VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

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MULTI-ATTRIBUTE EVALUATION AND MODELLING OF SUSTAINABLE URBAN DEVELOPMENT

Summary of Doctoral Dissertation
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Vilnius “Technika” 2004

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VILNIAUS GEDIMINO TECHNIKOS
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Introduction

Topicality of the research

Cities appeared approximately 7-9 thousand years ago, however, their rapid development started only at the end of 18th century. During several centuries the number of city population in the world has increased from 3 % up to 50 % due to various reasons. It is forecasted that in the future the process of urbanisation will not stop and in the year 2030 around 60 % of total world population will be living in cities. Cities have become the integral part of modern civilisation, forming social, economic and cultural life of people. Public welfare depends on the success of urban development.

Active production and commercial activity is found in cities, service sector is developed. Many inhabitants spend larger part of their lives in cities. Therefore, large amounts of water, fuel, food, electricity and other resources are utilized in cities. This causes overextension of natural resources and environmental pollution. On the other hand, social and economic problems, such as unemployment, criminality, resolution of population into levels, etc., are typical of cities.

A city is not a perfect derivative, because it is a result of people's creation, i.e. of urban specialists, architects and engineers, a result of intensive construction activity. Frequently due to incorrect engineering-technical solutions various problems arise, e.g. inefficiency of infrastructure, diseconomy of buildings, etc. Social-economic, environmental and engineering-technical problems are interrelated among each other, influencing each other. For instance, inappropriate formation of residential surroundings may cause asocial behaviour of inhabitants, criminality. Poor organisation of transport may determine accident rate, large time loss while travelling.

Analysis, planning and management of urban development is a complicated, complex, multi-aspect objective, which could be solved using modern scientific knowledge, technology and experience only. Meeting today challenges, adequate decisions must be taken, appropriate politics undertaken, various programs implemented. For this reason, comprehensive, objective information is required, prognoses must be structured, various decision variants must be analysed and discussed. All interested groups, seeking compromise among business, population and nature interests, must participate in decision-making process, important for the city. Sustainable development attitude, which appeared several decades ago, allows a complex evaluation and solution of urban social, economic and environmental problems. However, in this attitude engineering-technical component is not stressed. Deep, overall attitude to the city, as a complex, multi-criteria system is lacking. Modern informational technologies are insufficiently used. Therefore sustainable urban development must be not only the object of social, natural, but also of engineering sciences.

Research object – a city as a complex engineering, social, economic and ecologic system; identification of construction impact to all the components; search of balance among them.

Aim and objectives of the research

The main aim of the dissertation is to structure a theoretical model, allowing the evaluation of urban sustainability and urban development in the future with the help of multi-attribute decision making methods. This model would allow the consumers to perform analysis of urban engineering-technical, social, economic and natural surroundings' status, as well as possibility to compare cities among each other and prepare different alternatives of future urban development, compare the alternatives and select the best one.

The following factors must be taken into account while reaching the aim:

- Tendencies of modern cities' development discovered.
- The main problems of cities determined.
- Assumptions discussed and their application examples of sustainable urban development.
- Indicators and their systems characterising urban sustainability analysed;
- Multi-attribute methods, their application possibilities examined, the most suitable selected.
- Relation among construction and the processes of sustainable urban development determined.
- New sustainability component, characterising artificial urban surroundings formulated.
- Construction influence for the components of urban sustainability determined.
- Indicators, characterising results of urban construction process listed;
- Theoretical model of evaluation of urban sustainability and development planning created, described and tested.
- Analysis and planning automatisation tools of sustainable urban development existing in the world examined.

- Internet system of multi-attribute decision support of sustainable urban development created.

Methods of research

All official material of international organisations, up-to-date material in scientific data basis, information provided by Lithuanian institutions and other material on the internet are examined by the analysis method. Multi-attribute methods are compared and the most suitable selected applying comparative analysis. Values of alternative indicators are determined by statistical and analogy methods, and weights of indicators – by expert methods.

Scientific novelty of the research work

1. Idea of sustainable urban development complemented with the engineering-technical aspect.
2. Multi-attribute methods applied for the evaluation and modelling of urban sustainability.
3. Modelling of sustainable urban development divided into levels.
4. Up-to-date information technologies applied for the evaluation of urban engineering-technical, social, economic and environmental components.

Theoretical and practical results of the work

1. Conceptual system of indicators of urban sustainability suggested reflects interests of all interested groups, evaluates construction activity influence for urban sustainability.
2. Theoretical model for the evaluation of urban sustainability and modelling of sustainable development created, which allows determination of the balance of existing urban physical, social and economical surroundings; future urban development alternatives created and the most suitable selected.
3. Having applied the created model, sustainability of a particular city evaluated, alternatives of future development created and evaluated.
4. Original internet decision support system for the modelling of a sustainable city created.
5. The dissertation results, conclusions and suggestions are useful while solving development problems of Lithuanian cities, creating their visions, strategic plans or performing physical urban planning.

Approval of the research work and practical application of the results

1. The main propositions discussed in the dissertation have been presented and discussed in international and republican conferences in Lithuania, Poland, USA, and the Netherlands. The material presented in the dissertation is also published in thirteen editions of scientific articles and conferences.
2. Material accumulated in the dissertation has been applied while participating in the international Framework 6 project „Intelligent cities“.
3. Based on some material presented in the dissertation, master thesis are prepared.

Volume and structure of the research

The dissertation is comprised of introduction, four chapters, conclusions, suggestions, a list of literature sources and annexes. Volume of the dissertation – 143 pages.

The dissertation structure is provided in Figure 1.

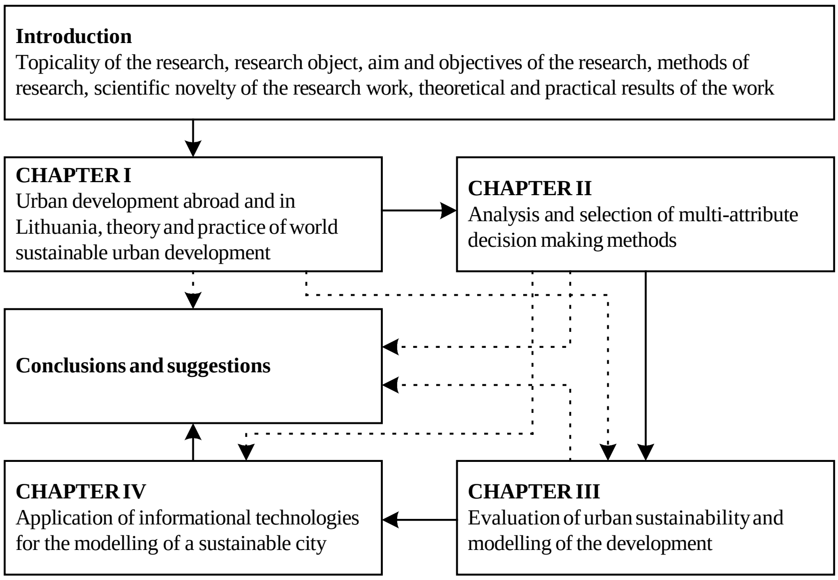


Fig 1. Dissertation structure

Up-to-date demographic and urban development tendencies are examined in the first chapter, world sustainable urban development theory and practice is analysed, urban sustainability indicators and their systems are also examined. Planning methods of sustainable urban development are overviewed.

Up-to-date multi-attribute decision making methods, ways of values of indicators and ways of weights determination are analysed in the second chapter.

Conception of sustainable urban development is suggested in the third chapter, original system of social, economic, environmental and engineering-technical indicators structured. Evaluation and planning model of sustainable urban development structured. External and internal sustainability of Vilnius city evaluated, three Vilnius future development scenarios structured and compared.

Automatisation tools of sustainable urban development surveyed in the fourth chapter, important international projects and the systems created during their implementation are examined, demonstration internet support system of decisions of sustainable urban development created.

At the end of the dissertation conclusions and suggestions are presented.

CHAPTER I. Urban Development Abroad and in Lithuania, Theory and Practice of World Sustainable Urban Development

A city is a complicated physical and social phenomenon, which constantly changes and evolves. Changes taking place in the city are quantitative and qualitative, having features of spontaneous, planning and controlled process.

One of the most characteristic processes – demographic changes and urbanisation. Their up-to-date analysis shows, that in the future number of urban population will increase in all continents of the world, and urban influence for the world economy and population life will increase. It is likely that a relative number of population in Lithuanian cities will also increase.

Obvious effects of urban development are as follows: transport jams, intense air pollution and accident rate, criminality, unemployment, unsuitable living conditions, inadequate provision with the housing area and services (water, garbage sanitation, transport, etc.), increase in land and construction prices. It is noticed that a lot of cities face geological problems: pollution of underground water, surface sedimentation due to the exploitation of underground water, erosion of riverbanks, etc. Undoubtful result of urbanisation – physical and social problems.

Principles of sustainable development are applied to solve or prevent the above mentioned urban problems, characterised by the following features: meeting of today's needs, without violation of ability to meet their own needs of future generations; improvement of quality of population life, concerning the protection of surrounding eco-system; security of environmental, economic and social welfare without danger to the systems, which provide that welfare; stimulation and guarantee of economic and social progress of mankind, so that this progress is followed by the advancement of other fields. In summary it could be stated, that a long-term welfare of urban citizens essentially depends on the fact, that sustainability (balance) among urban social, economic and environmental fields will be reached, and a sustainable city is only when its harmony of development is guaranteed, and influence for natural surroundings is as lesser as possible.

Urban sustainability is expressed by the system of indicators. As a survey of foreign and other information sources shows, grouping of sustainability indicators is very different. Selection of indicators system for a particular city depends on many factors, for example, from the size of a city and meaning on world or country dimension, quantity and quality of information in disposition.

Mathematic methods, determining the best variant are necessary to find the balance of social, economic and other components meeting the needs of all interested groups. Social, economic and physical status could be qualitatively and quantitatively evaluated by indexes. All urban surroundings are formally described by them. Detailed, objective system of indicators is required.

Researches performed presume to state, that modelling of a sustainable city is comprised of two components: analysis of the present situation and planning of the future development. For this reason, complex model is necessary, according to which, with the help of informational technologies, urban development analysis and sustainable development planning could be performed in the future.

CHAPTER II. Analysis and Selection of Multi-Attribute Decision Making Methods

Sustainability of urban surroundings is on the surface an impossible thing, because aims, contradicting each other are pursued. For example, maximum economic growth and prosperity, and at the same time very qualitative, healthy environment is pursued. In reality some balance between intensity of economic activity and pollution level is reached. On the other hand, no aim can be reached one hundred percent.

For the evaluation of a balance among urban physical, social and economic components, it is practical to apply multi-criteria methods, because they provide a one number answer. The larger the number, the larger the level of urban development, and the more satisfied are the needs of interested groups. Multi-criteria decision making methods are divided into two groups: multi-objective, when vectorial maximum problems are discussed; multi-attribute, when separate decisions are searched. Mathematic expression of multi-objective methods is complicated; they are hardly applied in practice. For this reason, only multi-attribute decision making methods are analysed and applied here.

There are a lot of multi-attribute methods in the world, but it is not easy to select the most suitable for the solution of a certain problem. Application possibilities of multi-attribute methods for a certain case are analysed according to the following features: number of tasks solved according to this method; the largest possible number of evaluated alternatives; the largest possible number of indicators; level of information on opinion of specialists, making decision, which will be important while applying this method; possibility of analysis of reliability of results worked out; time, devoted to train a worker to use the method, who has no knowledge on the method; time of a worker, necessary to perform a multi-attribute evaluation; means, necessary to solve a multi-attribute task by a certain method. In the author's opinion, besides the mentioned features, understanding of the method is very important. It could be easy, medium or complicated.

For the comparison of the methods simplified task of sustainable urban development is structured and two decision-making matrices are formulated. The first matrix is comprised of ten alternatives and five indices, the second one – from five alternatives and five indices.

Whereas indices with certain numbering meanings are used, the following multi-attribute methods are preliminary selected: simple additive weighting (SAW), multi-criteria decision making tool MCDM-23, analytic hierarchy process (AHP), ELECTRE III, TOPSIS and multiple criteria complex proportional evaluation method (MCCPEM).

Comparative analysis of multi-attribute methods is summarised in Table 1. Although calculation results of many mentioned methods are variable, all, except TOPSIS, have selected priority for the same alternative.

Table 1. Comparison of Multi-attribute Decision Making Methods

Method	Evaluation criteria			
	Consistency of results	Labour expenditures, necessary for the task solution manually*	Ease of understanding	Other features
SAW	Constant	Little	Easy	
MCDM-23	Constant	Little	Easy	Forms an ideal alternative
AHP	Variable	Little	Easy	
ELECTRE III	Variable	Large	Complicated	Takes into account variations of indices values
TOPSIS	Variable	Little	Easy	
MCCPEM	Variable	Little	Easy	

*This criteria is not important when multi-attribute evaluation is being performed entirely by computer.

Based on the comparative analysis of the methods and having examined their other specific features, a method of simple additive weighting is suggested for the evaluation of urban sustainability, MCDM-23, analytic hierarchy process, ELECTRE III and multiple criteria complex proportional evaluation method.

Very often urban environments is being described qualitatively. Then verbal decision making methods such as ZAPROS, ORCLASS, PARK, CLARA and CYCLE could be applied.

The main determination methods of indicators values and weights are examined. It is decided that quantitative indicators meanings are best determined based on statistic data and calculations, while qualitative indices – on the opinion polls.

For the determination of weights of quantitative and qualitative indices it is suggested to select expert ranking method. It is an easy method, objective and requires little labour expenditure.

CHAPTER III. Evaluation of Urban Sustainability and Modelling of the Development

Two main things are necessary for the modelling of sustainable urban development: an indicators system and one or several multi-attribute decision-making methods. An indicators system must have an overall description of urban social, economic and physical (natural and urban) surroundings. It seems that a large number of indices is necessary. However, two basic problems are faced in this situation. First of all, when there are many indices, a lot of time is devoted for the determination of their meanings, some indicators meanings could be impossible to determine. Secondly, when there are a large number of indices, for the experts it becomes difficult to determine their weights, moreover, probability appears, that meaningless indices, having no influence for the calculations appear. It becomes obvious, that the system, comprised of limited simple and complex indicators combination is necessary.

A survey of scientific literature shows, that evaluating urban sustainability the meaning of artificial, man-made created surroundings is not stressed. In a classical conception of sustainable city development buildings, transport and engineering infrastructure is characterised by the summarised component of surroundings. The latter includes natural and urbanised surroundings.

A modern competitive city is inconceivable without application of modern technologies, convenient and quick public transport, quality housing and living surroundings, as well as developed trading, service, social and other infrastructure. Therefore the author suggests complementing conception of sustainable city (see Figure 2).

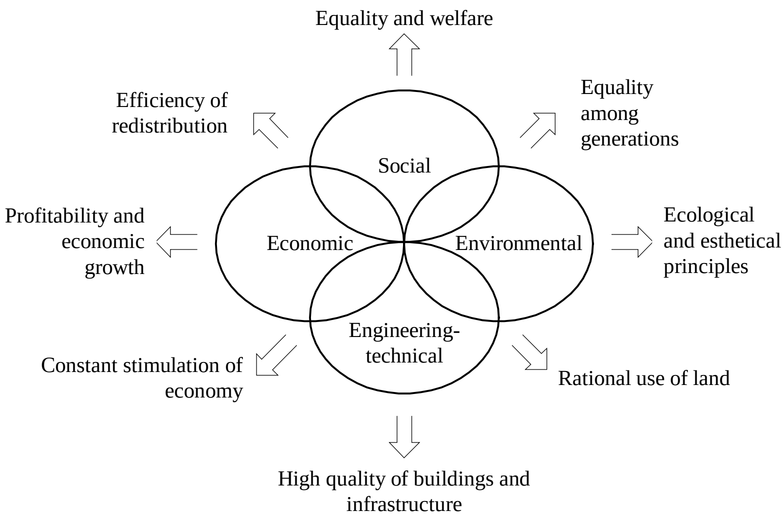


Fig 2. Conception (with principles) of Sustainable City Suggested by the Author

The fourth, engineering-technical component characterise only urbanised surroundings, i.e. buildings and their surroundings, transport and engineering infrastructure According to the suggested conception, environmental component would characterise only natural surroundings and ecological situation in the city.

Explanation of principles of the suggested conception of a sustainable city:

Equality and welfare. Equal possibilities of male and female are guaranteed; there are no people, living below the poverty line; health care, education, social security and law systems are well functioning.

Equality among generations. Resources (renewable and stable) are managed in the way that not only today but also future generations' needs would be satisfied.

Ecological and esthetical principles. Attractive, esthetical surroundings are formed; little environment pollution technologies are used; waste recycled, utilised; wastewater managed.

Rational use of land. Physical urban development is performed in three ways: new territories are built-up, densing of built-up of urbanised territories and renovation of built-up territories. Efforts are put that less expenditure would be used for the installation of engineering communications.

High quality of buildings and infrastructure. Buildings, constructions and infrastructure are properly operated, if necessary, renovated; degree of infrastructure development is such that fully satisfies the needs of population and business.

Constant stimulation of economy. Infrastructure is developed in the way, that it could satisfy certain economic activities.

Profitability and economic growth. High profitability of business enterprises; productive production activity; efficient service sector; large investments; application of high technologies.

Efficiency of redistribution. Social means are redistributed in the way, that they could guarantee subsistence of the people, unable to take care of themselves, however able-bodied people are motivated to work.

A construction place in the process of a sustainable city development is very important. All buildings and infrastructure are consequences of construction activity. Moreover, all ways of construction activity support the status of urbanised surrounding of a city, renovate it and finally develop. Therefore, construction has direct relation to the engineering-technical component. What is more, construction indirectly influences social, economic and environmental components of the city.

The author suggests to divide the construction activity in the city into three groups: 1) new construction; 2) renovation of buildings and surroundings; 3) renovation and development of communication and engineering infrastructure.

Variety of construction activity in a city shows, that construction is a mean for the increase of level of urban sustainability (see Figure 3).

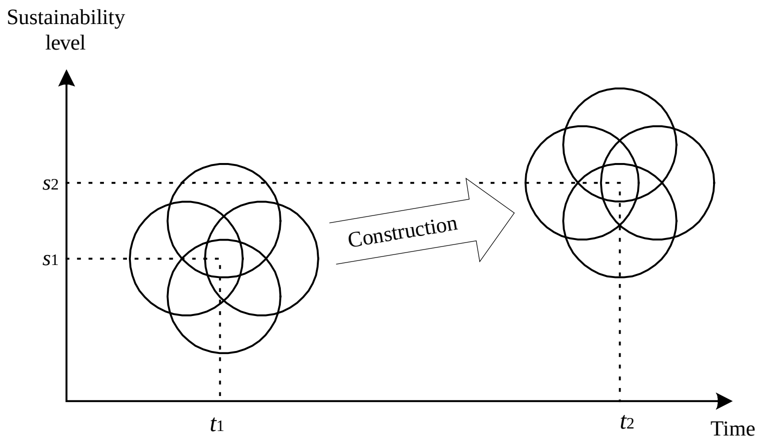


Fig 3. Alteration of Urban Sustainability Level Due to the Construction Activity

However, in some cases construction may cause negative results for a city, disturb sustainability. For example, unduly planned increase of built-up areas destroys parks, public areas, recreational zones, etc. Construction of large supermarkets in a city centre forms intense traffic flows, increases air pollution and noise. Concentration of objects of uniform service increases unhealthy competition, supersedes small and medium sized enterprises from the market. Consequently, construction may increase urban sustainability, as well as decrease. It depends on the fact, that this activity is developed in a right way.

The author suggests the grouping of indices of urban sustainability into four groups. The third group of social, economic and environmental indices represents the classical approach of sustainable development. Their interpretation, meaning to urban sustainability is discussed in detail. The fourth group of engineering-technical indices characterises “technical” side of sustainable city: engineering infrastructure (quality, efficiency, development degree, etc.), constructions and buildings of different purposes (wellness, economy, influence to the environment, aesthetics, etc.), decisions of physical territorial planning.

It is determined, that urban sustainability to a great extent depends on its qualities of physical surroundings, and therefore it is suggested to complement conception of sustainable urban development with engineering-technical aspect, which reflects unnatural, technical nature of a city.

It must be emphasized, that the suggested list of indices of urban sustainability is not complete. Every year hundreds of new indices are created in the world. Only several from the list are accepted to be suitable for use. There are also no recommendations how many indices must characterise a city. Regarding the consumers of the evaluation results, number of indices may range from 10 to 100. 60 indices have been suggested. It is not recommended to use all indices in order to characterise urban sustainability, the best way is to choose those, best meeting the evaluator’s priorities, specific qualities of a city, amount and character of information disposed. For example, if questions of international competition of a city are stressed, it is suitable to choose more economic indices (less indices of other groups); if pollution problems are urgent in a city, it is necessary to include more environmental indices.

Modelling methodology of sustainable city applied requires that all indices characterising a city should be minimised or maximised. This procedure with some indices is not complicated. For example, “number of criminal cases performed” or “number of the unemployed” must be as less as possible (or equal zero), therefore they could be implicitly minimised. And on the contrary, indicator “number of houses with electricity, water supply and sewerage networks” is maximised. Problems appear with the indices, such as “greenery area” or “number of buildings in reconstruction”. In this case present situation in the city discussed must be examined, as well as the best prevailing practice in the cities of the most advanced countries. If “greenery area” in the cities of the most advanced countries is larger than that of the city discussed, consequently, this indicator must be maximised. If quality of the buildings in the city discussed is poorer than that of advanced cities, this indicator is also maximised. Model of three levels is created for the evaluation of urban sustainability and planning of sustainable development (see Figure 4).

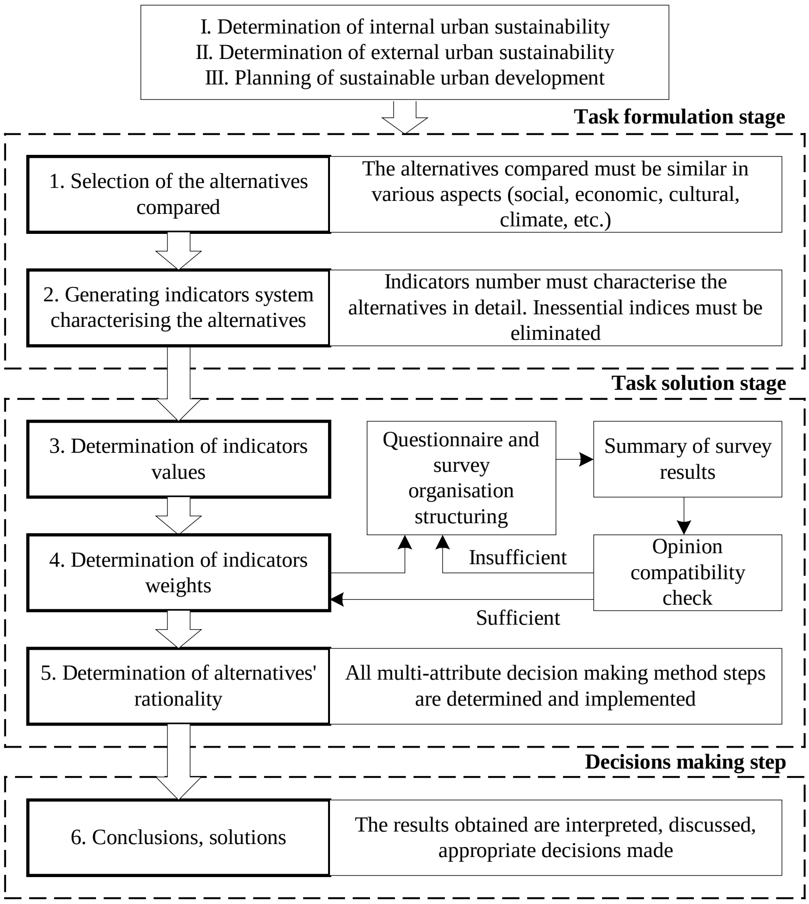


Fig 4. Model Structure of the Suggested Evaluation of Urban Sustainability and Planning of Sustainable Development

Separate levels allow the division of the total system of indices into three separate indicators groups, which characterise certain number of problems. For example, in the first level engineering-technical and environmental problems could be stressed, in the second – social and economic. Division of indicators system into groups is useful in the way, that while determining their weights, it is easier for the experts to evaluate a smaller number of indices, and weights are not so widely spread. One more important aspect – the information disposed. Certain specific information could be typical of each level; therefore it is rational to combine indicators system according to the information already obtained.

The first two levels are devoted to complex and detailed analysis of a present urban social, economy, natural surroundings, and engineering-technical status.

In the first level "Determination of internal urban sustainability" relative sustainability of certain compared districts or administrative units, for example, neighbourhoods, of the city discussed is evaluated. It is very important to choose comparative alternatives at this point. Suppose, it would be incorrect to compare industrial district with the residential or the one, situated in the central part of the city with the peripheral.

In the second level "Determination of internal urban sustainability" total relative sustainability level of the city discussed is evaluated. For this reason comparison of the city discussed is performed in comparison with other cities. At this stage it is also important to correctly select the cities compared. It would be incorrect to compare the capital with a common regional town, where most of its citizens are unemployed and live from social allowances. The best situation is when the compared cities are similar in many ways: number of population, their importance, social, cultural, economy, environmental and other ways.

In the third level "Planning of the future of sustainable city development" selection of different future development projections of the city discussed is performed, determining, which future status meets principles of sustainable development to the greatest extent. For the formal description of the future, in the author's opinion, *integrated* scenarios are the most suitable, which mathematically in detail describe peculiarities of urban development in the future. Each level of the model (I, II and III) consists of six steps (see Figure 4).

Applying the created model levels of Vilnius external and internal sustainability are evaluated. For the determination of internal sustainability ten neighbourhoods of the city are compared: Fabijoniškės, Justiniškės, Karoliniškės, Lazdynai, Pašilaičiai, Pilaitė, Šeškinė, Verkiai, Viršuliškės and Žirmūnai. Taking into consideration various indicators such as technical condition of buildings and infrastructure, it has been discovered, that Pilaitė is developing in the most sustainable way. Having compared Vilnius, Kaunas and Klaipėda city indices (most of them are results of construction activity), Vilnius external sustainability has been evaluated and it has been determined, that Vilnius is characteristic of the highest level of sustainability. According to social, economic and environmental indices sustainability of three Vilnius future development scenarios has been evaluated. The best one accepted is "Scenario, oriented to the society".

CHAPTER IV. Application of Informational Technologies for the Modelling of a Sustainable City

Informational technologies are the unit of organisational and technological tools, allowing gathering, save, analyse, reform, describe and send various data.

Evaluation of urban sustainability and foreknowledge and planning of future development consists of two main steps: information gathering and multi-attribute evaluation. For the first step detailed and various information is necessary, it must be suitably processed and classified, because sustainable city is characterised by complicated system of indices. For the performance of multi-attribute evaluation (the second step) a lot of decision-making methods are used, where their mathematical expression is quite complicated.

Manual modelling of sustainable city is a process, requiring a lot of input. Application of informational technologies allows to perform typical, many times repeated operations in an automate way, preventing the planners from expensive mechanical, slow and monotonous work.

The planners of the development of a sustainable city may use calculators, analysers, special programming equipment, neuron networks, expert and decision support systems, etc. It must be stressed, that classification of the mentioned tools is quite relative.

A lot of popular urban development modelling, decision-making support and other urgent problems for the urban society are widely used in the world.

Having examined the tools of sustainable urban planning, the conclusion has been deducted, that the system of sustainable urban development decision making is necessary, typical of the following qualities: having access to internet (non-user of resources of computer consumers); evaluating urban social, economy, environmental and engineering-technical factors in a complex way; available (because free of charge) and devoted to wide-ranging levels of consumers (scientists, politicians, ordinary citizens, etc.); undemanding special skills and experience.

Based on the presented requirements, the author suggests the following structure (see Fig 5) of internet decision support system being created.

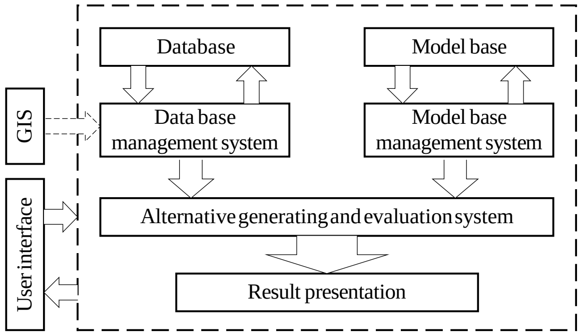


Fig 5. Structure of Decision Support System

Database consists of two modules: indices and scenarios. Detailed list of sustainability indices is presented in indicator module, description and dimension, suggestions for their minimisation or maximisation of each indicator are provided. Indices in this module are grouped alphabetically and according to type (social, economical, etc.). Two standard urban development scenarios and their descriptions are presented in the scenario module.

Data base management system allows the consumer to choose indices determined by the consumer for the characterisation of the alternatives from the list of indices. Moreover, the consumer may complement the list of indices by the new ones. The consumer may also include his/her own created scenarios in the scenario module.

Model base, in the same way as a database is composed of two modules: determination of weights and multi-attribute decision-making methods. Three evaluation ways of weights are foreseen: indicators pair comparison, ranking and including the meaning selected by the consumer. Applying the first two methods, it is necessary to perform expert questionnaire survey. Five decision making methods are foreseen in the module of multi-attribute methods: method of simple additive weighting, MCDM-23, analytic hierarchy process, ELECTRE III and multiple criteria complex proportional evaluation method.

Model base management system allows the consumer to choose any method from weights determination and multi-attribute evaluation methods. Possibility to complement model basis with new methods is foreseen.

Alternative generating and evaluation system. With the help of dialog windows formulated alternatives and indicators system describing them with certain weights and values are entered and presented in a table manner.

Having formed the alternatives, automatically result table is created, which reflects priority of each alternative.

GIS. In the future it is planned to integrate geographical information system (GIS) into the created DSS structure, with the help of which meanings of many indices may be determined.

DSS consumers. Team of future consumers is very large and includes all interested groups. They are urban planners, scientists, politicians and ordinary citizens.

DSS evaluation degree. With the help of created DSS it will be possible to evaluate sustainability in different degrees: living surroundings, city administrative unit, city or even region.

DSS time scale. With the help of DSS it will be possible to evaluate present situation, as well as model future alternatives.

DSS flexibility. Consumers will be able to form individual indicators systems according to their own interests.

Number of DSS alternatives being examined. Depends on the ability of consumers to generate alternatives.

The DSS being created, without the listed advantages will be distinguished by simplicity and will be completely free of charge.

According to the structure of decision support system the author created internet demonstrational version of multi-attribute decision support of sustainable city development.

Demonstrational version of the system launched as follows. With the help of the address *http://dss.vtu.lt* electronic business system is searched. By the click on the icon, symbolising the flag of the UK, English version of "Decision Support System for Innovation" is chosen. Further an icon on the left of the website is clicked with the title "Sustainable Development".

Work with the system is performed in the following sequence:

1st step. The task is written and the left mouse key is clicked on the task title (Fig 6);

Fig 6. The 1st step (comment: task title "Integrated assessment for sustainability appraisal in cities and regions")

2nd and 3rd steps. In the window opened urban development scenarios are described with the help of the keyboard; The left mouse key is further clicked on the title „Expert and Quantitative Description of Alternatives“ (Fig 7);

*4th and 5th step*s. With the help of the keyboard indicators titles, their measure units are entered in the opened window, it is stated, whether they are maximised or minimised, indicators weights and indicators values according to all scenarios; The left mouse key is clicked on the title „Results of Multiple Criteria Evaluation“ (Fig 8);

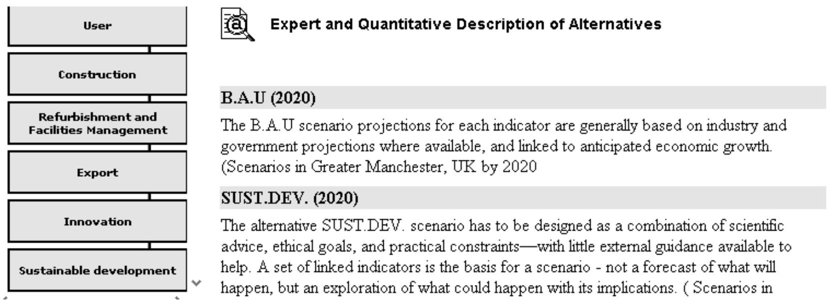
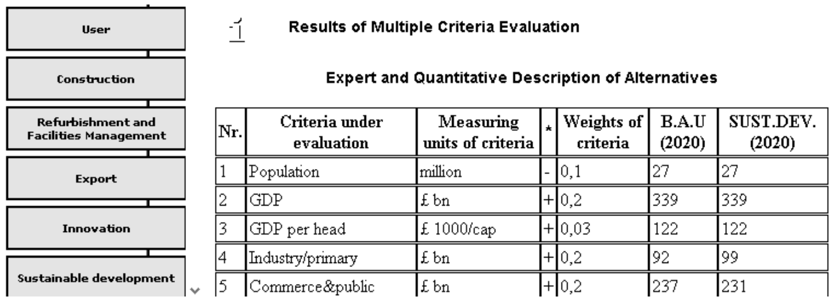


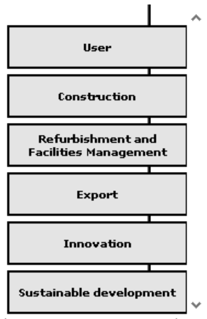
Fig 7. The 2nd and the 3rd steps



Nr.	Criteria under evaluation	Measuring units of criteria	*	Weights of criteria	B.A.U (2020)	SUST.DEV. (2020)
1	Population	million	-	0,1	27	27
2	GDP	£ bn	+	0,2	339	339
3	GDP per head	£ 1000/cap	+	0,03	122	122
4	Industry/primary	£ bn	+	0,2	92	99
5	Commerce&public	£ bn	+	0,2	237	231

Fig 8. 4th and 5th steps

6th step. The window is opened, where evaluation results are presented in a table manner. The most important index for the consumer is „Usefulness degree“, presented in the last row of the table. Larger index meaning shows, that solution is better (Fig 9).



Total air pass. travel	Mkm/y	-	0,1	0,06	0,04
Total freight traffic	Mkm/y	-	0,15	0,0932	0,0568
Total final energy demand	PJ/y	-	0,15	0,1042	0,0458
Total CO2 from transport inc. power	Mt CO2/y	-	0,2	0,1376	0,0624
The sums of weighted normalized maximizing indices of variant S_{+j}				0,4252	0,7048
The sums of weighted normalized minimizing indices of variant S_{-j}				1,5195	1,0805
Significance of variant Q_j				1,5057	2,2243
Usefulness degree N_j				67,69%	100%

Fig 9. 6th step (comment: ending of results table is shown)

Conclusions and suggestions

1. It is stated, that urban sustainability to a great extent depends on the qualities of its urbanised surroundings, therefore it is suggested to complement a classical concept of sustainable urban development with the engineering-technical aspect. It is identified, that construction has a direct influence for this aspect. Besides, construction influences on social and economic components of sustainable city.
2. The analysis of literature makes a suggestion, that urban sustainability is balance changeable in time and particular for each city. Modelling of a sustainable city comprises of two parts: analysis of the present situation and planning of the future development. A complex model is required for this reason, formally characterising social, economic and natural urban surroundings, and results of urban construction process.
3. It is proved that modelling of sustainable urban development requires the use of multi-attribute methods, evaluating many factors and determining the best compromise variant. They provide a one number answer, consequently it is possible to compare various alternatives.
4. After examination of six multi-attribute methods, it has been stated, that the following methods are the most suitable for the solution for the tasks being examined: method of simple additive weighting, MCDM-23, analytic hierarchy process, ELECTRE III and multi criteria complex proportional evaluation method. The mentioned methods have their

specific advantages and disadvantages, which must be evaluated while interpreting the results.

5. For the evaluation of urban sustainability the following number and combination of indices must be selected, which to the best reflects the interests of interested groups (businessmen, citizens, environmental specialists). The suggested conceptual system of urban sustainability indices is comprised of four main groups: engineering-technical, social, economic and environmental.
6. The three-dimensional model of the evaluation of urban sustainability and planning of sustainable development is created. It can evaluate internal (comparing different neighbourhoods) and external (comparing different cities) sustainability. The creation of urban future scenarios and their comparison included in the model allows actively plan urban sustainability in the future.
7. Having applied the created model, three practical tasks are solved. In the first ten neighbourhoods of the city are compared and it has been discovered, that Pilaitė is developing in the most sustainable way. In the second Vilnius, Kaunas and Klaipėda city indices are evaluated and it has been determined, that Vilnius has the highest level of sustainability. In the third according to social, economic and environmental indices sustainability of three Vilnius future development scenarios has been evaluated. The best one accepted is “Scenario, oriented to the society”.
8. It is stated, that final results of urban sustainability evaluation is variable and depend on five key factors: a) correctness of comparative alternatives selection or formation; b) particularity of indicators system; c) accuracy of indicators values; d) correctness of assumptions applied; e) objectivity of weights determination. Due to these factors it is difficult to obtain objective solutions from the first time. Only calculation with the approximation method will guarantee satisfaction of needs of all interested groups.
9. It is examined, that many tools of urban analysis and automatisation of sustainable development planning solve limited circle of problems; their data basis are related to a certain country; they require special knowledge and skills; they are heavily available for many consumers. Therefore original internet structure of sustainable urban development decision support system is suggested.
10. According to the created structure of the decision support system it is possible to create simple, secure, available and flexible internet system of decision. Due to the system it will be possible not only in a complex

way, but also separately examine all the components of urban sustainability. Therefore a team of potential consumers is very large - ranging from scientists to ordinary citizens.

11. Internet system of the decision support creates large possibilities for the interested groups to evaluate social, ecological and engineering-technical urban situation, as well as in the processes of visionisation, strategic and physical planning, urban construction and renovation.
12. A demonstrational version of a multi-attribute system of sustainable urban development, in which appraisal of two urban future scenarios are demonstrated (searching for a better) in a complex proportional evaluation method, is created and placed on the internet.

THE LIST OF SCIENTIFIC PUBLICATIONS REGARDING DOCTORAL THESIS

MOKSLINIŲ PUBLIKACIJŲ DISERTACIJOS TEMA SĄRAŠAS

In the publications reviewed:

1. Šaparauskas J. Development evaluation of Vilnius, Riga and Tallinn from sustainable point of view. In: Proceedings of 8th International conference “Modern buildings, structures and technologies”, held in Vilnius, May 19-21, 2004, p. 129–130.
2. Šaparauskas J. Evaluation and comparison of alternative building design schemes by using the Internet’s potentialities. In: Proceedings of International conference “Modelling and Simulation of Business Systems”. Edited by H. Pranevičius, E. K. Zavadskas, B. Rapp. Vilnius: Technika, 2003, p. 319–321 (in **ISI** Proceedings data base).
3. Šaparauskas J. Multiple criteria evaluation of buildings with emphasis on sustainability. *Journal of Civil Engineering and Management*, Vol IX, No 4. Vilnius: Technika, 2003, p. 234–240.
4. Šaparauskas J. The idea and approach of sustainable construction and environment development in various countries. *Technological and Economic Development of Economy*, Vol VII, No 1. Vilnius: Technika, 2001, p. 20–23 (in Lithuanian).
5. Šaparauskas J. Development and multiple criteria evaluation of Vilnius city future scenarios. *Technological and Economic Development of Economy*, Vol IX, No 3. Vilnius: Technika, 2003, p. 123–128 (in Lithuanian).
6. Zavadskas E. K., Kaklauskas A., Šaparauskas J., Raslanas S., Gikys M. Web-based multiple criteria analysis of sustainable urban development

problems. In: Proceedings of Third International Conference on Information Systems in Engineering and Construction (ISEC 2003), held in Cocoa Beach, Florida, June 12-13, 2003 (in compact disc).

7. Zavadskas E. K., Kaklauskas A., Vainiūnas P., J. Šaparauskas, Raslanas S., Gikys M. A multiple criteria decision support web-based system for sustainable urban development. In: Proceedings of 20th International Symposium on Automation and Robotics in Construction, held in Eidhoven, September 21-24, 2003, p. 295–300.

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1. Kaklauskas A., Zavadskas E. K., Vainiūnas P., Šaparauskas J., Gikys M. Web-based decision support in sustainable urban development. In: Abstracts of papers of the International Conference on Sustainability Indicators and Intelligent Decisions (SIID-2003), held in Vilnius, October 9-11, 2003, p. 51–52.
2. Šaparauskas J. Aspects of creation building information system. In: Proceedings of 4th Conference of Lithuanian Young Scientists "Lithuania without science – Lithuania without future" (Civil Engineering), held in Vilnius, March 30, 2001, p. 136–143 (in Lithuanian).
3. Šaparauskas J. Sustainable construction problems. In: Proceedings of 5th Conference of Lithuanian Young Scientists "Lithuania without science – Lithuania without future" (Civil Engineering), held in Vilnius, March 27-29, 2002, p. 19–24 (in Lithuanian).
4. Šaparauskas J., Ramanauskaitė J. Evaluation and comparison of alternative building design schemes by using internet's potentialities. In: Proceedings of 6th Conference of Lithuanian Young Scientists "Lithuania without science – Lithuania without future" (Civil Engineering), held in Vilnius, March 27-28, 2003, p. 70–75 (in Lithuanian).
5. Zavadskas E. K., Kaklauskas A., Šaparauskas J. Sustainable urban development and web-based multiple criteria analysis. In: Abstracts of 9th German-Lithuanian-Polish Colloquium "Planning Instruments in Construction Management", held in Kolobrzeg, May 28-31, 2003, p. 16–17.
6. Zavadskas E. K., Kaklauskas A., Vainiūnas P., Šaparauskas J. Modelling and forecasting of sustainable urban development. In: Abstracts of papers of the International Conference on Sustainability Indicators and Intelligent Decisions (SIID-2003), held in Vilnius, October 9-11, 2003, p. 54–55.

DARNAUS MIESTO VYSTYMO(-SI) DAUGIATIKSLĖ SELEKTONOVACIJA

Santrauka

Darbo aktualumas. Miestai atsirado maždaug prieš 7–9 tūkstančius metų, tačiau sparti jų plėtra prasidėjo tik XVIII a. pabaigoje. Dėl įvairių priežasčių per kelis šimtmečius miesto gyventojų skaičius pasaulyje nuo 3 proc. išaugo iki 50 proc. Prognozuojama, kad ateityje urbanizacijos procesas nesustos ir 2030 m. miestuose gyvens maždaug 60 proc. visų pasaulio gyventojų. Miestai tapo neatskiriama šiuolaikinės civilizacijos dalimi, jie formuoja žmonių socialinį, ekonominį ir kultūrinį gyvenimą. Nuo miestų vystymosi sėkmės priklauso visuomenės gerovė.

Miestuose vyksta aktyvi gamybinė ir komercinė veikla, išplėtotas paslaugų sektorius. Daugelis gyventojų miestuose praleidžia didžiąją savo gyvenimo dalį. Todėl miestuose sunaudojami didžiuliai kiekiai vandens, kuro, maisto, elektros ir kitų išteklių. Tai sukelia gamtos išteklių pereikvojimą ir aplinkos taršą. Kita vertus, miestams būdingos tokios socialinės ir ekonominės problemos, kaip nedarbas, nusikalstamumas, gyventojų susiskirstymas į sluoksnius ir pan.

Miestas nėra tobulas darinys, nes tai žmonių, t. y. urbanistų, architektų ir inžinierių, kūrybos rezultatas, intensyvios statybos veiklos padarinys. Dažnai dėl neteisingų inžinerinių-techninių sprendimų iškyla įvairių problemų, kaip antai: infrastruktūros neefektyvumas, pastatų neekonomiškumas ir kt. Socialinės-ekonominės, aplinkos ir inžinerinės-techninės problemos yra tarpusavyje susijusios, darančios įtaką viena kitai. Pavyzdžiui, netinkamas gyvenamosios aplinkos formavimas gali sukelti gyventojų asocialų elgesį, nusikalstamumą. Prastas transporto organizavimas gali lemti didelį avaringumą, didžiulius laiko nuostolius keliaujant.

Miestų vystymosi analizė, planavimas ir valdymas yra sudėtingas, kompleksinis, daugiaaspektis uždavinys, kurį galima išspręsti tik panaudojus šiuolaikines mokslo žinias, technologijas bei patirtį. Priimant nūdienos iššūkius, turi būti priimami adekvatūs sprendimai, vykdoma atitinkama politika, įgyvendinamos įvairios programos. Tam reikia išsamios, objektyvios informacijos, turi būti sudaromos prognozės, nagrinėjami, diskutuojami įvairūs sprendimų variantai. Priimant miestui svarbius sprendimus turi dalyvauti visos suinteresuotos grupės, siekiančios kompromiso tarp verslo, gyventojų ir gamtos interesų. Prieš keletą dešimtmečių atsiradęs darnaus vystymosi požiūris leidžia kompleksiškai įvertinti ir spręsti miesto socialines,

ekonomines ir aplinkos problemas. Tačiau tame požiūryje neakcentuojamas svarbus inžinerinis-techninis dėmuo. Trūksta gilaus, visaapimančio požiūrio į miestą, kaip į sudėtingą, daugiakomponentę sistemą. Nepakankamai naudojamos šiuolaikinės informacinės technologijos. Todėl darnus miesto vystymasis turi būti laikomas ne tik socialinių, gamtos, bet ir inžinerijos mokslų objektu.

Tyrimų objektas – miestas kaip kompleksinė inžinerinė, socialinė, ekonominė ir ekologinė sistema; statybos poveikio visiems šiems komponentams nustatymas; pusiausvyros tarp jų paieška.

Darbo tikslas ir uždaviniai. Pagrindinis darbo tikslas – sudaryti teorinį modelį, kuris leistų daugiatiksliais sprendimų paramos metodais įvertinti miesto darną ir planuoti miesto vystymąsi ateityje. Šis modelis leistų vartotojams atlikti miesto inžinerinės-techninės, socialinės, ekonominės ir gamtinės aplinkos būklės analizę, suteiktų galimybę palyginti miestus tarpusavyje ir sudaryti įvairias miesto ateities vystymosi alternatyvas, jas palyginti bei atrinkti geriausią.

Siekiant tikslo turi būti:

- rastos šiuolaikinių miestų vystymosi tendencijos;
- nustatytos pagrindinės miestų problemos;
- išnagrinėtos darnaus miesto vystymosi prielaidos ir jų taikymo pavyzdžiai;
- išanalizuoti miesto darną apibūdinantys rodikliai ir jų sistemos;
- ištirti daugiatiksliai metodai, jų taikymo galimybės ir parinkti tinkamiausi;
- nustatytas ryšys tarp statybos ir darnaus miesto vystymosi procesų;
- suformuluotas naujas darnos komponentas, apibūdinantis dirbtinę miesto aplinką;
- nustatytas statybos poveikis miesto darnos komponentams;
- įvardyti rodikliai, apibūdinantys miesto statybos proceso rezultatus;
- sukurtas, aprašytas ir išbandytas miesto darnos įvertinimo ir vystymosi planavimo teorinis modelis;
- ištirtos pasaulyje egzistuojančios darnaus miesto vystymosi analizės ir planavimo automatizavimo priemonės;
- sukurta internetinė darnaus miesto vystymosi daugiatikslė sprendimų paramos sistema.

Tyrimo metodika. Visa oficialioji tarptautinių organizacijų, naujausia medžiaga mokslinių duomenų bazėse, Lietuvos institucijų pateikiama informacija bei kita medžiaga internete tiriama analizės būdu. Daugiatiksliai metodai lyginami bei parenkami tinkamiausi taikant palyginamąją analizę. Alternatyvų rodiklių reikšmės nustatomos statistiniais ir analogijos metodais, o rodiklių reikšmingumai – ekspertiniais.

Mokslinis darbo naujumas

1. Darnaus miesto vystymosi idėja papildyta inžineriniu-techniniu aspektu.
2. Miesto darnos įvertinimui ir modeliavimui pritaikyti daugiatiksliai metodai.
3. Darnaus miesto vystymosi modeliavimas suskaidytas į lygmenis.
4. Panaudotos šiuolaikinės informacinės technologijos miesto inžineriniams-techniniams, socialiniams, ekonominiams ir aplinkos komponentams vertinti.

Teoriniai ir praktiniai darbo rezultatai

1. Pasiūlyta koncepcinė miesto darnos rodiklių sistema, atspindinti visų suintersuotų grupių interesus, įvertinanti statybos veiklos įtaką miesto darnai.
2. Sudarytas miesto darnos įvertinimo ir darnaus vystymosi modeliavimo teorinis modelis, kuris leidžia nustatyti esamą miesto fizinės, socialinės ir ekonominės aplinkų pusiausvyrą, sudarytos miesto ateities vystymosi alternatyvos bei atrinktos geriausios.
3. Pritaikius sukurtąjį modelį, įvertinta konkretaus miesto darna, sudarytos bei įvertintos ateities vystymosi alternatyvos.
4. Sukurta originali internetinė sprendimų paramos sistema darniam miestui modeliuoti.
5. Darbo rezultatai, išvados ir pasiūlymai yra naudingi sprendžiant Lietuvos miestų vystymosi problemas, sudarant jų vizijas, strateginius planus, ar atliekant miesto fizinį planavimą.

Darbo aprobavimas ir praktinis rezultatų naudojimas

1. Pagrindiniai disertacijoje nagrinėjami teiginiai išdėstyti ir aptarti tarptautinėse ir respublikinėse konferencijose Lietuvoje, Lenkijoje, JAV, Nyderlanduose. Taip pat darbe išdėstyta medžiaga paskelbta trylikoje mokslinių straipsnių ir konferencijų leidiniuose.
2. Darbe sukaupta medžiaga panaudota dalyvaujant tarptautiniame Framework 6 projekte „Intelligent cities“.

3. Remiantis kai kuria disertacijoje išdėstyta medžiaga, parašytos magistro tezės.

Apimtis ir struktūra. Darbą sudaro įvadas, keturi skyriai, išvados ir pasiūlymai, literatūros šaltinių sąrašas ir priedai. Darbo apimtis – 143 puslapiai.

Išvados ir pasiūlymai

1. Nustatyta, kad miesto darna labai priklauso nuo jo urbanizuotos aplinkos savybių, todėl siūloma klasikinę darnaus miesto vystymosi sampratą papildyti inžineriniu-techniniu aspektu. Identifikuota, kad statyba turi tiesioginį poveikį šiam aspektui. Be to, statyba veikia socialinį ir ekonominį darnaus miesto komponentus.
2. Literatūros analizė leidžia teigti, kad miesto darna yra kintanti laike pusiausvyra ir individuali kiekvienam miestui. Darnaus miesto modeliavimas susideda iš dviejų dalių: esamos situacijos analizės ir ateities vystymosi planavimo. Tam reikalingas kompleksinis modelis, formaliai apibūdinantis socialinę, ekonominę ir gamtinę miesto aplinkas bei miesto statybos proceso rezultatus.
3. Įrodyta, kad darnaus miesto vystymosi modeliavimui reikia naudoti daugiatikslius, daugelį veiksnių įvertinančius ir geriausią kompromisinį variantą nustatančius metodus. Jie atsakymą pateikia vienu skaičiumi, todėl galima palyginti įvairias alternatyvas.
4. Ištyrus šešis daugiatikslius metodus, nustatyta, kad nagrinėjamiems uždaviniams spęsti labiausiai tinka šie metodai: paprastų svorių sudėjimo metodas, MCDM-23, analitinis hierarchijos procesas, ELECTRE III ir daugiakriterinio kompleksinio proporcingo įvertinimo metodas. Minėti metodai turi savo specifinių privalumų ir trūkumų, kuriuos reikia įvertinti interpretuojant rezultatus.
5. Miesto darnos įvertinimui turi būti parinktas toks rodiklių skaičius ir derinys, kuris geriausiai atspindi suinteresuotų grupių (verslininkų, gyventojų, aplinkosauginінkų) interesus. Pasiūlyta koncepcinė miesto darnos rodiklių sistema, sudaryta iš keturių pagrindinių grupių: inžinerinės-techninės, socialinės, ekonominės ir aplinkos.
6. Sudarytas miesto darnos įvertinimo ir darnaus vystymo planavimo trijų lygmenų modelis. Jis gali įvertinti miesto vidinę (lyginant skirtingas seniūnijas) ir išorinę (lyginant skirtingus miestus) darną. Jame numatytas miesto ateities scenarijų sudarymas ir jų palyginimas leidžia aktyviai planuoti miesto darną ateityje.

7. Pritaikius sukurtąjį modelį, išspręsti trys praktiniai uždaviniai. Pirmajame palyginta dešimt miesto seniūnijų ir nustatyta, kad darniausiai vystosi Pilaitė. Antrajame kompleksiškai įvertinti Vilniaus, Kauno ir Klaipėdos rodikliai ir rezultatai parodė, kad Vilnius pasižymi aukščiausiu darnos lygiu. Trečiajame pagal socialinius, ekonominius ir aplinkos rodiklius palyginti trys Vilniaus ateities vystymosi scenarijai. Geriausiu pripažintas „Orientuotas į visuomenę scenarijus".
8. Nustatyta, jog miesto darnos įvertinimo galutiniai rezultatai yra kintamas dydis ir priklauso nuo penkių pagrindinių veiksnių: a) lyginamųjų alternatyvų parinkimo ar suformavimo korektiškumo; b) rodiklių sistemos išsamumo; c) rodiklių reikšmių tikslumo; d) priimtų prielaidų teisingumo; e) reikšmingumų nustatymo objektyvumo. Dėl šių veiksnių sunku iš pirmo karto gauti objektyvius sprendinius. Tik skaičiavimas priartėjimo būdu užtikrina visų suinteresuotų grupių poreikių patenkinimą.
9. Ištirta, jog daugelis miesto analizės ir darnaus vystymosi planavimo automatizavimo priemonių sprendžia siaurą problemų ratą; jų duomenų bazės susijusios su kokrečia šalimi; jos reikalauja specialių žinių ir įgūdžių; yra sunkiai prieinamos daugeliui vartotojų. Todėl pasiūlyta originali internetinės darnaus miesto vystymosi sprendimų paramos sistemos struktūra.
10. Pagal sudarytą sprendimų paramos sistemos struktūrą galima sukurti paprastą, patikimą, prieinamą ir lanksčią internetinę sprendimų paramos sistemą. Jos dėka bus galima ne tik kompleksiškai, bet ir atskirai nagrinėti visus miesto darnos komponentus. Todėl potencialus jos vartotojų būrys labai didelis – nuo mokslininkų iki paprastų piliečių.
11. Internetinė sprendimų paramos sistema atveria plačias galimybes suinteresuotoms grupėms įvertinti socialinę, ekonominę, ekologinę ir inžinerinę-techninę miesto situaciją, taip pat pagelbėti vizionavimo, strateginio ir fizinio planavimo, taip pat miesto statybos ir atnaujinimo procesuose.
12. Sukurta ir internete patalpinta darnaus miesto vystymosi daugiatikslės sprendimų paramos sistemos demonstracinė versija, kurioje demonstruojamas dviejų miesto ateities scenarijų vertinimas (ieškant geresnio) kompleksiniu proporcingo įvertinimo metodu.

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