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GEOINFORMATION APPROACH TO THE URBAN GEOGRAPHIC SYSTEM RESEARCH (CASE STUDIES OF KHARKIV REGION)

С. В. Костріков, Л. М. Нємець, К. Ю. Сегіда, К. А. Нємець, Ч. Морар. ГЕОІНФОРМАЦІЙНИЙ ПІДХІД ДО ДОСЛІДЖЕННЯ УРБАНІСТИЧНИХ ГЕОГРАФІЧНИХ СИСТЕМ (на прикладі м. Харків та області). *Стаття присвячена вдосконаленню і подальшому розвитку концептуального підходу щодо дослідження урбаністичних геосистем (УГС) через ГІС-засоби. Урбогеосистема визначається як онтологічна сутність, що функціонує і розвивається в окремому географічному екстенті урбанізованої території. Подаються два рівня урбогеосистем: екстернальна УГС, як сукупність взаємозв'язаних окремих міст, та інтернальна урбогеосистема – множина районів окремого міста. Отримала подальший розвиток ідея про те, що урбаністичну геосистему можна відтворювати через три модельні сутності: набір дискретних (точкових) географічних об'єктів, що подають суспільно-географічні та економічні атрибути окремих населених пунктів або виокремлених частин одного міста; сукупність лінійних об'єктів, що визначають взаємодії між цими складовими УГС; та множина об'єктів площі, які, власне, і описують елементи УГС. Пояснюється, чому подібна формалізація змісту УГС надає широкі можливості саме для застосування ГІС-засобів для моделювання, аналізу і візуалізації урбогеосистем. Деталізуються чинники, що обумовлюють необхідність впровадження геоіформаційного підходу до дослідження цих систем. У вигляді блок-схеми формалізується алгоритм дослідження УГС через засоби ГІС із подальшим розглядом кожного з його ключових блоків. Зокрема, особливо підкреслюється застосування Лідар-технології як для генерації моделей УГС, так і для аналізу їхньої динаміки. Розглядаються ГІС-інтерфейс та функціональність відповідного програмного забезпечення. Наводиться приклад дослідження екстернальної урбогеосистеми – в інтерфейсі ГІС MapInfo була впроваджена модель маятникової міграції, побудована через аналіз властивостей УГС. Подаються тематичні приклади відтворення інтернальної УГС. Розглядається послідовність її моделювання через Лідар-дані. Обговорюється побудована на платформі ArcGIS модель локалізації ділянок міста із визначенням функціонального впливу урбогеосистеми на особливості розподілу закладів соціальної сфери. На завершення узагальнюються результати дослідження і переваги даного підходу щодо цілей муніципального менеджменту.*

***Ключові слова**: урбогеосистема, ГІС, геоінформаційний підхід, урбаністичні дослідження, алгоритмічна послідовність, екстернальна та інтернальна урбогеосистеми, тематичні дослідження.*

С. В. Костриков, Л. Н. Немец, К. Ю. Сегида, К. А. Немец, Ч. Морар. ГЕОИНФОРМАЦИОННЫЙ ПОДХОД К ИССЛЕДОВАНИЮ УРБАНИСТИЧЕСКИХ ГЕОГРАФИЧЕСКИХ СИСТЕМ (на примере г. Харькова и области). *Статья посвящена дальнейшей разработке концептуального подхода, касающегося исследования урбанистических геосистем (УГС) с помощью геоинформационных систем и технологий. Урбогеосистема определяется как некая онтологическая сущность, которая функционирует и развивается в отдельном географическом экстенте урбанизированной территории. Представлены два уровня урбогеосистем: екстернальная УГС, как совокупность взаимосвязанных отдельных городов, и интернальная – множество районов одного города. Получила дальнейшее развитие идея о том, что урбанистическую геосистему можно воссоздавать через три модельные сущности: набор дискретных (точечных) объектов, которые представляют социально-географические и экономические атрибуты населенных пунктов или выделенных районов одного города; совокупность линейных объектов, которые определяют взаимодействия между указанными составляющими УГС; и множество объектов площади, которые, собственно, и описывают элементы урбогеосистемы. Объясняется, почему подобная формализация содержания УГС предоставляет широкие возможности именно для применения ГИС-технологий моделирования, анализа и визуализации урбогеосистем. Детализируются факторы, которые обусловливают необходимость внедрения геоинформационного подхода для исследования этих систем. В виде блок-схемы формализуется алгоритм исследования УГС через ГИС-*

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инструменты с дальнейшим рассмотрением каждого из его ключевых блоков. В частности, отдельно подчеркивается применение Лидар-технологии как для генерации моделей УГС, так и для анализа их динамики. Рассматриваются ГИС-интерфейс и функциональность соответствующего программного обеспечения. Приводится пример исследования экстернальной УГС – в интерфейсе ГИС Mapinfo была построена модель маятниковой миграции, сгенерированная посредством анализа свойств УГС. Представлены тематические примеры моделирования интернальной УГС. Рассматривается последовательность ее моделирования на основе Лидар-данных. Затем обсуждается построенная на ГИС-платформе ArcGIS модель локализации участков города с определением функционального влияния урбогеосистемы на распределение объектов социальной сферы. В завершение обобщаются результаты исследования и преимущества данного подхода применительно к целям муниципального менеджмента.

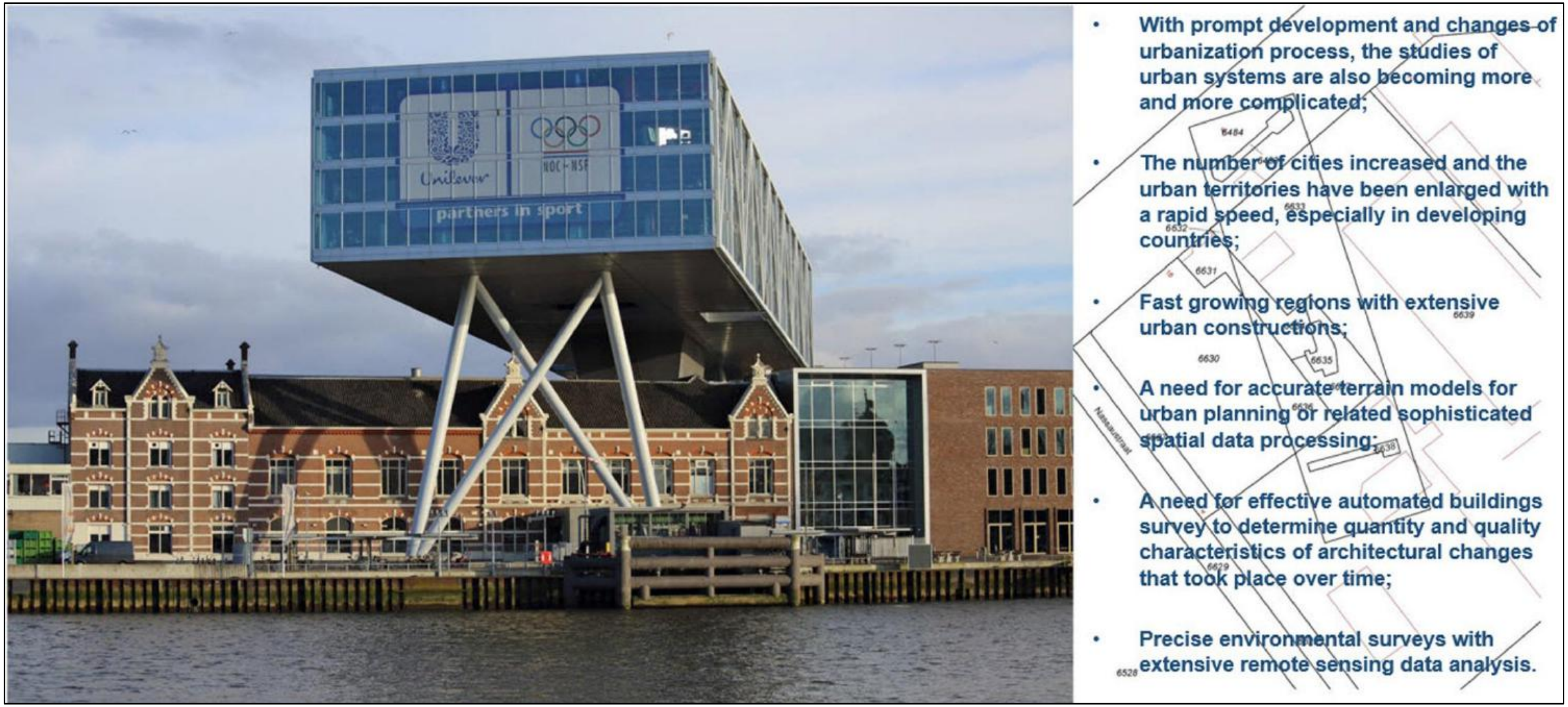
***Ключевые слова**: урбогеосистема, ГИС, геоинформационный подход, урбанистические исследования, алгоритмическая последовательность, экстернальная и интернальная урбогеосистемы, тематические исследования.*

Research problem introduction. It is a common fact that the global world has been transforming to the information society for several recent decades. We may also accept a *Geographic Information System – GIS* as one of the core tools of this transformation. Just this period of time has also been featured by the continuing urbanization process that still takes place in many first of all – in developing countries. According to the estimation of the United Nations experts (http://esa.un.org/), if the whole world population grows up to 32% till 2050, then the urban population in the world – up to 70%, and thus, up to 68% of world population will reside in the cities. It means that we may face the largest urban growth wave throughout the whole mankind history, which also concurs with the drastically rapid development of the information technologies, computer sciences, geoinformatics, and GIS.

For several recent decades it has been recognized by many researches that with the world population and urban growth more and more cities are operating and developing as more and more complicated *urban systems* [7, 14, 15, 19, 45]. This complexity is also a key feature of the contemporary urbanization process that circumstance requires to be evaluated by taking into account not only spatial, but purely geographic issues as well. Both the mentioned rapid urbanization growth, and its attendant alterations in both old, and new cities do not allow us to accept any other alternative to consideration a city as *an urban geographic system entity – an urbogeosystem (UGS)*, which operates within a certain extent of the geographic space [49-51]. Thus, a geographer-urbanist needs both a reliable research approach, and advanced innovative technological tools developed to identify the nature and spatial peculiarities of the urbanization process in a given area. This methodology and its applied derivative solutions meet the necessity for more efficient *urban mapping*, *city understanding*, and *municipal management*. All three mentioned domains may be combined in one innovative development – *3D City Cadaster*, intended to resolve those complex property and infrastructural situations, in which a traditional 2D digital cadaster is rather limited [5]. The relevant illustration from a paper, we have just referred to, has been used by the authors as the background for outlining the reasons of the urbogeosystem concept introduction (Fig. 1).

For the time being, a GIS is used every day by everyone in the developed world for various, both routine, and complicated operations with different spatial data formats: digital elevation models; scanned images and their processing applications; vector map data – roads, rivers, contours; raster map data – aerial photos, satellite images; 3D objects – buildings, geobodies; engineering data – surface and subsurface, etc.; LiDAR and orthophoto point clouds [24, 33]. The new virtual GIS-worlds and spatial images elaboration with all these data extend our own real world and allow us to think about our only world in many remarkable ways. In this context, GIS is simply one part of a larger tradition of digital data handling and spatial representation at all levels – global, national, and local one [16, 34]. There has been rapid growth of GIS software using for urban management in recent decades accompanied by improvements and expansions of the city simulation capabilities together with the methods / rules / interfaces developed for various modeling-visualizing packages [11, 18, 22, 31, 43].

Apart from some other reasons, the mentioned fact was based mainly on the following circumstance. It was the ability of the advanced GIS applications to solve the partial differential equations of the unsteady urban area expansion and relevant population movement by numerical techniques and describe properly different spatial regularities of urbanization types based on the models developed. The relevant methodological approach had been created even earlier, than either the introduction of GIS technique took place, or a GIS was involved in urban studies [7,8,12, 19,41,42,46]. Only somewhat later, on the one hand, a GIS became a routine tool for municipal planning and urban studies for about 25 years before [15], and it is a sustainable part of both ambitious developing programs [6], as well as it is a subject of the university agenda for the time being [10]. On the other hand, there still may be lack of fundamental research with only few exceptions, which would combine the strong spatial aspect of the urban system analysis with the GIS application advantages, while, for example, a general trend of the system approach, in the research of both urban, and environmental systems was con-



- With prompt development and changes of urbanization process, the studies of urban systems are also becoming more and more complicated;
- The number of cities increased and the urban territories have been enlarged with a rapid speed, especially in developing countries;
- Fast growing regions with extensive urban constructions;
- A need for accurate terrain models for urban planning or related sophisticated spatial data processing;
- A need for effective automated buildings survey to determine quantity and quality characteristics of architectural changes that took place over time;
- Precise environmental surveys with extensive remote sensing data analysis.

Fig. 1. The list of necessary reasons for the urbogeosystem concept introduction. The visual from [5, P. 2857] is used as this figure background (a complicated situation of the city property – to the left; the ordinary 2D cadastral scheme that does not outline this situation – to the right). The text on this figure is completely our original one

clusively outlined in the subject literature [3,33, 36,41].

The main **research goal** of this paper is to provide the urban geosystem research concept based on) of GIS and remote sensing data processing software involvement and to give some details about this concept applied implementation. Few regional examples (case studies) of its practical application are also provided. We accept this concept as the core part of the broader Human Geography methodology of using GIS, once represented by two authors [27]. Our paper recognizes the conceptual research approach relevant to the GIS-tools of urban data geoprocessing, modeling and visualizing on the basis of either open, or municipal attributive urban data, as well as based on the data extracted by *LiDAR*-technology remote sensing. It is obvious that an emphasized spatial aspect of the urban research implies the GIS procedures, tools, and operations involvement, what we attempt to examine briefly in the text below.

The geoinformation concept of the urban geographic system research. The external and internal urbogeosystems. Mostly the urban studies completed in the fifties–early seventies of the past century defined an urban system as a straightforward set of separate units (different cities or, in rare case studies - different areas in a single city). Some scant attention, if any, was directed to connections among cities. There were two seminal publications in the second half of the seventies, which introduced the nodal structure of the system of cities, which gave us the chance to determine interconnections and relationships among its structural nodes, thus revealing the pure systematic features [7, 19]. Urban system modeling techniques and initial elements of urban system analysis were represented a few years later. The authors announced, that they simply summarized these issues for practical applications and methods, which had existed since the fifties [3, 23]. Nonetheless, all four referred to publications demonstrated only a few research examples, which could be defined as phenomena of pure emergent properties of an urban system, while this system does not only refer to the set of cities in a certain area, but also demonstrates some unique relationships among them.

This certain drawback can be explained by the circumstances that in the wide-spread acceptance of the “urban system” definition many key spatial aspects have been simply lost. As an attempt to remediate the disadvantage mentioned by one of the authors, the category of *an urban geographic system* was once suggested [49]. This catergory has been already mentioned in our text above. The UGS is *an urban system, located within a definite extent of the geographic space; it is an unsustainable social-environmental system which is also a united entity of various architectural features and dramatically changed natural ecosystems*. The direct reference to the certain spatial extent of the geographical space is the key issue in the UGS definition. This not only allows providing all necessary prerequisites for GIS involvement in urban studies, but also securing detailed consideration of most linkages and relationships within a given area, and finally – reveals pure emergent properties of an urbogeosystem.

The nodal structure of the system of cities [7, 14] implies understanding of each single system component as *a point object*, while relationships among all city pairs within a given system entity – as *a linear object*. It is easy to accept that, a certain set of cities located within a definite region, simply is within a chosen *areal object*. In this way, taking into account the relevant thoughts reported earlier [7, 8, 14, 15,19, 20], it is possible not only to introduce the GIS techniques in urban studies, but also to outline some initial UGS hierarchy, making the assumption that point, lines and areas are fundamental spatial constituents of an urban geographic system. What is more, the given methodological assumption looks like a unique method, that allows us to introduce the so- called *geographical scalability*, while we consider a certain instance, a city, as a *point feature* upon some small scale, and that very city upon another, larger, scale – as a *feature related to some area*. If we apply the scalability to the *linear features*, representing various interconnections among the constituents of some cities set, we may obtain these linear features of different ranks, which would mirror the power of each particular connection between each pair of the chosen cities.

Thus, in the case of GIS-modeling one can easily see the correspondence just mentioned above of these UGS spatial constituents to the so- called *basic graphic primitives as GIS features*, which are also *points*, *lines*, and *areas*. This already explained key research component of any system study, the method of scalability, can easily be implemented exactly with the GIS-tools. For instance, in some regional case, by zooming in upon a set of cities study, we pass sooner or later that already mentioned threshold, after which “a city as a point” becomes “a city as an area”. Thus, firstly, a set of ***N*** cities presents the matrix of ***N*N***, while the latter defines a number of linear features, which mirror spatial linkages in *an external urbogeosystem* in terms of human, industrial, commercial, and information traffic. Secondly, not the same, but similar matrix represents ***N*** city districts with all pairs of connections among them within *an internal urbogeosystem*, which upon straightforward consideration is simply a set of city districts.

Algorithmic sequence of the urbogeosystem study with a GIS. Based on the foregoing and taking into account once presented “components and process of GIS for urban system analysis” [15, p. 214], we introduce one of the core issues of the geoinformation approach to the urban geographic system studies – the *algorithmic sequence* of this research provision with GIS (Fig. 2).

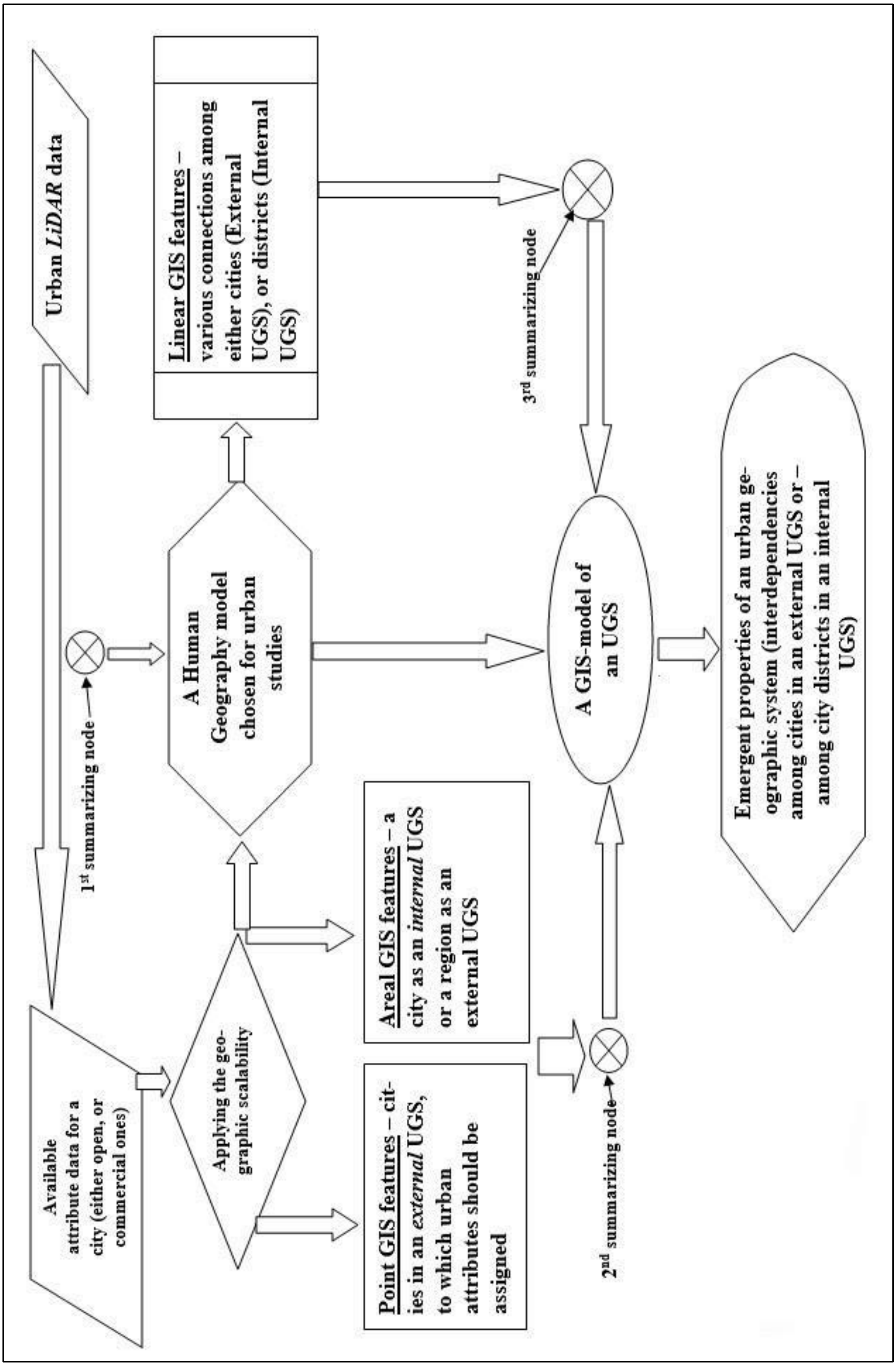


Fig. 2. The algorithmic flowchart of the urban geographic system studies with GIS-tools

This algorithmic flowchart starts with ***the first data algorithmic block*** – a block of gathering urban LiDAR (Light Direction and Ranging) data. This flowchart block has been already introduced in details as a set of terrain / vegetation / buildings acquisition techniques in one of our previous papers [50]. What is more, since then one of the authors leads the R&D program at the EOS Company (https://eos.com), which elaborates the LiDAR data processing web-based software intended for urban studies – the *ELiT* – EOS LiDAR Tool server-client application [28, 29].

The remote sensing information obtained from LiDAR-tools has gradually become to be preferred to traditional photogrammetric tools for the last few decades in many subject areas of interest related to the feature extraction, because of its better operability, productivity, accuracy, and higher resolution [40]. Moreover, these tools have been already applied for urban studies since the beginning of this century [44].

Almost all LIDAR devices are either Airborne types (ALS, aircraft based), or Terrestrial (vehicle based) ones. The latter are also called Mobile Laser Scanning (MLS) devices. The LIDAR unit uses the GPS-high precision and an Inertial Measurement Unit (IMU) to define the placement and measure the attitude of the aircraft in order to determine the ground location of the return pulse. The LIDAR sensor generates a series of point measurements (LiDAR Point Cloud sets) that consists of plain coordinates (X & Y) and the elevation (Z) of both natural and man-made features in the environment. Since we emphasize that AL LiDAR data may be sooner the dominant ones for urban studies, we depict some summarizing content of the LiDAR ALS survey as the following scheme (Fig. 3).

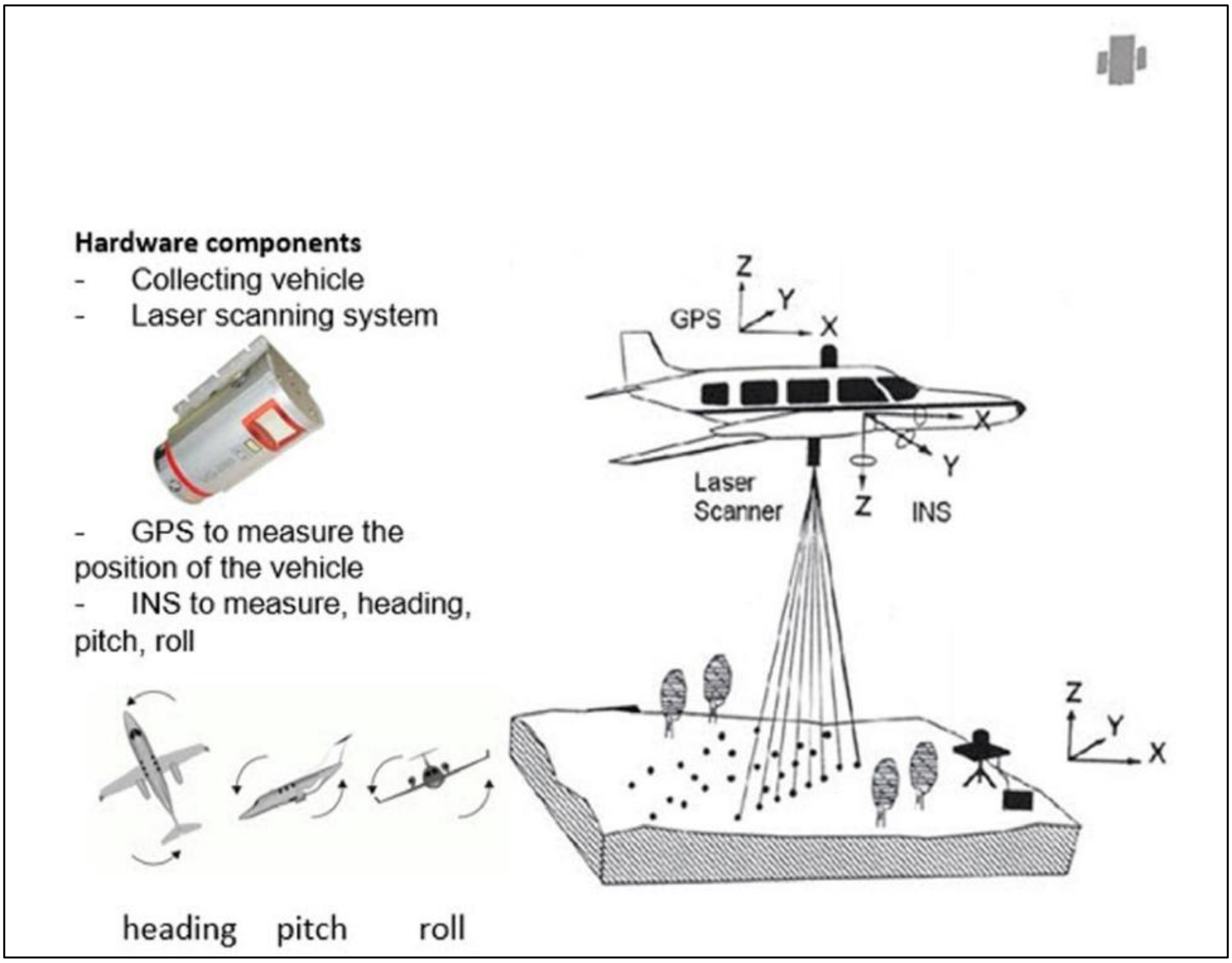


Fig. 3. Airborne LiDAR techniques and operations
(this illustration content originally combined by the authors of this paper)

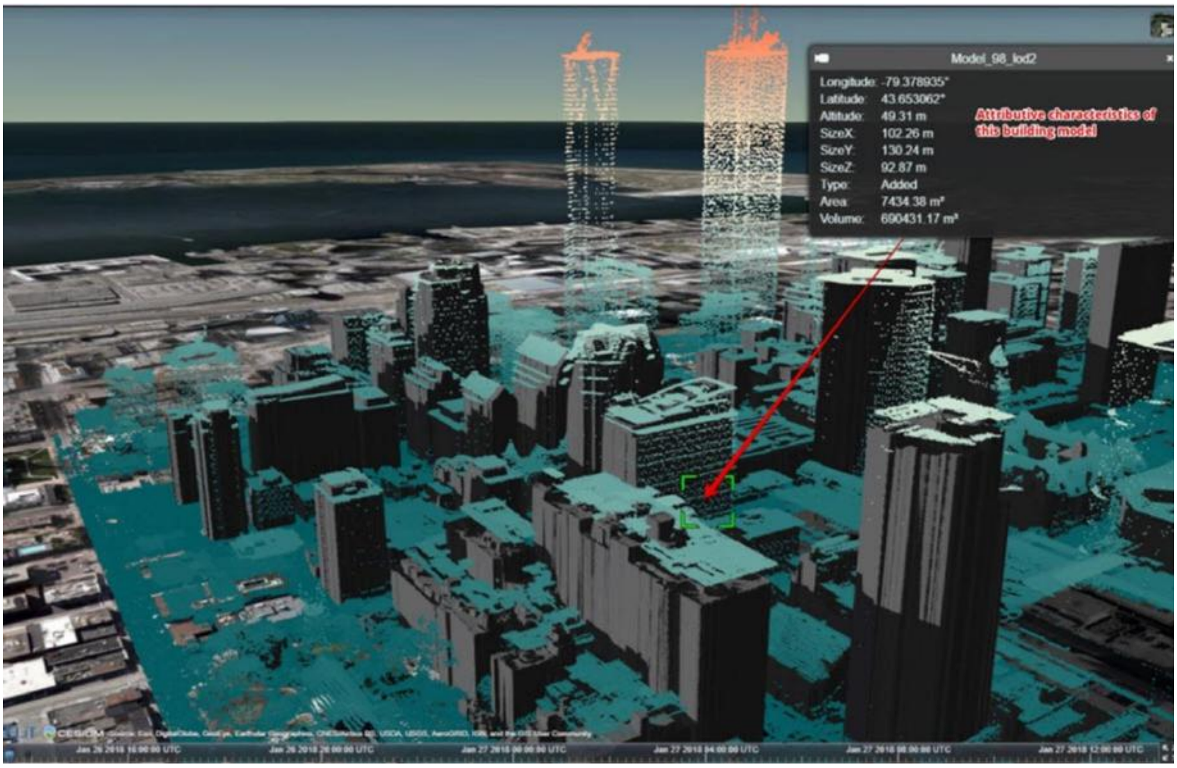
In our papers previously issued in this subject domain we emphasized that LiDAR remote sensing can broadly be defined as the technique set used to obtain the information about the topographic surface, vegetation, and various features of the human infrastructure at certain distance from them (buildings, bridges, roads, power lines, etc.) for further processing [28, 29, 50]. This information is usually the result of the low range airborne LiDAR data processing, which has the second return attribute defined. It measures reflected light from distant features to determine the range, and consequently from this information, to determine a feature position. Ordinary data resolution of our processing technique is between 5 and 90 *LiDAR* points per square meter. One of the principal LiDAR data and its further processing contribution is to increase our knowledge of the land surface, vegetation, about those mentioned human infrastructural features and, hence, to improve their use.

While normally photogrammetric techniques rely on remote sensing images, mainly – on the aerial ones, LiDAR sensors provide the fundamentals for further generation of 3D building models from point clouds all over various urban areas.

Certainly, any operations within the flowchart first data block are omitted, there is plenty of available attribute data, or the possibility of LiDAR data involvement is absent.

Automated feature extraction (AFE) has been the main topics of discussion in papers and in forums during the last one and a half decade. It means, first of all, extraction of city buildings and other infrastructural urban features [2, 9, 30, 32, 37, 38 39, 47]. Now, AFE is still a vitally crucial part of what is done and what people are trying to do better. How have we further progressed with AFE recently? We hope that our paper text will contribute, to a certain extent, to a possible answer to this question.

Derivative data of building extraction together with complicated classified information for the area of interest, gained from these point clouds too, may strongly enhance *the second data algorithmic block* – a block of attributed data for a given city (see Fig.2). Attribute data, representing different characteristics of this city, may be either commercial ones, or those that are in the open access. Attribute properties are prescribed to various types of GIS features according to standardized procedures [25]. Main attribute characteristics for each city (a case of the *external* UGS), or for each district (a case of the *internal* UGS) depict its basic properties, e.g., an urban area size, social geographic properties, including industries, services, transportation, and other features of municipal economies. While we are enhancing city attributes by derivative information obtained on the basis of the LiDAR data processing, we enter *the first summarizing node* into this flowchart, which indicates the *initial* key point of geoprocessing. With the *ELiT* web-based software functionality we can prescribe, edit, and visualize a set of various attributes with the ELiT Viewer for any urban object modeled from a LiDAR point cloud and provide processing of attributes for a whole layer of these objects [29] (Fig. 4):



Longitude: -79.378935°
Latitude: 43.653062°
Altitude: 49.31 m
SizeX: 102.26 m
SizeY: 130.24 m
SizeZ: 92.87 m
Type: Added
Area: 7434.38 m²
Volume: 690431.17 m³

Fig. 4. Visualization of the modeled urban feature attributes
by the *ELiT Viewer* of the *ELiT* web-based software

An algorithmic block of the branching *Applying the geographic scalability* directs the flowchart route either to study of the external urbogeosystem, or the internal one. The key issue of this choice is the availability of two alternatives – we may examine a region with point-cities, or look through a continuing urban area of city districts. Thus, we mainly operate with point GIS-features in the first case, and with areal features in the second one. This flowchart *second summarizing node* is the *intermediate* key point of geoprocessing, that redirects processing flow either towards modeling an external UGS, or to modeling an internal one.

The core block of flowchart is a subject area model block – *A Human Geography model chosen for urban studies.* A right choice of a proper subject area model prevents us from any probable failure upon the finalizing an ultimate GIS-model of an urbogeosystem. Choosing one among the series of Human Geography models, we need to address the model which provides the most effective and accurate estimate of the existing spatial patterns and regularities according to the content of data entering blocks in our flowchart. In general, a provider of this flowchart can select a required model from both a number of classic urban models (Burgess – 1924, Hoyt – 1939, Ullman and Harris – 1945, etc.), and from some updated ones, such as "land value / bid rent model", "model of multiple-nuclei urban structure", "urban realms model" [1, 4, 13]. Applying the scalability together with a selected subject area model allows us to obtain an initial set of linear linkages among these urban system units. Before the final completion of an UGS GIS-model these linear GIS-features have to be exposed to *final* geoprocessing at *the third summarizing node* of a flowchart. The final flowchart block of visualization – *Emergent properties…* - in the optimal case has to expose the core structural properties of an urban geographic system by visualizing it either in a map window, or in a graphic window, as well as in a browser window of a graphic user interface.

A case study of the external urbogeosystem. In two following paper sections we take a few examples of both external and internal urban geographic systems of Kharkiv region, Eastern Ukraine, to demonstrate in what way the geoinformation approach to UGS research can be provided in a practical perspective. Two from these authors have already published some unique results due to the regional commuting modeling by GIS *MapInfo Professional* [26].

By developing further Renkow-Hoover's model of commuting [35] and representing corresponding mathematical techniques, we introduced the spatial econometric analysis for commuting study directed to a regional workforce market. It has been proved that both labor migration and commuting are two dominant issues for studying any workforce market, either at the national level, or at its regional one. What is more, in our attempts to understand a regional migration level, we should select just commuting as its dominant trend. The elaborated model has assisted to estimate a rough number of regular daily-weekly commuters to the central one and other cities in the region in 2012-2014.

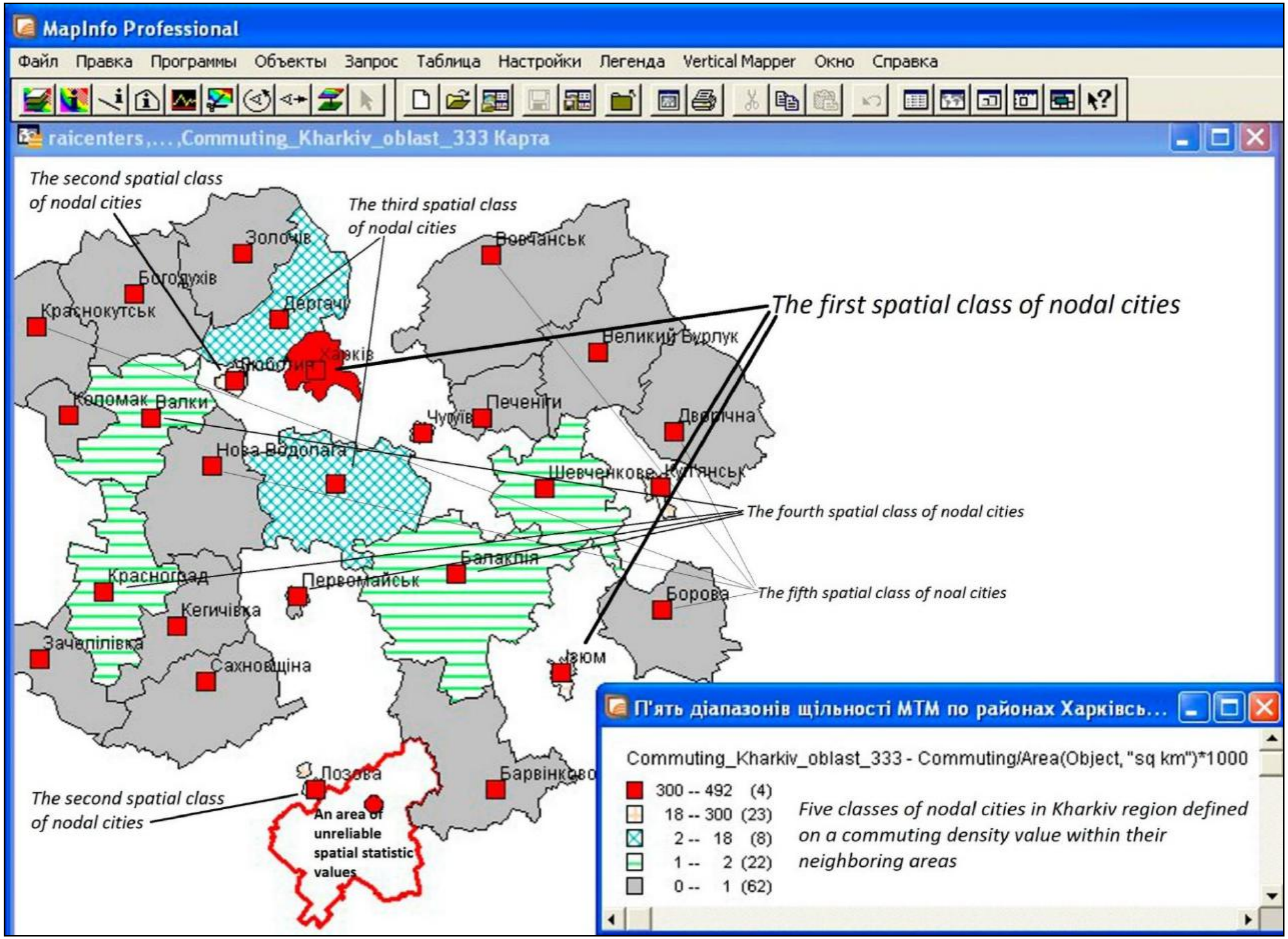
Built within the research referred to framework a detailed geodatabase (GDB) of the social geographic properties of the region significantly assisted in determination by the flowchart above (refer to Fig. 2) of the external UGS spatial distribution / interaction pattern completed by main individual cities of this area. With three summarizing nodes of the flowchart, which finally built the interactive structure of GIS-linear features, key cities of the regional nodal network, accepted as an external UGS core, have been defined by analyzing all initial linkages and derivative interdependencies among all city pairs in the region.

Strong spatial correlation has been defined between a city nodal rank, which it possesses in the external UGS and the value of commuting density (a number of commuters per sq. km) introduced by us in the previous publication referred to [26]. Afterwards a number of interactions for each county center with all its neighboring settlements was calculated, valued, and ranked.

The *MapBasic* programming language module has been developed for this purpose, and results of its application are visualized in the next illustration (Fig. 5). Five classes of nodal cities have been defined in the GDB on the basis of commuting density value spatially modeled for their neighboring areas. Randomly selected, spatially referenced point values of commuting density bounded to a settlement (a city or a village), which was completed at *A GIS-model of an urbogeosystem* block of the flowchart (refer to Fig. 2), have been finalized with the following results of a spatial GIS-classification (refer to Fig. 5):

- Taking into account the contemporary economic situation in Ukraine (the drastically forced labor migration from rural to urban areas), the highest values of commuting density (the first class) were prescribed by default to all urban areas of county centers in the region (red square symbols both in the map, and in the classifying legend – refer to Fig. 5);
- *The first class* (300 – 492 commuters per sq. km) – there are 4 spatially referenced point values of commuting density in city neighboring areas belonging to this class;
- *The second class* (18-300 commuters) – 23 point values;
- *The third class* (2-18 commuters) – 8 point values;
- *The fourth class* (1-2 commuters) – 22 point values;
- *The fifth class* (0-1 commuters) – 62 point values.

The key assumption is that commuting density around a certain urban area should reflect a nodal weight of a corresponding city. Such an assumption may be made proceeding from common references about some connection existing between the degree



Commuting_Kharkiv_oblast_333 - Commuting/Area(Object, "sq km")*1000

🟥 300 -- 492 (4)
☐ 18 -- 300 (23)
☒ 2 -- 18 (8)
▤ 1 -- 2 (22)
■ 0 -- 1 (62)

Five classes of nodal cities in Kharkiv region defined on a commuting density value within their neighboring areas

Fig. 5. Spatial classification of nodal cities in the external urban geographic system of Kharkiv region in *MapInfo* GIS

of commuting activity in a certain area and a number of interactions of a given city, which is the aim of commuters [20, 21]. For proving the reliability of city nodal weighting definition through commuting values we attempted to define *spatial correlation ratios* between point values belonging to each class, on the one hand, and a number of significant interactions for each city from this class. The interaction significance was determined at *Linear GIS features* block of the flowchart according to modeling technique of *the urban geosystem of two levels GIS-model* published earlier (Кострiков, 2016). The first class possesses the aggregated correlation ratio value of 0.645; the second class – 0.747, the third class – 0.710, the fourth class – 0.797, and the fifth – 0.891. All classes of spatial ratios have been defined as statistically significant, if we apply to the variety of their separate point values bounded to a certain cities Student's t-criterion of the correlation ratio significance.

Those administrative counties that demonstrated the lack of aggregated data according to these two criteria – commuting values and a number of significant interactions – are depicted as blank spaces on the map (See Fig. 5). Some cities were included in modeling based on the territory directly adjacent to a city, not a whole country area (a case of Kupiansk, Izium, Lozova, Pervomaisk, and Liubotyn). Chuguiv has been excluded from calculations, because the adjacent territory, where commuting density can be reliably estimated, is extremely small. One county (Blyzniuky as a county center) showed an unreliable correlation ratio between the two basic parameters, and it was excluded from modeling (bordered by a red line in the map – Fig. 5).

Proceeding from two interactive factors outlined above, we have provided the following spatial classification of *nodal cities and their neighboring territories*, which nodal rank is diminished from the first class to the fifth one. The "nodal cities + adjacent areas" classes of the external UGS possess the following cities of Kharkiv region:

- *The first class:* Kharkiv-City; Izium, and Kupiansk;
- *The second class:* Liubotyn, Lozova;
- *The third class:* Derhachi, Zmiiv;
- *The fourth class:* Valky, Krasnograd, Pervomaisk, Balakliya;
- *The fifth class:* Krasnokutsk, Vovchansk, Nova Vodolaga, Borova, and Dvurichna.

Both nodal *cities ranging* and their spatial distribution over Kharkiv region generally correspond to known social economic regularities in the area, but nonetheless it also demonstrates some deviations, which should be a subject of further research.

Case studies of the internal urbogeosystem of Kharkiv-City. Two other applied examples introduced in this paper are related to the internal UGS of Kharkiv-City.

In the first example of the internal UGS study the LiDAR data obtained from both an aircraft (airborne LiDAR – ALS data), and from a mobile surface vehicle (MLS data) have been processed by our original software, developed by one of the leading authors and presented in our earlier paper [50]. Processed results were employed for estimation of architectural dynamics of Kharkiv-City and for enhancement of the available attribute data for the city according to the first two blocks of the flowchart of the urbogeosystem study (refer to Fig. 2).

Not the *ELiT* web-based software, but our desktop LiDAR data processing application, developed few years earlier, has been employed. The *Surface Detector tool* of this software is designed to deal with the low range airborne LiDAR data that has the second return attribute defined. Normal data resolution of the developed technology is between 5 and 80 *LiDAR* points per square meter, which means some advantage in comparison with most of the similar techniques existed [37, 39, 40]. *The Building Extractor tool* is designed to operate with both the low range ALS and the MLS data. The approach aims to produce the output building models with resolution of 35 cm approximately. This supposes that the input MLS data should have the resolution of 400 points per square meter or more. The approach also intends to build the colorized planes (images) based on RGB attribute of MLS data to be draped on a building model. This assumes that the input MLS data should have the RGB attribute assigned to each data point. Testing MLS-survey provided within an area-of-interest (AOI) - a selected key parcel of Kharkiv-City proves the reliability of its results (Fig. 6).

Procedures of the LiDAR point cloud AFE and classification have been provided further on the base of testing surveys described above. In the following example for a test site, which belongs to Kharkiv urban area, the LiDAR data processing desktop software assigns point objects to *one* certain class from *four* nominated (i.e. *ground, vegetation, buildings, other human infrastructure*) (Fig. 7).

Successful spatial classification secures further applying of thematic GIS-mapping and allows us to provide prompt visual data analysis "on fly". Then any particular class of defined points can be put into a separate mapping layer for further processing. As a final output, a number of pseudo-vector files (of *.3D Obj* format) are produced, where each file represents one separate building extracted while processing from LiDAR. These files reference to separate image files. The latter contains textures to be draped on the *3D* models. All this completes a combined *3D* picture of a certain urban area, which can be almost of any size according to city borders upon applying the geographic scalability procedure (refer to Fig. 2).

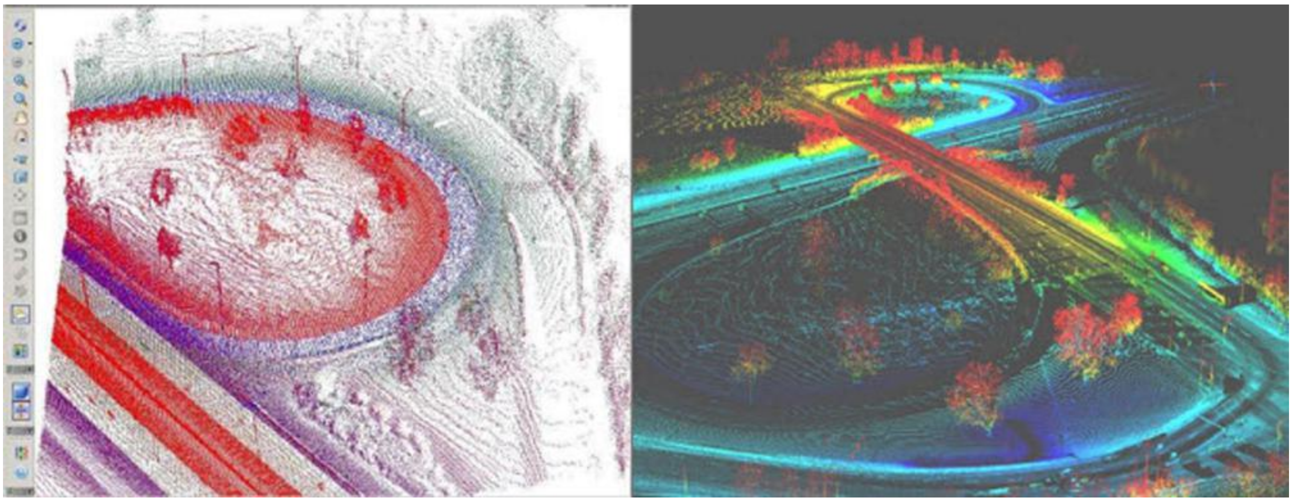


Fig. 6. Environmental survey with MLS processed results for a chosen AOI: ground cover, low and high vegetation belt, surface human infrastructure

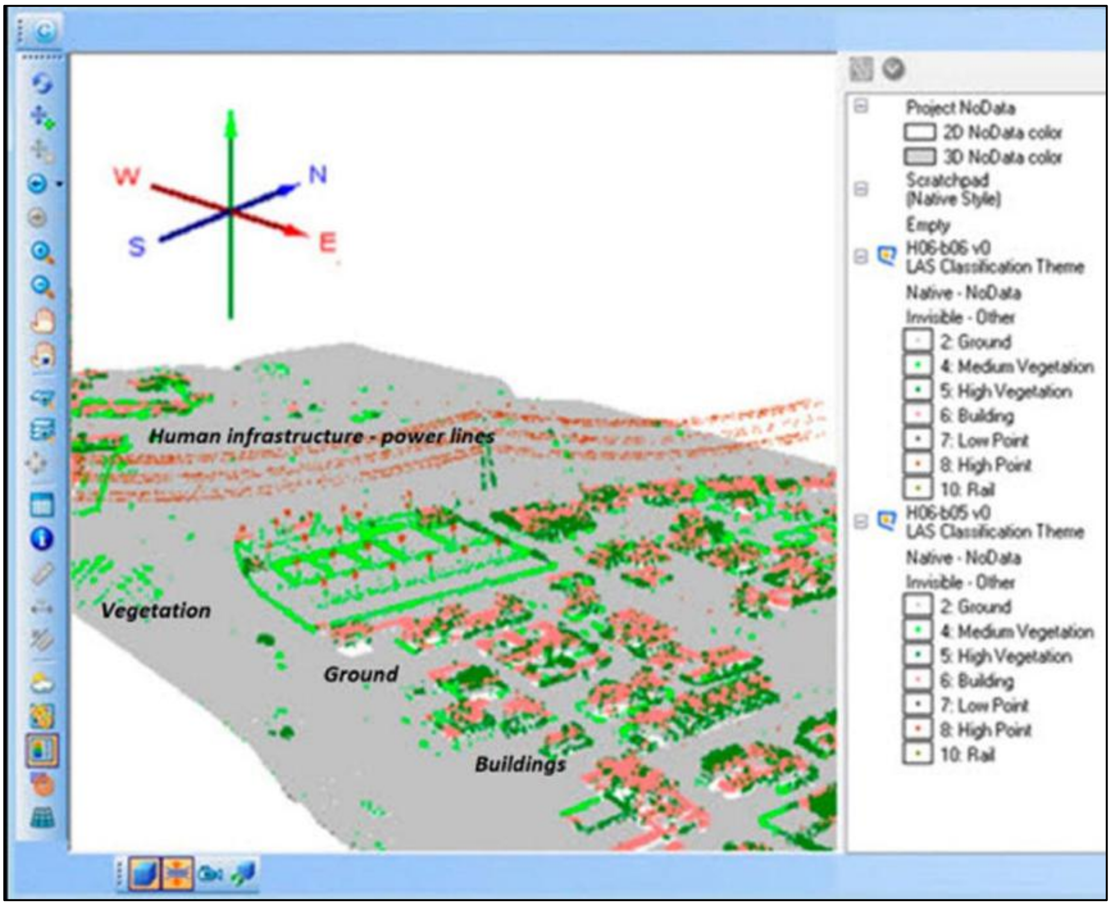


Fig. 7. Results of LIDAR data automated classification for a test site

With respect to the case study examined, the high-resolution LiDAR data generated from the point clouds have been proved to be the most efficient information for automated extraction of buildings in densely built-up parts of Kharkiv urban territory in comparison with any other remote sensing data.

Any significant changes in the spatial structure of the internal UGS mean changes in social economic attributes of a city. The latter understandably can be traced by monitoring city architectural modifications. All aforementioned in this paper section explains, why architectural alterations in the optimal way should be monitored by application of LiDAR tools thus enhancing the quality of whole city attribute data.

The second example concerning the internal UGS study, introduces this urbogeosystem function research with GIS-tools through a megalopolis urbanized area. In this case, the arrangements of catering services over the urban area of Kharkiv have been examined as a urbogeosystem function [48]. The municipal social sphere, which includes these services, has been described as a key city attribute according to the second data block of the flowchart. Geoprocessing, analysis, and visualization of the catering services spatial distribution has been completed within an advanced GIS-interface of the *ArcGIS 10.2* platform (Fig. 8).

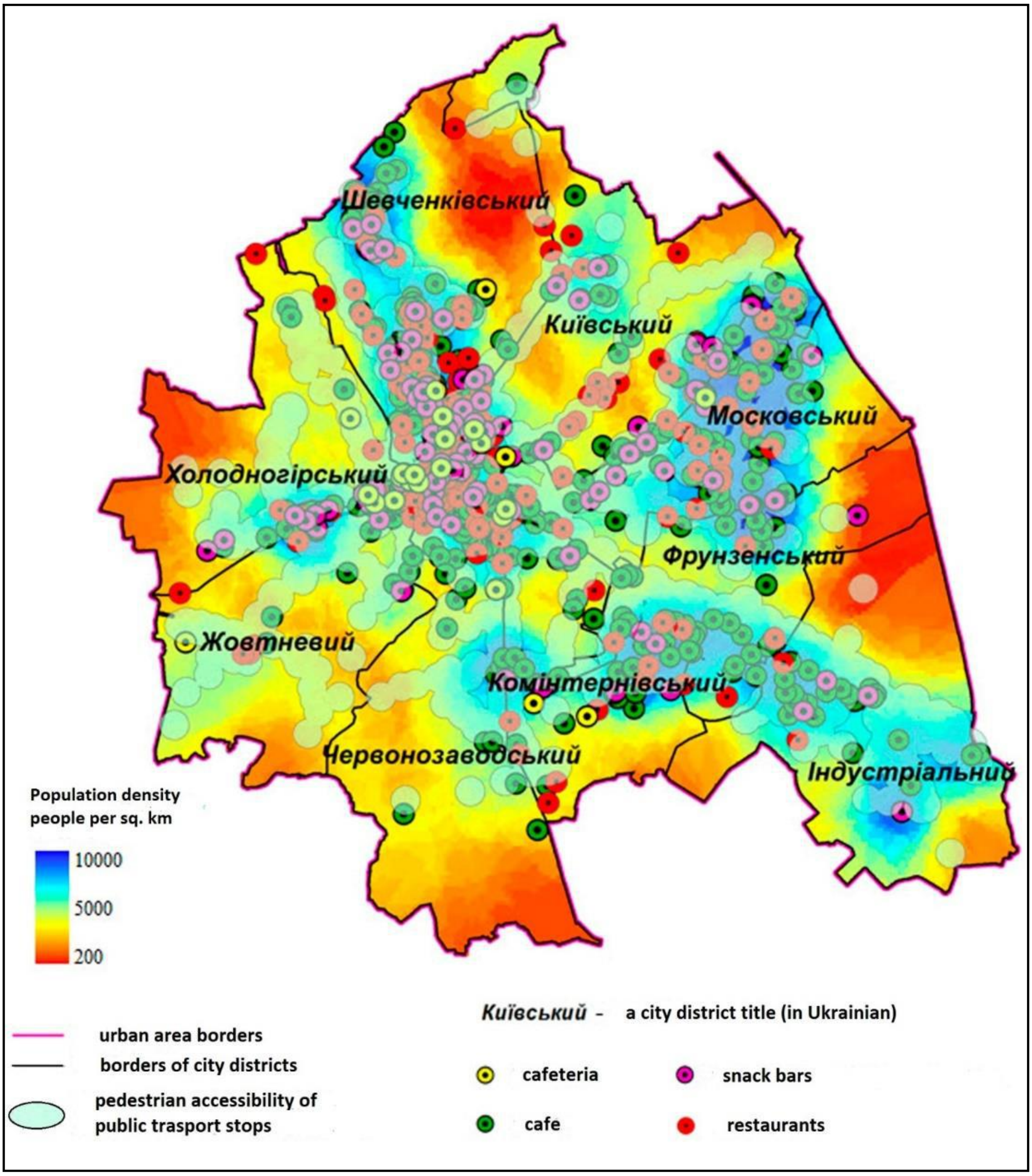


Fig. 8. Mapping overlay of spatial distributions of population density (raster layer), catering services (vector features), and buffer zones of pedestrian availability along main routes of public transport network: a case study of Kharkiv-City [48, p. 97]

Spatial distribution of the urban population density and population income, as well as spatial characteristic features of the city public transport network have proved to be three key factors of the catering services allocation (only statistically estimated the most visited ones have been selected for visualization).

At the first sight, it is reasonable for municipal authorities to place catering services in the place where townsmen change public transport for walking (and opposite) upon their daily routes. Such allocation upon the factor of mandatory pedestrian availability (5-7 minutes of walking and 400-500 m of distance) provides complete covering of all customers independently of city district borders. To check this rule of catering services allocation we have built 400 m buffer zones by the Zone burring methods around each public transport stop and merge all zones into one mapping layer all over the city with assistance of *ArcGIS tools* [17].

We overlaid both factor layers, and a resulted layer of spatial correlation to reveal the internal UGS emergent properties caused by its functionality. The final overlaid picture of spatially correlated three factor layers (population density, pedestrian accessibility of public transport stops, and intracity borders of districts) and one resulted layer (catering services allocation) is shown above (refer to Fig. 8). Topological and geometric regularities of defined spatial zones of catering services distribution indicate definite impact of the urban geosystem functionality on this distribution. This impact consists in such topological entity generation though a whole urban area as a “six petal flower” of these services spatial distribution. Had catering services been allocated only on the base of municipal socio-economic rules mentioned above, any topological definite entity would have hardly been defined over a whole urban area. It means that spatial structure of city districts as components of an internal urbogeosystem does impact social infrastructure allocation throughout an urban area.

Results and conclusion. The authors of this paper have further developed the concept of the geoinformation approach to the study of two-level urban geographic systems. The authors have attempted to prove that an urban geographic system itself is not merely a straightforward aggregate of either cities upon the external case study, or city districts in the internal one. The whole methodological approach can be considered as some general outlining in what way to use a geoinformation software for the analysis of an urban geographical system. Analytical capabilities of the geoinformation software, both desktop and web-based one, for an UGS, have been listed and briefly discussed with the emphasis on the LiDAR data processing operational procedures. The proposed urbogeosystem concept may appear highly essential for both visual research, and a set of different analysis applied for urban areas, including, for instance, city planning, urban viewshed analysis, municipal properties inventory, allocation of transportation network and other infrastructure, facility management, etc.

Within this research provided we have completed the following issues:

- Brief summary of the GIS and LiDAR data processing software contemporary performance in urban studies focused on some specific issues of this technique application;
- Introduced GIS-approach to urban studies has been further developed and additionally proved to be a significant constituent of the Human Geography methodology;
- The definition of an urban geographic system has been specified and theoretically grounded more in details in comparison with its earlier introduction;
- Basics of GIS-primitive features use in urban studies have been extended further;
- Template algorithmic sequence for the UGS research with GIS has been proposed, accurately explained and proved;
- Two levels of an urbogeosystem (external and internal ones) outlined earlier have been featured with applied examples;
- A regional case study of the external UGS of Kharkiv region has been provided with GIS *MapInfo* tools;
- Two urban case studies of the internal urbogeosystem of Kharkiv-City have been introduced – one with the original software of LiDAR data processing for enhancement of the city attribute data, and the other – with *ArcGIS* spatial analysis tools for estimation of the urbogeosystem functionality impact on spatial distribution of some socio-infrastructural objects and services.

***Authors Contribution**: All authors have contributed equally to this work.*

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GEOINFORMATION APPROACH TO THE URBAN GEOGRAPHIC SYSTEM RESEARCH (CASE STUDIES OF KHARKIV REGION)

Research problem introduction. The main research goal of this paper is to provide the urban geosystem research concept with both the theoretical basics presentation of GIS involvement in urban studies, and with examples of its practical applications.

An urbogeosystem (UGS) has been presented not as a simple aggregate of cities, but as the emergent entity that produced complicated interconnections and interdependencies among its constituents. By the urbogeosystem concept the authors attempt to introduce a reliable research approach that has been deliberately developed to identify the nature and spatial peculiarities of the urbanization process in a given area. The exigency of this concept elaboration is listed by the number of needs and illustrated with ordinary 2D digital city cadaster limitations. The methodological background has been proposed, and its derivative applied solutions meet the number of necessities for more efficient urban mapping, city understanding, and municipal management.

The geoinformation concept of the urban geographic system research. External and internal urbogeosystems. The authors explain why an UGS can be formalized as three major components: an aggregate of point features, a set of lines, an aggregate of areal features. The external UGS represents a set of cities, the internal one – a set of delineated areas within one urban territory.

Algorithmic sequence of the urbogeosystem study with a GIS. The authors introduce algorithmic sequence of research provision with GIS, in which the LiDAR data processing block has been examined in the details with the procedure of the automated feature extraction explanation. Relevant software user interface sample of the visualization of the urban modeled feature attributes is provided.

A case study of the external urbogeosystem. The regional case study of the external urbogeosystem modeling is introduced with GIS *MapInfo Professional*. The authors present the spatial econometric analysis for commuting study directed to a regional workforce market. The results of the external UGS research mainly correspond to some published social economic regularities in the area, but nonetheless it also demonstrates significant deviations that may be explained by this system's emergent properties.

Case studies of the internal urbogeosystem of Kharkiv-City. Two case studies of the internal urbogeosystem of Kharkiv City have been demonstrated, too. In the first one, automated feature extraction provided by the authors' original software from LiDAR data has been applied for modeling this UGS content throughout a densely built-up urban parcel. In another case the GIS-analysis of the urbogeosystem functional impact on the catering services spatial distribution has been provided with the *ArcGIS* software.

Results and conclusion. Summarizing all primary and derivative data processed with this technique as well as generalizing key ideas discussed in the text, the authors underline this whole methodological approach as such that can be considered as a general outlining showing how to use geoinformation software for the analysis of urban areas. Concluding their research, the authors emphasize that the urbogeosystem concept may be quite useful for visualization and different analysis applied for urban areas, including city planning, facility and other municipal management methods. The short list of the obtained results has been provided at the end of the text.

Keywords: urbogeosystem, GIS, geoinformation approach, urban studies, algorithmic sequence, LiDAR, external and internal urban geosystems, case studies.

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