technogenisation degree in respect to technogenised areas (Fig. 19). The groups of technogenisation types (extremely, averagely and weakly technogenised and natural or extremely weakly technogenised) are rather evenly distributed. The sections illustrate a rather limited territorial fragmentation: the hotbeds of technogeneity are represented by large massives. Big natural objects are located in the peripheral parts of cities. According to the average amount of EE in the landscape, Klaipėda considerably overweighs Šiauliai what can is illustrated by the average values of EE in the sections. Nevertheless these cities can be classified as occupyin an intermediate position between the most technogenised Kaunas and the most natural Vilnius (Figs 20 and 21).

The sections of technogenic structure not only show the variations of EE and locations of technogenisation areas but also convey the internal structural composition and quantitative parameters of technogenisation types. The different types of technogenisation are distinguished by certain amounts of embodied energy. Yet this amount in some cases may considerably vary within types and areas (to the limit indicated in the scale).

Figs 20 and 21 show the average amount of energy accumulated in the central zones of cities (histroical cores) and neighbouring zones of technogenic type. In Klaipėda, the EE index in the technogenic areas of the central zone is the highest. Its average value exceeds 1733 $Mj/\ m^2$ what indicates the concentration of technogenic material in the old town (> $3600 Mj/m^2$). Moving toward the boundaries of technogenic areas, the EE gradually decreases. Farther from the centre, in the southern direction in particular, the technogeneity degree becomes lower yet technogeneity hotbeds (technogenic, technogenised, etc. types) with smaller amounts of EE still remain. The section of Klaipėda validates the development model of technogenic structures (the central zone of the fourth stage; lower rank technogenic structures farther from the central zone; territorial formations of the lowest or embryo stages in the periphery). The structure of the central zone is similar in Kaunas Nevertheless, in EE of the central technogenic areas Kaunas stands behind Klaipėda (the average EE of the central typological zones of technogeneity is 1436 Mj/ m^2). Bearing in mind the comparatively high total EE of the city section, data of the section curve and territorial distribution of technogenisation degree (Fig. 26) we can conclude that the technogenic material in Kaunas is considerably more evenly distributed than in Klaipėda. Formations of high technigeneity degree (technogenic types) occur beyond the central concentration of climax stage araes. This is especially evident in the southern-central part of the curve. By the way, the flat tops of curve maximums show even territorial distribution of technogenic material and the tapering tops show unevenness and fragmentation (Fig. 20 and 21). One more obvious feature of city structure reflected in the EE section can be pointed out in relation with Kaunas. The curves of the central most technogenic part of the city have two distinct maximums which stand out in the general context for technogeneity. The first maximal and main peak of technogenic accumulation corresponds with the central part of the city (old town). It is clearly visible that the location of technogenic maximum, as distinct from Klaipėda, is located at a distance from the centre. In the course of technogenic evolution, the natural zone (Nemunas River) distinguished in the neighbourhood has acted as a barrier for technogeneity expansion. The process of technogenisation took place along or away from the barrier. The second distinct peak of technogeneity is located in the opposite part of technogenic areas accumulation (Fig. 20).

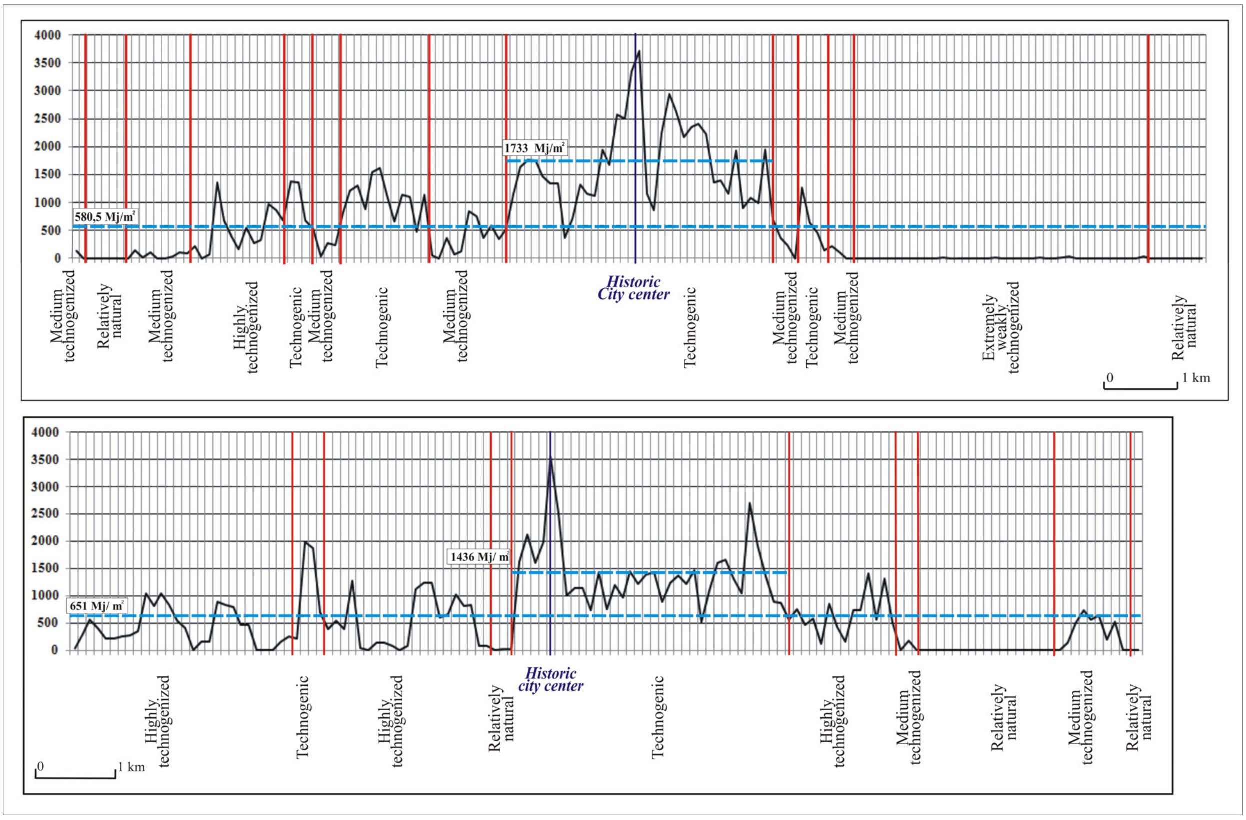


Fig. 20. Sections of Klaipėda and Kaunas technogenic landscape structure

This zone corresponds with the industrial territories located in the northern part of Žaliakalnis eldership. In their EE and technogeneity degree, these territories resemble the southern zones of especially high concentration of technogenic material in the central and historical parts of the city (Fig. 26). The central technogenic zones of Šiauliai partly resemble the ones of Kaunas. The most highly technogenised territory represents the city core (the regenerated old part of the city).

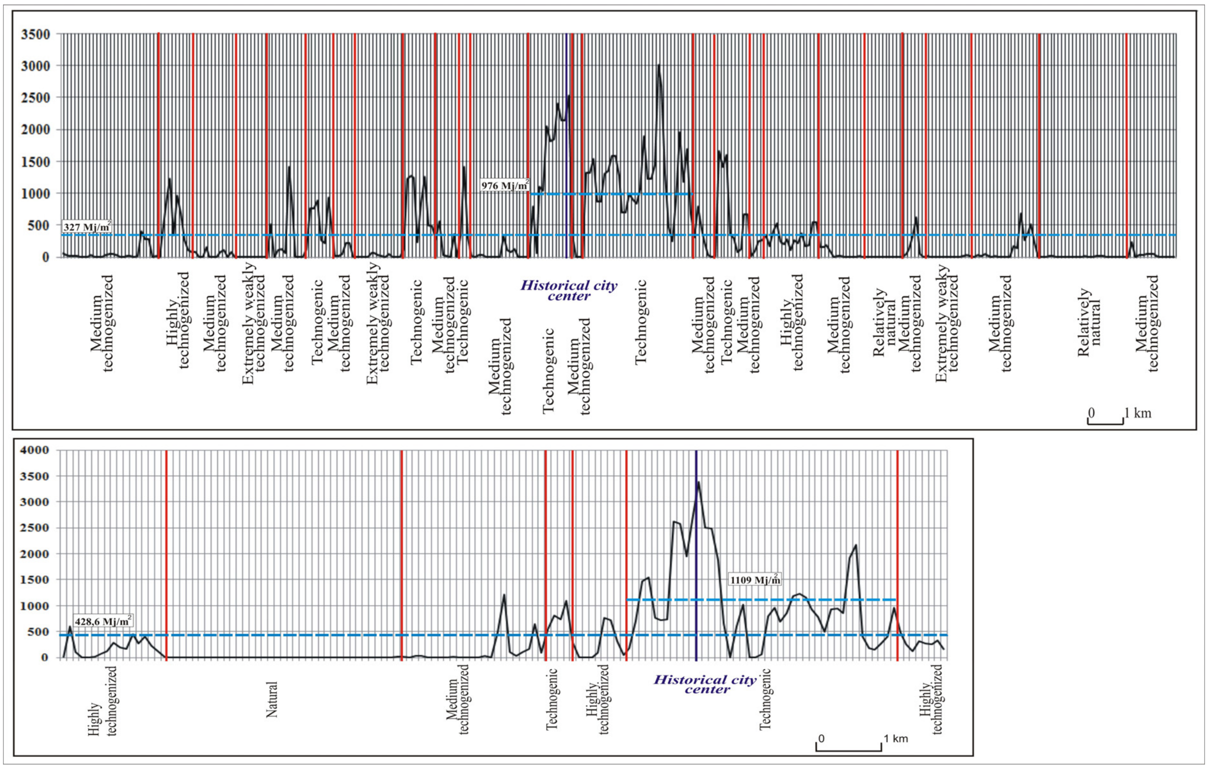


Fig. 21. Sections of Vilnius and Šiauliai technogenic landscape structure

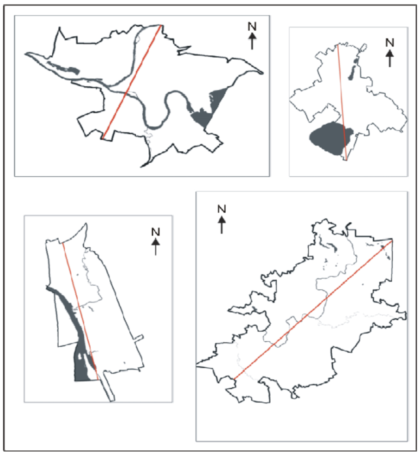


Fig. 22. Technogenic landscape section location

According to the technosystem evolution model, the core (EE maximum) of climax stage technogenic areas is located southernmore. The hotbed of technogeneity areas is binary as in Kaunas. The second peak also is located in the indistrial area. The average EE of the central technogenic areas is 428,6 Mj/ m^2, ie.e lower than in Klaipėda and Kaunas. This index is even smaller in the largest Lithuanian city Vilnius (976 Mj/ m^2). In comparison with other cities, Vilnius also has the lowest average amount of embodied energy accros the profile (976 Mj/m^2). The technogenic areas of the central part of the city are distinguished for uneven patterns of the internal structure and EE. The old town or the historical core is bounded by energy depression, i.e. areas of average technigeneity, which correspond with the areas of parks, Neris River and its embankments. As in other cities, the technogenisation hotbed is binary. The first energy peak is located in the old town and the second in the northward industrial and storage zone of Žirmūnai neighbourhood. Abundance of technogeneity depressions and maximums of naturalness is the distinguishing feature of Vilnius. Moving from the central part of the city, isolated islands bounded by the areas with low amount of EE can be identified. These average technogeneity islands often coincide with the territories of settlements. The technogenic or technogenised peaks of the section are located farther from the centre.

Generalisation of the diversity of technomorphological properties of technogeneity types of landscapes

The types of technogenisation degree distinguished according to the amount of EE in the aspect of territorial distribution were defined based on their technomorphological properties. The properties of technogenisation types can be seen in the sections of technogenic structures (Figs 20 and 21). The sections do not present concrete indices. Yet the contours of the section curves are sufficient for determining the technogeneity degree and description of the distribution character of technogenic material. The above described central technogenic parts of the cities (hotbeds of technogenic areas) can be mentiond as an example. The central parts of the cities often are predominated by big (high and with large amount of EE) forms with flat tops what implies technogenic evenly distributed material: even dense buiding pattern and high artificiality degree. Pointed tops of narrow profile, in their turn, usually represent uneven fragmentarily distributes technomaterial This is confirmed by the maps of landscape technogenisation degree in cities (Figs 23, 24, 25 and 26).

The sections and technogeneity maps in particular demonstrate the diversity of technomorphological properties of landscape types of different technogeneity degree. This diversity is generalised in Table 4.

Table 4. Variation of the indices of technomorphological properties in different types of landscape technogenisation

Techno genic	**Highly technogenize d**	**Medium technogenized**	**Weakly technogenized**	**Extremely weakly technogenized**	**Relatively natural**
E24-D5	E23-D62	E12-D2	E12-D1	**E11-D1**	**E0-D0**
E24-D4	*E23-D61*	**E11-D2**	*E11-D2*		
E23-D4	*E22-D61*	E11-D1	**E11-D1**		
E23-D3	*E13-D61*				
E23-D62	*E13-D62*				
E23-D61	*E12-D3*				
E23-D5	**E12-D61**				
E13-D62	E12-D2				
E22-D3	E11-D2				
E22-D61					
E22-D62					
E13-D62					
E13-D61					
E13-D4					
E12-D62					
E12-D61					

The bold type marks the dominant and most common properties of technogeneity types. The italic marks common and the plain type rarer technomorphological properties.

Generalising the properties of technogenic types of cities we may point out that technogenic type of landscapes is distinguished for the highest diversity of properties. The degree of material concentration in technogenic landscapes varies from average even/fragmented building pattern to extremely high degree of concentration. True, the average degree of technomaterial accumulation in this type of areas is rare.

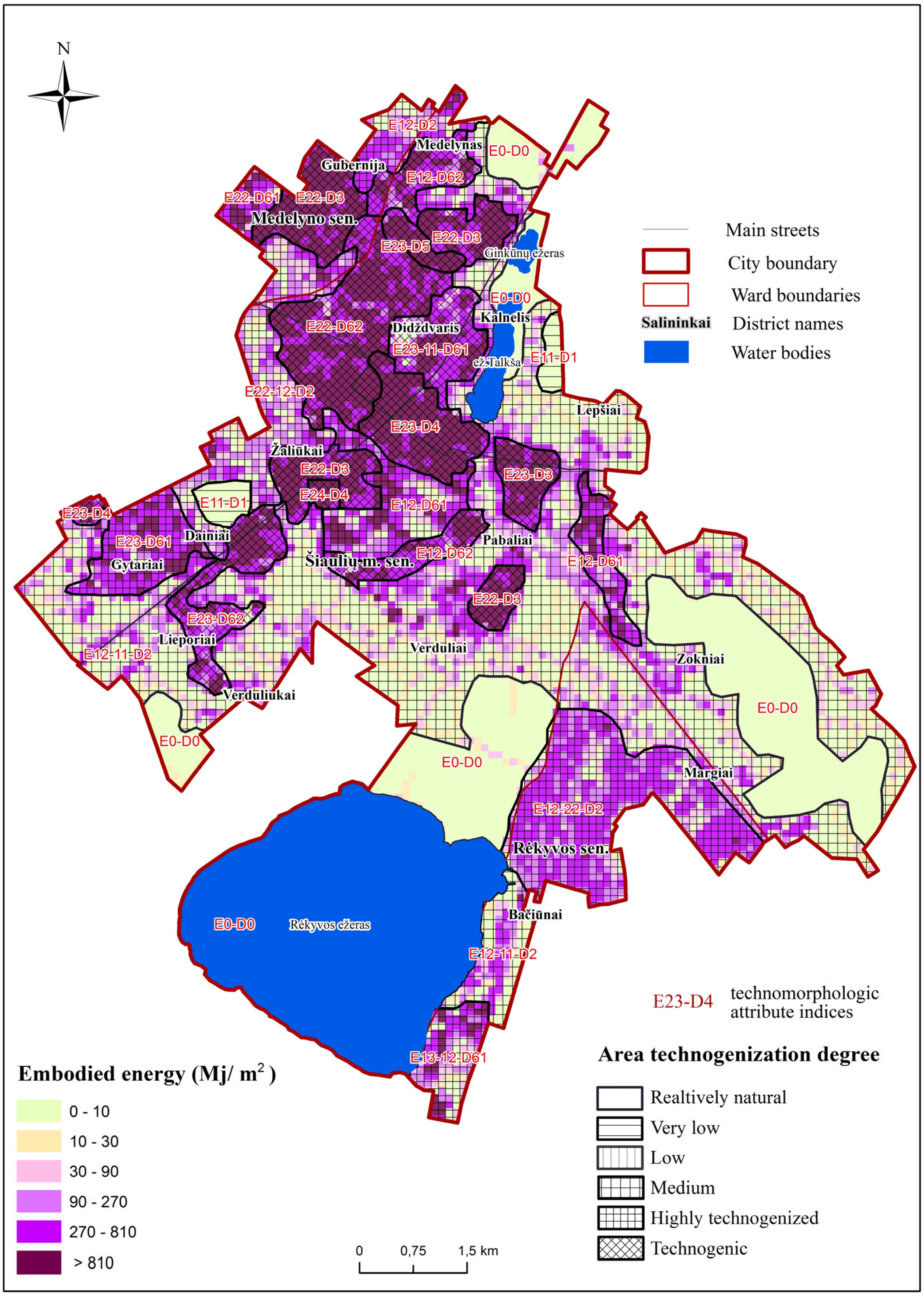


Fig. 23. Distribution of the types of landscape technogenisation degree in Šiauliai

The degree of territorial artificiality also noticeably varies. The average, high, extremely high and mixed (average-high or lower-average) technogeneity degrees are distinguished. In the technogenic typological territories indices E23-D4 and E-13-D62 are dominant. The first index applies to evenly built up territories of high technogenic material concentration degree and high degree of technogeneity. The second index is applied to territories of unevenly distributed technomaterial and mixed technogeneity (average-high)(Table 4).

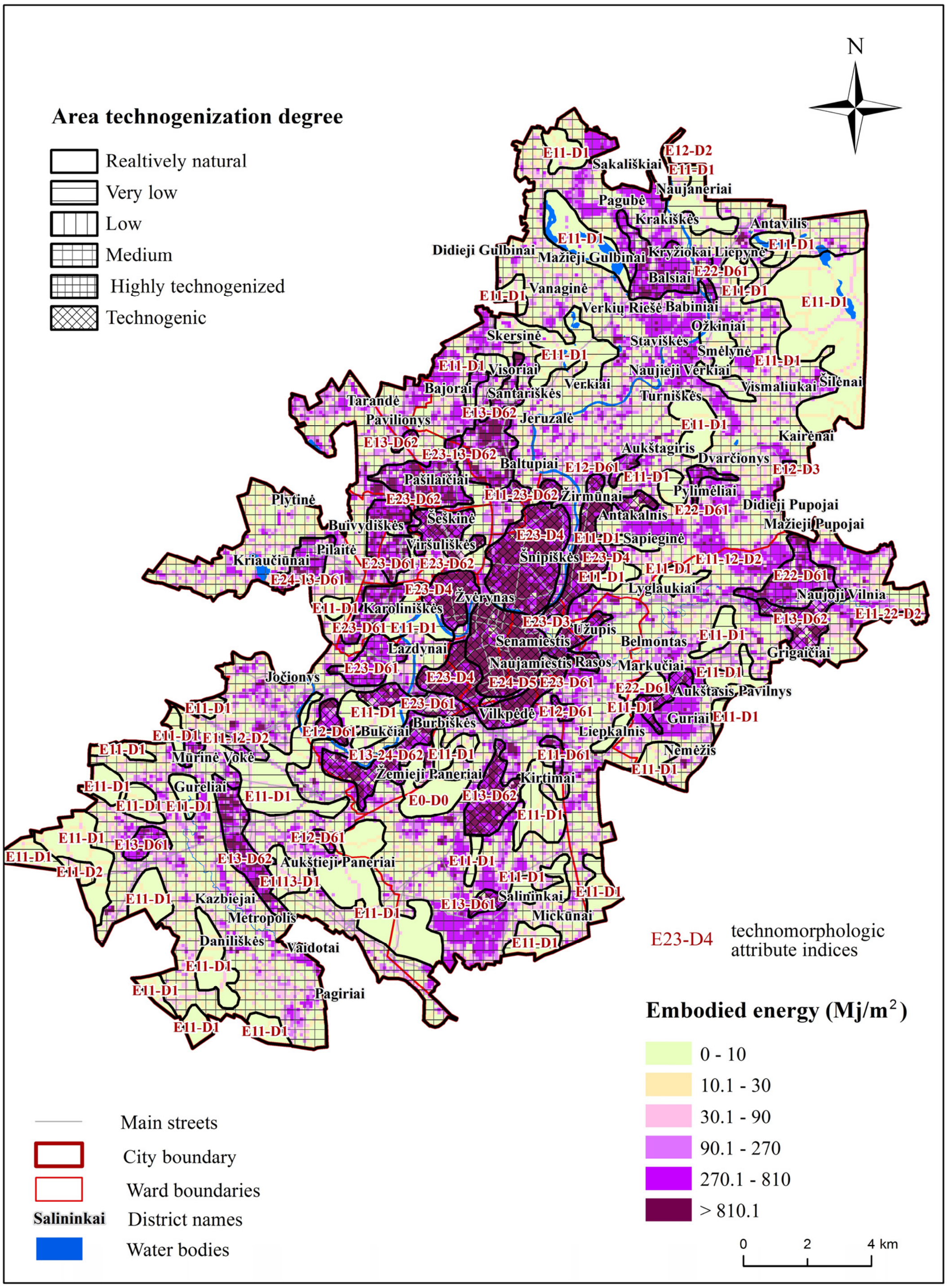


Fig. 24. Distribution of the types of landscape technogenisation degree in Vilnius

The technogenised type is poorer in technomorphological properties than the discussed technogenic type. The dominant properties of this type are E12-D61, i.e. average concentration of low-average ergotechnicity degree technogenic material. Areas with different properties also can be distinguished. The mixed (low-average) degree of ergotechnicity of material is their typical feature. The types of average or low ergotechnicity or mixed ergotechnicity (average-high) are less common. The average fragmented spatial differentiation type is the dominant type of spatial distribution of ergotechnicity. Types 1.3 and 2.3 (high concentration level and uneven or even spatial distribution) also are rather common.

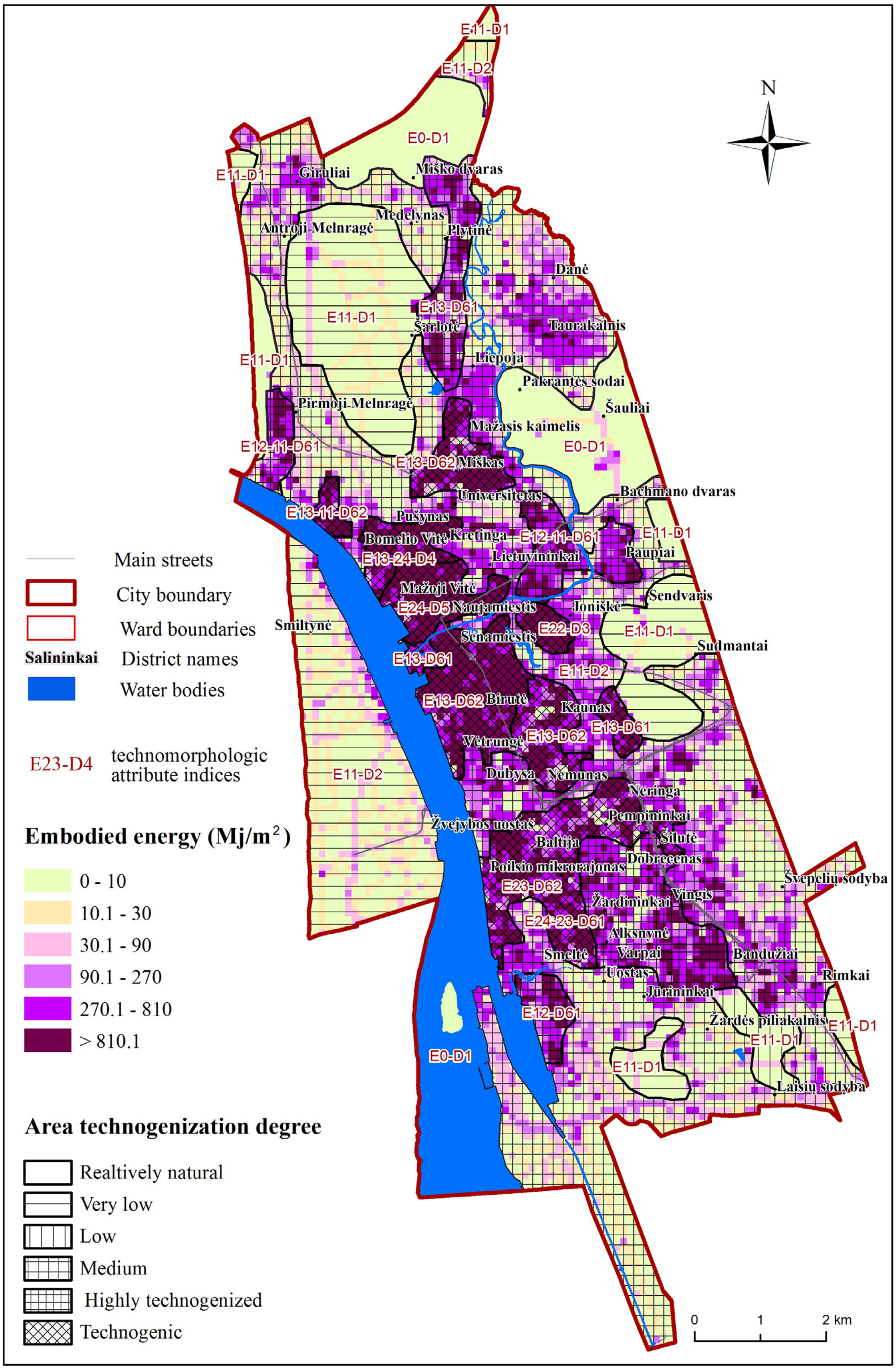


Fig. 25. Distribution of the types of landscape technogenisation degree in Klaipėda

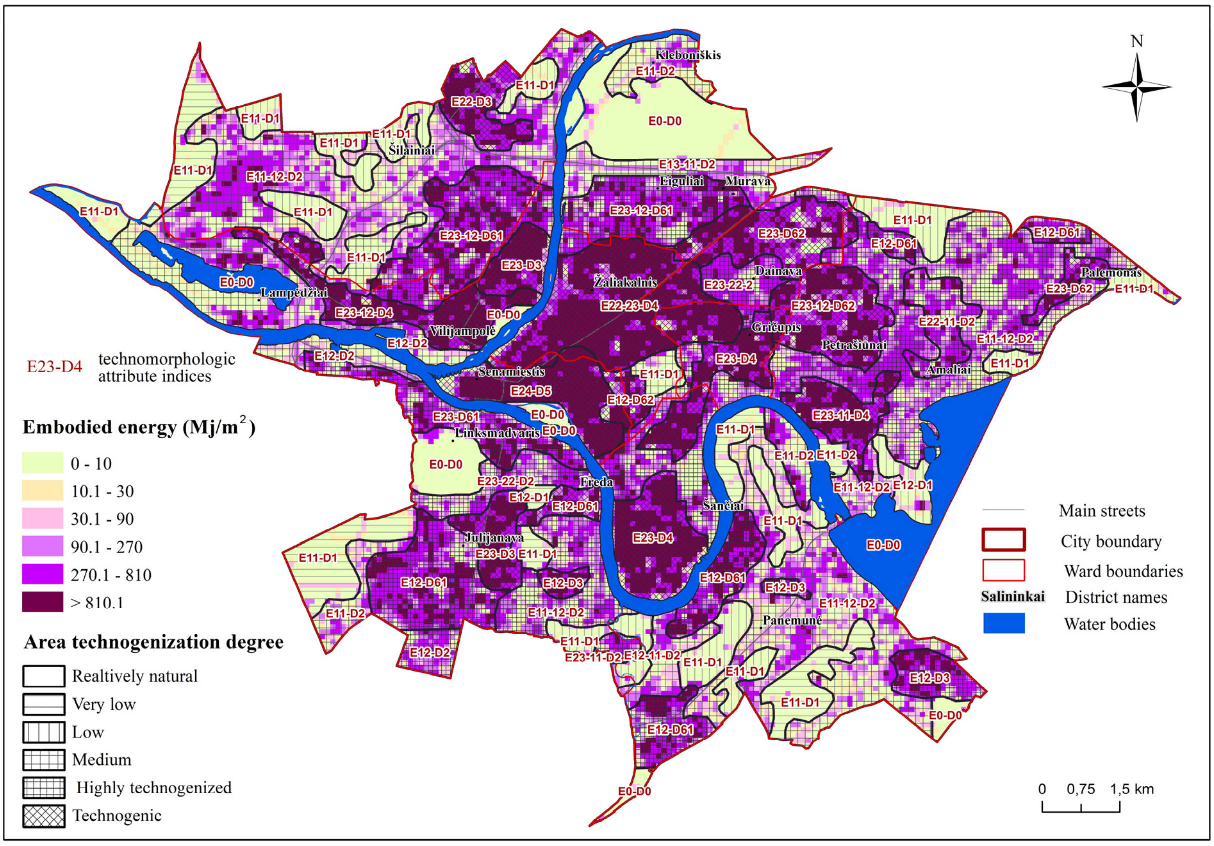


Fig. 26. Distribution of the types of landscape technogenisation degree in Kaunas

In isolated cases, the properties of distinguished areas reach low ergotechnicity and low technogeneity degrees (Table 4). In general these properties are characteristic of urban landscapes of average technogenisation degree yet in some cases, i.e. territories of settlements, garden communities, etc., the EE index exceeds 270 Mj/ m^2 therefore the mentioned city zones should be classified as technogenic.

The abundance of the types of landscape technomorphological properties tends to decrease with decreasing technogenisation degree (Table 4). In average technogeneity degree areas, the possible combinations fall into three types with the dominant type E11-D2 (low degree of technogenic material concentration and low technogeneity of material). In the technomorphological properties and abundance of their types, the weakly technogenised landscape is rather comparable with the averagely technogenised landscape. Only the index of technogeneity of the dominant type of properties differs (extremely low technogeneity). In extremely weakly technogenised and weakly technogenised landscapes are similar in qualitative indices of technomass with the only difference that in the latter sparse small buildings can be found among isolated roads and streets whereas in the extremely weakly tchnogenised landscapes only isolated 10.1- 30 Mj/m^2 grids of narrow roads or streets can be found (Fig. 23, 24 25 and 26). The index of relatively natural landscape, or more precisely its zero values, implies that objects of technogenic material were not distinguished in the territory.

CONCLUSIONS

1. Literature analysis of energy involved in landscape anthropogenisation processes reveals rising relevance of research of landscape naturality/

artificiality and demand for objective evaluation indices. It could be implemented by quantitative analysis of embodied energy.

2. Conception of embodied energy oriented to landscape technogenisation research does not meet the definition used in technological sciences, its application in landscape geography requires concretization and elimination of energy that was used in transportation of constructional materials.

3. Landscape technogenisation evaluation includes system of indexes from three hierarchical ranks where embodied energy is on the highest position it consists of partial indices- ergotechnicity and matter artificiality, for evaluation of which morphometric and objects materiality parameters are required. Not only for urban landscape technogenisation degree evaluation, but for all landscape types this system of indices can be applied.

4. Values of territorial index of matter artificiality mostly depends on quantity of technogenic material present in area, matter artificiality plays secondary role. Maximum values of this index are dominant in greatest matter artificiality core territories of cities with very high building density level.

5. Maximal values of ergotechnical and territorial matter artificiality indices are fundamental technogenic landscape attributes. These values are dominant in core areas of technogeneity- historic city centers, where extremely high quantity of embodied energy is accumulated, industrial areas, also characterised by large technogenic objects coincides satellite core areas status. Going from a center to periphery embodied energy in core units decreases, as does the degree of tecgnogeneity of area.

6. Landscape technogenity regionalization enables to compare cities by the aspect of territory artificiality. Kaunas stands out with an abundance of technogenic and highly technogenized area’s type, which are concentrated in city’s center and surrounding areas. Technogenic matter spread evenly, but quantity of it gradually decreases toward to periphery. Vilnius characterized by a greatest diversity of technogenisation area types, it can be seen in whole city’s structure, also in the center of it. Average embodied energy rates in a center and in the rest parts are lowest among all cities. The highest embodied energy rates are in Klaipėda, in city’s artificiality core- old city and a part of city’s port. However city includes large areas of natural and extremely weakly technogenised tipes, this in general view diminishes landscape technogenisation degree. Clear spatial differentiation of technogenisation types can be seen in Šiauliai: Natural and extremely weakly technogenised areas are located in city’s south part, in the center and to the north from it- technogenic and highly technogenised types prevails. However average rates of embodied energy in city center are lower than in Kaunas or Klaipėda.

7. Embodied energy evaluation based on cities landscape technogeneity degree regionalization enables to develop the integral cultural landscape regionalization, morphologic city research and city landscape sustainability, planning and protection.

LIST OF PUBLICATIONS

In peer-reviewed editions of international databases recognized by Science Council of Lithuania:

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Jukna, L. (2010-2011). Technogeninės energijos tyrimai kraštovaizdžio geografijos mokslo darbuose. Annales geographicae. 43-44: 144-157.

In editions of scientific conferences:

Jukna, L. (2011). Методологические аспекты оценки воплощенной энергии техногенных элементов ландшафта. Теоретичні, регіональні, прикладні напрями розвитку антропогенної географії та геології : матеріали третьоі мижнародноі науковоі конференциіі. 62-70.

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SANTRAUKA

ĮVADAS

Temos aktualumas

Žmogus kraštovaizdžio raidos kontekste reikšdamasis kaip ekspansyvi, ekologiškai plastiška ir ypatingai destruktyvi rūšis, tūkstantmečiais agresyviai veikė ir veikia įvairiausius gamtinių sferų elementus, juos transformuoja, erdvę užpildo naujais, savo sukurtais technogeniniais objektais. Mokslininkų tarpe jau ne vieną dešimtmetį vyksta diskusija, susijusi su klausimu, kaip derėtų traktuoti žmogaus veiklos pėdsakus gamtinės aplinkos kontekste, ar antropogeniškai kuriamą aplinką ir jos objektus reikėtų laikyti gamtos dalimi (Comer, 1997), ar „svetimkūniu" natūralioje gamtoje- dirbtino, nenatūralaus išraiška (Hunter, 1996; Machado, 2003; Angermeier, 2000). Šiame darbe laikomasi pastarojo požiūrio. Tokios pozicijos pasirinkimą įtakoja žmogaus gebėjimas sąmoningai suvokti savo veiklos padarinius, mastus, dėl to vykstančių procesų priežastingumą, kas jį beje ir išskiria iš kitų bioorganizmų rūšių. Todėl šalia gyvosios, gamtinės sferos- biosferos, skiriama antroposfera- žmonija su savo kultūrine, socialine, ekonomine aplinka ir jos veiklos padarinys- technosfera, žmogaus sukurtų techninių įrenginių, dirbtinių ir transformuotų gamtinių objektų visuma (Balandin,1978; 1982; Rozanov,1987; 1998; Kavaliauskas, 2011; Kavaliauskas, Veteikis, 2004; Veteikis, 2002; Jankauskaitė; Veteikis, 2005a; 2009; 2012). Technosferos elementai- įvairaus dirbtinumo laipsnio, antropogeninės transformacijos lygmens objektai kraštovaizdyje pasiskirstę ir jį veikia labai nevienodai, todėl įvairiose srityse, tokiose kaip kraštovaizdžio tvarkymas, planavimas, gamtinių teritorijų apsauga, geosistemų ar ekosistemų būklės vertinimas, teritorijos natūralumo ir atvirkščiai- dirbtinumo laipsnio nustatymo metodikų ir rodiklių kūrimas bei praktinis jų taikymas iki šiol nepraranda savo aktualumo bei svarbos.

Visgi, egzistuoja visa aibė jau sukurtų kraštovaizdžio dirbtinumo/ technogeniškumo ir atvirkščiai- natūralumo vertinimo metodikų. Tarp jų, ryškią kiekybinę persvarą įgauna bioekologinės, biologinės krypties tyrimai. Natūralumas, dirbtinumas tokio pobūdžio darbuose dažnai yra vienas iš gamtinio kraštovaizdžio apsaugos kriterijų (conservation value), tik labai nedaugelyje darbų pateikiami tikslūs vertinimo metodai ir rodikliai (Macdado, 2003). Kai kuriais atvejais minimos tik teorinės problemų vertinimo prielaidos (Anderson, 1991; Angermeier, 2000). Kitais, pasikliaujama kokybiniu vertinimu. Augalijos rūšinė sudėtis, invazinių ir vietinių rūšių paplitimas, potencialiai natūrali augalija, kultivacijos laipsnis – tai tik dalis kokybinių natūralumą nusakančių rodiklių (Ellenberg, 1979; Blume, Sukopp, 1976; Grant, 1995; Edarra,1997 Jalas, 1995; Kovarik, 1999; Sukopp, Hejný, Kovarik, 1990;). Kažkodėl šioje srityje vengiama kiekybinio vertinimo. Vienas iš retų pavyzdžių J. L. Ferma- Almanda natūralumo rodikliai (kilometrai kelių ar namų kiekis tenkantys teritorijos vienetui, brandžios augalijos užimama teritorija, saugomų teritorijų plotas) (Ferman- Almanda, 2001).

Tokie natūralumo laipsnio vertinimo pavyzdžiai rodo pakankamai siaurą šių metodikų taikymo galimybę. Jose naudojami rodikliai tinkami mažai žmogaus veikiamoms ir tik iš dalies antropogenizuotoms teritorijoms su vyraujančiais gyvosios gamtos komponentais. Tuo tarpu, sudėtinga nustatyti antropogeninių teritorijų ar technogeninių objektų atskirai, dirbtinumo ar išlikusio natūralumo laipsnį.

Kiek kitokios tyrimų krypties laikosi kai kurie kraštovaizdžio geografai, architektai. Natūralumas dažnai nagrinėjamas per percepcinę suvokimo prizmę (Ode, fry, 2009; Tveit, Ode, 2006; Palmer, 2004, Lamb, Purcell, 1990), remiamasi respondentų apklausų metodais, nagrinėjant skirtingos struktūrinės kompozicijos, antropogenizacijos lygmens kraštovaizdžio vaizdus. Toks percepcinis požiūris į šį klausimą remiasi subjektyvumu, nes yra priklausomas nuo tyrėjo ar respondentų nuomonės. Savo ruožtu šis darbas aktualus ir svarbus tuo, jog tai mėginimas naudojant kiekybinius rodiklius, metodus išspręsti maksimaliai objektyvaus dirbtinumo laipsnio nustatymo problemą.

Darbo tikslas ir uždaviniai.

Strateginis darbo tikslas- Sukurti metodologiją kiekybiniam kraštovaizdžio technogeniškumo laipsnio įvertinimui. Konkretus tikslas- atskleisti įkūnytos energijos, kaip kraštovaizdžio technogeniškumo indikatoriaus, erdvinės sklaidos dėsningumus.

Uždaviniai:

1. Išanalizuoti energijos kryptingai nukreiptos į technogenines aplinkos deformacijas tyrimų tendencijas;
2. suformuoti įkūnytos energijos sampratą technogeninio kraštovaizdžio tyrimų kontekste;
3. sukurti rodiklių kraštovaizdžio technogeniškumo laipsniui įvertinti per įkūnytos energijos kiekį sistemą;
4. nustatyti kraštovaizdžio technogeniškumo vertinimo rodiklių sklaidos ypatumus;
5. atlikti analizuojamų teritorijų kraštovaizdžio technogeniškumo laipsnio teritorinį rajonavimą;
6. atskleisti praktines ir teorines sukurtos metodologijos pritaikymo galimybes.

Tyrimo objektas

Iki šiol sukurtos metodikos netaikytos struktūriškai sudėtingiausiems bei technogeniškiausiems antropogeninio kraštovaizdžio tipams, tokiems kaip urbanizuotas kraštovaizdis. Be jokios abejonės, gamtinių, natūralių elementų miestų aplinkoje išlikę labai mažai, o kai kuriais atvejais neišlikę visai, tačiau atviru klausimu lieka- kokio dirbtinumo laipsnio yra žmogaus sukurti ar transformuoti kraštovaizdžio elementai, kiek giliai pakeista aplinka, kurioje mes egzistuojame, gyvename ir kokie yra dirbtinumo teritorinės sklaidos ypatumai. Taigi, disertacinio darbo tyrimo objektas plačiąja prasme šiuolaikinis kraštovaizdis apimantis įvairaus antropogenizacijos, technogenizacijos laipsnio komponentus. Siaurąja prasme, tyrimo objektas apima miestų technogeninį kraštovaizdį, technogeniškai veikiamus jo komponentus.

Mokslinis naujumas

1. Suformuota geografinė įkūnytos energijos, kaip kraštovaizdžio technogeniškumo indikatoriaus, samprata.
2. Kraštovaizdžio technogeniškumo tyrimams- morfometrinių technogeninių elementų parametrų nustatymui, pritaikyti ir panaudoti erdviniai lazerinio paviršiaus skenavimo duomenys (LIDAR).
3. Sukurta didžiųjų Lietuvos miestų pastatų erdvinių parametrų skaitmeninė duomenų bazė.
4. Suformuota kraštovaizdžio technogeniškumo laipsnio- įkūnytos energijos vertinimo metodika.

5. Sudaryti specializuoti didžiųjų Lietuvos miestų tipologiniai technogeninių komponentų morfometrinių ir medžiaginių savybių teritorinės sklaidos rajonavimai, technogeninės medžiagos, teritorinio dirbtinumo sklaidos rajonavimai ir miestų kraštovaizdžio technogeniškumo laipsnio rajonavimas.
6. Nustatyti miestų kraštovaizdžio technogeninės struktūros teritorinio pasiskirstymo dėsningumai.

Pritaikomumas

Disertaciniame darbe sudaryta metodologija, jos taikymo pavyzdžiai, turi tiek praktinio, tiek teorinio pritaikymo galimybes. Įkūnyta energija yra viena iš technogeninės kraštovaizdžio struktūros energetinės organizacijos dedamųjų ir galėtų tapti pagrindu išskiriant technoenergetinius teritorinius kompleksus (energotopus). Kraštovaizdžio technogeniškumo laipsnio objektyvus nustatymas, yra ir vienas iš žingsnių aplinkos optimalumo vertinimuose. Technourbosistemų technomedžiagos kiekybinės ir kokybinės savybės (detaliai išnagrinėtos darbe) galėtų pasitarnauti urboekosistemų metabolizmo tyrimuose. Praktinio darbo pritaikymo galimybės gludi ūkinės veiklos planavimo, krašto tvarkymo srityse.

Ginamieji teiginiai

1. Siekiant kompleksiškai įvertinti kraštovaizdžio technogeniškumo laipsnį IR atlikti įkūnytos energijos vertinimą, reikalinga daugiapakopė rodiklių sistema.
2. Įkūnytos energijos kiekis priklauso nuo medžiagos dirbtinumo ir teritorijoje sukauktos technogeninės medžiagos kiekio.
3. Didžiausias įkūnytos energijos kiekis sukauptas centrinėse, tankiausio užstatymo miestų dalyse ir stambiose technogeninės medžiagos santalkos zonose.
4. Analizuotiems miestams būdinga skirtinga, savita kraštovaizdžio technogeniškumo erdvinės struktūros sankloda.

Rezultatų aprobacija

Darbo tema paskelbti ir publikuoti 3 straipsniai, 2 mokslo žurnale „Geografijos metraštis“, vienas recenzuojamame tarptautinės konferencijos leidinyje „Теоретичні, регіональні, прикладні напрями розвитку антропогенної географії та геології : матеріали треть“.

Skaityti du pranešimai mokslinėse konferencijose: Jaunųjų mokslininkų konferencijoje „Bioateitis: gamtos ir gyvybės mokslų perspektyvos“ (Vilnius, 2011); Tarptautinėje antropogeninįs geografijos konferencijoje „Теоретичні, регіональні, прикладні напрями розвитку антропогенної географії та геології“ (Kryvij Ryg, 2011).

Darbo apimtis ir struktūra

Darbą sudarytas iš šių pagal Lietuvos mokslo tarybos nutarima Nr. VI- 4 rekomenduojamų pagrindinių dalių: įvado, tyrimų apžvalgos, metodologijos, rezultatų, išvadų, naudotos literatūros sąrašo. Darbe yra išnagrinėtas 131 literatūros šaltinis, , sudaryti 32 žemėlapiai, 75 diagramos ir paveikslėliai, 7 lentelės.

IŠVADOS

1. Energijos, tiesiogiai nukreiptos į kraštovaizdžio antropogenizaciją, tyrimų apžvalga atskleidžia augantį kraštovaizdžio dirbtinumo/ natūralumo vertinimo tyrimų aktualumą ir objektyvių vertinimo rodiklių poreikį, kuris gali būti realizuotas per kiekybinę įkūnytos energijos analizę.

2. Į kraštovaizdžio technogeniškumo tyrimus orientuota įkūnytos energijos samprata neatitinka technologijų moksluose naudojamų apibrėžimų turinio, jos pritaikymas kraštovaizdžio geografijoje reikalauja konkretizavimo, konstrukcinių medžiagų transportavimo energijos etapo eliminavimo.

3. Kraštovaizdžio technogeniškumo vertinimas apima trijų hierarchinės eilės pakopų rodiklių sistemą, kurios viršuje yra įkūnytos energijos rodiklis, susidedantis iš medžiagos dirbtinumo ir ergotechniškumo, pastarųjų vertinimui būtini objektų morfometriniai ir medžiagiškumo parametrai. Tokia rodiklių sistema gali būti taikoma ne tik urbanizuoto kraštovaizdžio, bet kraštovaizdžio apskritai technogeniškumo vertinimui.

4. Miestų teritorijų medžiagos dirbtinumo rodiklio reikšmės, visų pirma priklauso nuo technogeninės medžiagos, sukauptos teritorijoje kiekio, mažesnis svoris tenka pačios medžiagos dirbtinumo laipsniui. Maksimalios erdvinės šio rodiklio reikšmės vyrauja didžiausių technogeninės medžiagos židinių (tankaus, daugiaaukščio užstatymo) teritorijose.

5. Pagrindinis technogeninio kraštovaizdžio bruožas- maksimalios ergotechniškumo ir teritorijos medžiagos dirbtinumo rodiklių reikšmės. Tokios reikšmės būdingos itin didelį įkūnytos energijos kiekį sukaupusiems miestų technogeniškumo židiniams – istoriniams centrams ir stambiais technogeniniais objektais pasižymintiems pramonės, gamyklų kompleksams, atitinkantiems palydovinių technogeninio kraštovaizdžio tipo židinių statusą. Įkūnytos energijos kiekio židiniai tolstant nuo centro link periferijos blėsta, o jų vidutinės įkūnytos energijos reikšmės mažėja, kaip mažėja ir pačios teritorijos technogenizacijos laipsnis.

6. Kraštovaizdžio technogeniškumo rajonavimas, teritorijų dirbtinumo aspektu, leidžia palyginti tirtas teritorijas: Kaunas išsiskiria technogeninio ir technogeniško tipų teritorijų gausa, dideliu technogeninės medžiagos kiekiu, sukoncentruotu centre ir aplinkiniuose arealuose, technogeninė medžiaga pasklidusi tolygiai, tačiau jos kiekiai periferijos link palaipsniui mažėja. Vilniui būdinga didesnė technogenizacijos laipsnio tipų įvairovė, margesnė teritorinė tipų sąskaida, tiek centrinėje miesto dalyje, tiek visame mieste. Vidutinis ĮE rodiklis centrinėje dalyje ir bendrai mieste- mažiausias tarp visų miestų. Klaipėdos dirbtinumo branduolyje- senamiestyje ir dalyje uosto teritorijos, ĮE rodiklis aukščiausias lyginant miestus, visgi miesto teritorijai priklauso stambūs natūralūs ir labai silpnai technogenizuoti arealai, kas bendrame miesto ribų kontekste sušvelnina kraštovaizdžio technogenizacijos laipsnį. Šiaulių ribose technogeniškumo tipai aiškiai susidiferencijavę: pietinėje dalyje vyrauja natūralūs arba silpnai technogenizuoti arealai, miesto centre ir šiauriau-

technogeninis ir technogeniškas tipai, visgi vidutinis miesto centrinės dalies ĮE mažesnis negu Kaune ir Klaipėdoje.

7. Miestų kraštovaizdžio technogenizacijos laipsnio rajonavimas, paremtas įkūnytos energijos skaičiavimu ir iš esmės atitinkantis kraštovaizdžio energotopus sudaro prielaidas integruoto kultūrinio kraštovaizdžio rajonavimui vystyti, miestų kraštovaizdžio morfologinių tyrimų plėtrai ir subalansuotam bei tvariam miestų kraštovaizdžio planavimui, vystymui bei apsaugai.

CIRUCULUM VITAE

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2009 m.	Bendrosios geografijos ir kraštotvarkos studijų programos magistras, Vilniaus universitetas
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Moksliniai interesai Kraštovaizdžio antropogenizacija/ technogenizacija, kraštovaizdžio geografijos metodologija, GIS technologijų panaudojimas geografijoje.