UDK 332.14 https://doi.org/10.31548/zemleustriy2020.04.05

MODERN URBANIZATION RESEARCH TOOLS AND CLASSIFICATION METHODS

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Abstract. *The paper introduces the classification of modern urbanization research tools and scientific research methods. Urbanization is a prominent field of multidisciplinary study that describes the population dynamics, land use changes, land cover and green areas, traffic and architectural city planning and many others. The paper deals with issues of research classification, what are the main subfield of urbanization research and which scientific methods can be used in each of them. This paper explores the main urbanization research tools, such as computational, map and information and smart city toolsets. Key component of any of the above-mentioned tools is data. We classified data by its application and research subfield that it is used at.*

Economics study is at the heart of any modern urban scientific work. City budget, cost of living in the city, employment data and land prices are among the most widely used fields of research in this area. The paper highlights that city growth and development, Urbanization patterns, and spatial planning and distribution are prominent subfields of urbanization economics research. The article purpose is to address the challenges any new researcher encounters is lack of extensive overview and classification of available tools.

Keywords: *urbanization, computer vision, neural networks, prediction, visualization, land cover, GIS, real estate, system modeling, big data.*

Topicality.

Effective and practical scientific work requires understanding of underlying mechanics and knowledge not only of the field of study but of set of tools that can be used for such work. Study of urbanization and its subfields is a complex task. Urban studies include, among many other such areas as real estate, land use, governmental policies, and municipal governance regulations, geographical information, and social studies. Besides sustainable development, concept of green cities and effective natural resources use planning have gained attention during the past decade and are at focus of many of the modern researchers. Meanwhile the current state of urbanization research has presented a new challenges and research opportunity to work on. It became evident that to proceed in their studies researchers in this field need to establish a new set of tools and methods. The advancement in computer science and current state of computational capabilities allow for real time system modeling and geospa-

tial data visualization in 3D. In addition to this, article presents the urbanization scientific methodology research process. This process can serve as foundation for future scientific efforts and work in urbanization and adjacent fields.

Analysis of recent research and publications.

Urbanization research field is relatively new area of study. Larger portion of existing research is multidisciplinary and cross field study, with economy, sociology and ecology being core fields. While more of modern research papers have narrow focus on certain subfields, such as GIS, spatial development, city management or real estate market analysis. Author notes the lack of comprehensive quality information that provides deep analysis and presentation of urbanization as standalone scientific field, which it undoubtedly is. Process of urbanization cannot be explored and studied without first establishing set of tools and scientific methods that are specific to this field. Author acknowledges scientific discoveries and considerable progress in the field of computer sciences. Computer science can serve as strong scientific tools foundation for modern urban studies. Without a doubt tools such as computer vision that enable us to effectively analyze and classify spatial data or advancement in area of machine learning, that allows for robust real estate prediction models or real city models built using 3D modeling platforms, provide a strong argument for their use by urban researchers.

The aim of the study. Therefore, the aim of this research work is to present the modern robust set of scientific research tools in the field of urbanization research and study. Author plan to present the list of computational and information system research tools that will enable effective research process. Besides, in this research paper we outline and analyze subfields of urbanization.

Materials and methods of research.

In this paper we covered a great deal of scientific papers and information both on urbanization and computer science areas [1,2, 3]. We used qualitative method to establish the urbanization in context of a broad research field. Quantitative method helped us outline the main chart and data used in majority of urban economy articles, which is bid rent curve and is widely used for land price modeling and prediction. Another key research output is importance of studying the point(s) of market equilibrium when modeling land use prediction. Author employed scientific abstraction, system modeling, and theoretical generalization to build a concept of Urbanization research cycle as an iterative cyclical process.

Research results and their discussion.

Urbanization is a multidimensional and complex field of scientific study. It exists at intersection of many fields of study such as economics, ecology, sociology, urban and city planning, law, and regulations [4]. In past decades, many researchers focused their efforts on economics, with focus on real estate and property analysis, financial modeling, and prediction modeling. With current state of urbanization expansion, it is no longer effective to limit the scope of urban research work. Instead, these challenges provide tremendous opportunity

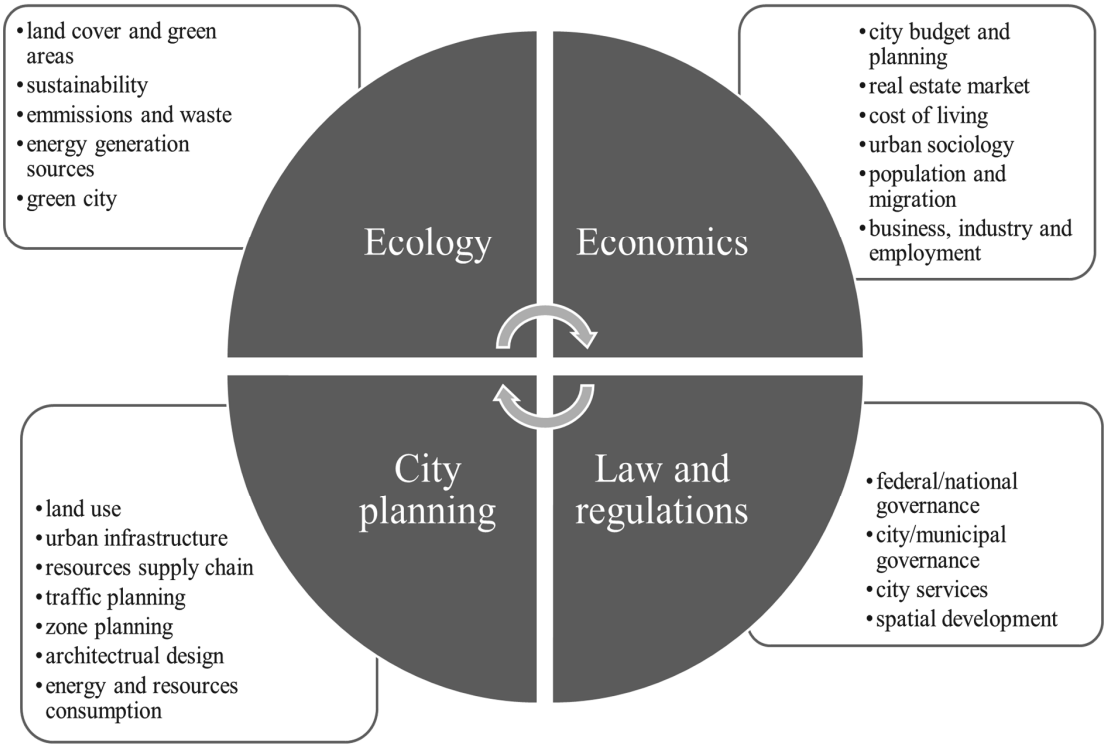

Fig.1 Urbanization fields of research [1,4]

for new shift in studies of urban process, it is subfields and adjacent fields. Urbanization cannot just be classified as subarea of microeconomics study. It is evident that urban process has impact on ecology situation, on local and national economic development, financial markets and both national and international laws and regulations that govern the modern city. In this paper we present tools and methods that can be used by different researchers coming from different areas of scientific study. The current state of urbanization research field and its connection to existing major scientific areas are presented in Figure 1.

There are four major fields of research that enable us to study urbanization process. They are ecology, economics, city planning and laws. Each of these four fields has many layers and sub fields. In Figure 1 we highlighted those fields that are directly connected with urbanization process. Some fields, such as sustainability or urban infrastructure or city budget are connected to other fields of study and form the basis of what is now classified as multidisciplinary research. This fact alone can serve as major evidence to prove that urban studies field is multidisciplinary area and require background, knowledge, and experience in adjacent research areas.

Table 1 provides extensive overview of fourteen major urbanization research subfields. They are grouped by main field of scientific research, ecology, sociology, economics, city planning, Computational and information systems, Law, and regulations. Structure field denotes core areas of potential research work. It should be noted that some fields share similar or same structure, such as Land use and resources management. Methods field represent list of scientific research methods that can be used to study specific subfield.

Table 1. **Overview of urbanization research subfields***

№	Subfield	Field(s) of research	Structure	Methods
1	Urban ecology	Ecology	Policies Resources System outcomes	Analysis and hypothesis Legal research
2	Green city	Ecology	Buildings Energy Environment Land use Waste management	Analysis and hypothesis Legal research Qualitative Quantitative System modeling
3	Population, dynamics, and health	Ecology Sociology	-	Qualitative Quantitative System modeling
4	City growth and development	Economics	Urban development	Analysis and hypothesis Quantitative System modeling
5	Urbanization patterns	Economics City planning	-	Qualitative Quantitative System modeling
6	Spatial planning and distribution	Ecology Economics City planning	Land cover	Qualitative Quantitative System modeling
7	Real estate market	Economics City planning Law and regulations	Market analysis Price modeling Supply and demand forecast	Quantitative System modeling
8	Urban planning and monitoring	City planning Law and regulations	-	Legal research Qualitative
9	Smart city	City planning Law and regulations Computational and information systems	City governance City data modeling Predictive modeling	Legal research Qualitative Quantitative System modeling
10	Urban Modeling	City planning Law and regulations Computational and information systems	-	Qualitative Quantitative System modeling
11	Land Development	City planning Law and regulations	City visualization Predictive scenarios	Legal research Qualitative System modeling
12	Land-use and infrastructure planning	City planning	Land use regulations GIS modeling	Legal research Qualitative System modeling
13	Environmental monitoring and acts	Ecology Law and regulations	-	Legal research Quantitative System modeling
14	Urban planning law	Law and regulations	-	Analysis and hypothesis Legal research Qualitative

* prepared based on personal research data, UN report, Britannica and Statista services [1, 2, 3, 4]

Important part of any modern research work is tools that are used to study certain area or subfield. Table 2 resents results of our work on list of most widely used urbanization research tools. In this paper we note seven major tools type and provide their classification - computational system, information system, general city data, GIS and maps, official documentation, smart city tools, tools, and equipment. Information that is presented in Table 2 is divided into five section. There are three important sections that we should note – tool component, tool data types and field of application. Components section present empirical sub areas that can be used for specific study, while data field denotes major data type that is used by this tool, to help make an opinion on which tool to use for specific research work. In application section we present list of research subfields that this tool can be used in.

Three major types of data are used in urbanization research – numerical data (financial, distance, statistical etc.), Geographic data and information (incl. maps and digital visualization of cities), text information (city plan, laws, and municipal acts etc.). It should be noted that one of the newer subfields of research is Smart City. Smart City research requires researcher to work and analyze tremendous amounts of various types of data. We should note that detailed examination and presentation of Smart City subfield falls outside of the scope of current research work and will be published as separate research work in future.

Table 2. **Urbanization research tools classification***

№	Tool	Components	Data	Application
1	Computational system	Data mining Machine learning Computer Vision	Digital Images Numerical data	Data analysis Image processing Prediction systems
2	Information system	Big Data Data visualization	3D objects data Digital Images Numerical data	3D Modeling Data processing, storage, and analysis
3	General city data	Real estate City statistics	Statistical data Land use data	Economic modeling Environmental planning
4	GIS and maps	Aerial map Cadastral map Satellite map	Geographic data and information	Data analysis General modeling and planning Surveying
5	Official documentation	Agreements Law Planning Regulations Reports	Text and general information	General economic, ecology and city planning related
6	Smart city tools	City management sys. Monitoring data	Numerical data	City governance City surveillance
7	Tools and Equipment	3D/LiDAR scanners Land Surveying UAVs	Digital images Sensors data	City planning Construction Land use planning

* prepared based on personal research data, UN report, and Britannica services [3, 4, 5]

Table 3. **Modern computational and information system analysis tools classification***

№	Tool	Category	Data Type	Output	Urbanization subfield
1	3D visualization	Modeling Presentation	Geographical Images	Digital model City plan	Green city Spatial planning and distribution
2	Computer Vision	Modeling Presentation	Images Digital data	Map data	Urban planning and monitoring
3	Digital recording devices	Modeling Technical system	Digital data	Indicators Misc. data	Smart city Urban ecology
4	GIS	Modeling Presentation	Geographical Images	Map data City plan	Land Development Land-use and infrastructure planning
5	Information systems	Decision Modeling Presentation Planning	Financial Statistical	Information	Smart city Population, dynamics, and health
6	Machine learning	Decision Modeling Planning	Numerical Scientifical	Information	Real estate market
7	Prediction systems	Modeling Planning	Numerical Financial Statistical	Information	Smart city

* prepared based on personal research data and Britannica [3, 5, 6]

Computer science tools and methods are widely used in all major fields of scientific research, Urbanization being one of them. Table 3 provides list of major computational and information system analysis tools that can be employed by scientist working on urban research field. Table 3 is as extension of Table 2 and focuses specifically on computer set of tools. There are five sections in Table 3, computer science tool, tool category, data types that are used withing this tool context, output results of using this tool and urbanization subfield that this tool is most extensible used in (refer to Table 1).

Author provides a concept of Urbanization research cycle in Figure 2. This concept is based on scientific research method and is a result of previous research work on urbanization. This cycle consists of twelve stages, each of them is separate research phase. New research work starts with problem definition, outlining of subfield of research and scope of research work, next step is search for information within the scope of research work. The research information that has been gathered need to be studied, grouped, and classified. After information has been grouped and studied, research should form an initial set of hypotheses based on which he will later build a scientific model. Scientific model is an iterative four steps sub-cycle within main research cycle. It starts with initial model, then researcher picks a set of tools within context of this model, using established set of tools he conducts a set of one or multiple experiments using the data that has is an output of information processed and grouped before. After the experi-

ment has been conducted the scientist test the results and compares them to his initial hypothesis and analyses it based on existing set of information. If the results prove on par with hypothesis the research work can proceed to next step. Otherwise, the model cycle has to be repeated with new set of input parameters or with different set of tools, until the results are satisfactory. Once the hypothesis has been confirmed or validated the research model output data is gathered and the results are formatted to be presented to the research community. It is important to note the importance of two last steps in the cycle – output analysis and research model presentation. They are the main result of conducted research work and denotes the materials that are presented to scientific community later.

Economics research field is major part of urban studies. There are many tools and methods that are available for researcher working in field of urban economics. One of the most commonly used and effective tools is bid rent curve and gradient (Figure 3). It is used to analyze the land or real estate rent price for various purposes (commercial use, industrial use, or residential use) and map the points of market equilibrium. Also, it shows what is the optimal (finance related) distance from the central business district to the planed construction site. In such model's city is divided into four major zones, central business district, that is also part of inner-city ring area, middle ring, and outer ring area. Computational and information systems tools are used to build similar curves. Quality of information is one

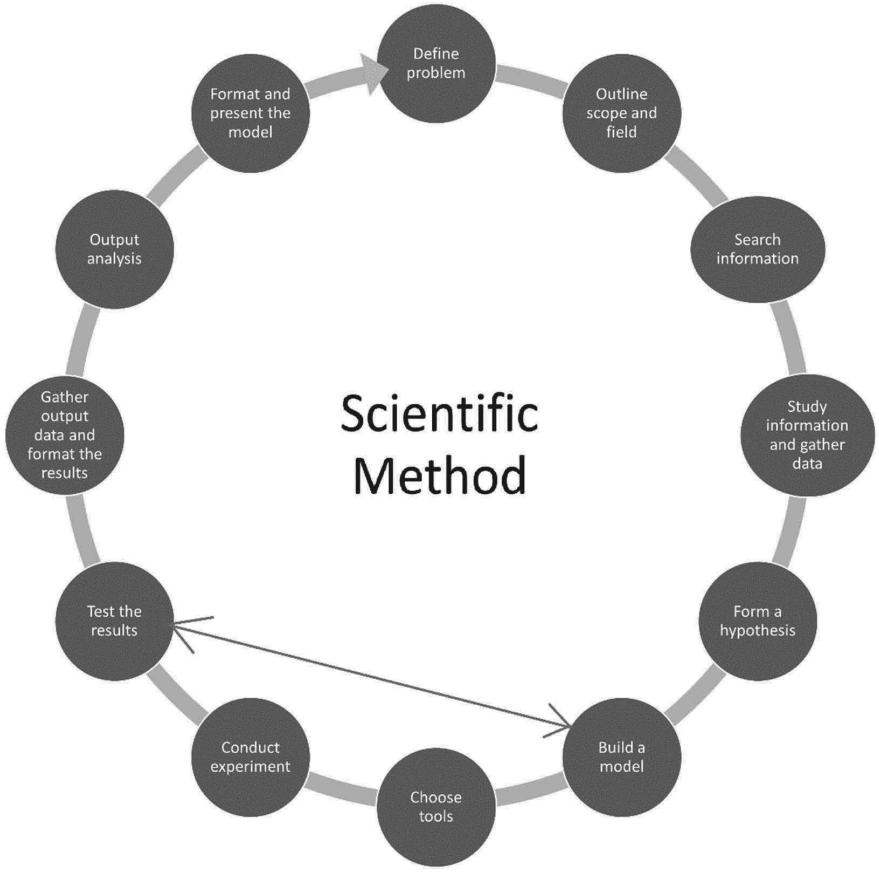

Fig.2 Urbanization research cycle concept [6]

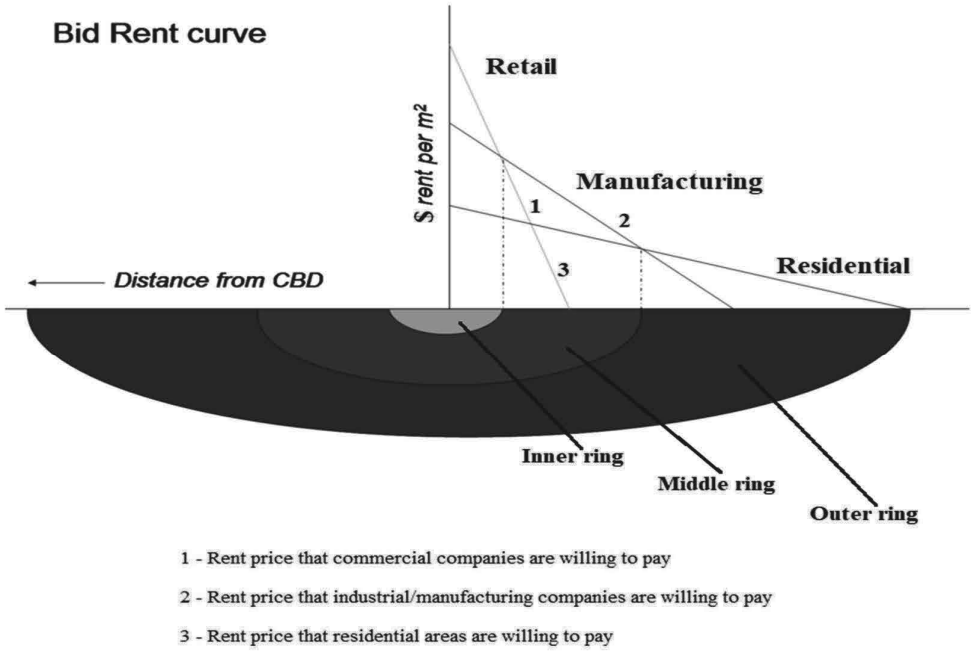

Fig.3 Economic research bid rent curve and gradient [6]

of key determining factors when plotting rent curves and gradient. Machine learning instruments (software) can be employed to make a future predations or work with large amounts of input data to purpose optimal rent models.

One of modern and prominent fields of study is 3D modeling and visualization (Figure 4). Geographical data and information are sued to visualize the city and land cover in virtual 3D environment. Such models can be both static and dynamic. In later case, researcher have ability to set parameters and test the models in real time with visualization of research output information. This set of powerful tools require greater computational resources and skills to be tuned and set up.

Fig.4 Geospatial data visualization in 3D for city processes modeling in Unreal Engine 4

Conclusions and prospects.

Urban research requires for researcher to first define the problem and then analyze the data available, to build an effective model. As a rule, the data that is required in any new research are multidimensional and comes from various sources, usually not directed corelated, such as financial data, digital images, and land use regulations. Nowadays any new researcher has more tools and information at their disposal then those two or three decades ago. Information and computational systems form the basic set of tools of modern urban researcher. However, both require data to be inputted first and parameters to be set for modeling purposes. Larger quantities of such data that are used in urbanization research modeling are either of numerical or geographical type, while some research efforts require both. In this work we provided a definition and classification of four core urbanization fields – economics, ecology, city planning; law and regulations. Based on this classification and study of research tools we presented a cyclical twelve stages urbanization research cycle concept. In future we plan to present a comprehensive research framework that relies on presented computational and information system analysis tools.

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КЛАСИФІКАЦІЯ СУЧАСНИХ ЗАСОБІВ ТА МЕТОДІВ ДОСЛІДЖЕННЯ ПРОЦЕСУ УРБАНІЗАЦІЇ

https://doi.org/10.31548/zemleustriy2020.04.05

Анотація. *У статті представлена класифікація сучасних інструментів досліджень та методів наукових досліджень урбанізації. Урбанізація є визначною сферою мультидисциплінарного дослідження, яке описує динаміку змін чисельності населення, зміни землекористування, земельного покриття та зелених зон, дорожнє та архітектурне містобудування та багато іншого. У статті розглядаються питання класифікації методів досліджень, які на основні підсвідомості урбанізаційних досліджень і, які наукові методи можуть бути використані в кожному з них. У цій роботі досліджуються основні інструменти урбанізації, такі як обчислювальні, картографічні, інформаційні та розумні інструменти міста. Ключовим компонентом будь-якого з вищезгаданих інструментів є отримані дані. Ми класифікували дані за їх застосуванням і дослідницькими галузями, де вони використовуються.*

Економічне дослідження лежить в основі будь-якої сучасної наукової роботи щодо урбанізації. Міський бюджет, вартість життя

у місті, дані про зайнятість населення і ціни на землю є одними з найбільш широко використовуваних напрямків досліджень у цій сфері. У статті наголошується, що ріст і розвиток міст, моделі урбанізації, просторове планування та розподіл земельних ресурсів є галузями економічних досліджень урбанізації. Мета статті полягає у вирішення проблем, з якими стикається будь-який новий дослідник, відсутність великого огляду та класифікації доступних інструментів.

Ключові слова. *Урбанізація, комп'ютерне бачення, нейронні мережі, прогнозування, візуалізація, земельний покрив, ГІС, нерухомість, системне моделювання, великі дані.*

В. А. Назаренко

КЛАССИФИКАЦИЯ СОВРЕМЕННЫХ СРЕДСТВ И МЕТОДОВ ИССЛЕДОВАНИЯ ПРОЦЕССА УРБАНИЗАЦИИ

https://doi.org/10.31548/zemleustriy2020.04.05

Аннотация. *В статье представлена классификация современных исследовательских инструментов и методов научных исследований урбанизации. Урбанизация является важной областью междисциплинарных исследований, описывающая динамику демографических изменений, изменений в землепользовании, землепользовании и зеленых зонах, дорожном и архитектурном городском планировании и многое другое. В статье рассматривается классификация методов исследования, которые находятся на основных подсознательных городских исследований и какие научные методы могут быть использованы в каждом из них. В настоящем документе рассматриваются основные инструменты урбанизации, такие как вычислительные, картографические, информационные и интеллектуальные городские инструменты. Ключевым компонентом любого из вышеперечисленных инструментов являются полученные данные. Мы классифицировали данные по их применению и научно-исследовательским отраслям, где они используются.*

Экономические исследования будут в центре любой современной научной работы по урбанизации. Городской бюджет, стоимость жизни в городе, данные о занятости и цены на землю являются одними из наиболее широко используемых областей исследований в этой области. В статье подчеркивается, что рост и развитие городов, модели урбанизации, пространственное планирование и распределение земельных ресурсов являются областями экономических исследований урбанизации. Цель этого документа заключается в решении проблем, с которыми сталкивается любой новый исследователь, отсутствия тщательного обзора и классификации имеющихся инструментов.

Ключевые слова. *Урбанизация, компьютерное видение, нейронные сети, прогнозирование, визуализация, земельный покров, ГИС, недвижимость, системное моделирование, большие данные.*