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The performance of the digital city projects in urban studies of the megalopolises (the case studies of Kharkiv and Dnipro cities)

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ABSTRACT

Introduction of the research problem. Urbanization drives Digital City Projects (DCPs) to create smarter urban environments using advanced technologies. DCPs aim to make cities more connected and responsive, adapting to changing needs. The **objective** of this paper is to evaluate the performance of DCPs in megalopolises, focusing on Kharkiv and Dnipro in Ukraine.

The previous works done. The various literature sources demonstrate the rise of Digital Cities stemming from Smart Cities. Kharkiv and Dnipro in Ukraine exemplify digitalization's role amid Russian aggression.

Exposition of the main research material. ***The performance of the theoretical urbogeosystemic approach and its UOM in the provision of practical Digital City projects.*** This subsection delves into the practical application of the urbogeosystemic approach and its Urban Ontological Model (UOM) in DCPs. The UOM guides urban studies by defining components and relationships. Implementing DCPs begins with building simulation models using LiDAR data.

Case Study First - Kharkiv: A feasible perspective of a full-format DCP implementation. This subsection discusses implementing a DCP in Kharkiv, emphasizing data integration from *OpenStreetMap (OSM)* and LiDAR. The authors propose that a DCP should serve as a comprehensive model of a real city, encompassing all its structural elements and key objects, going beyond the capabilities of a typical GIS project. Possible user's scenarios include energy consumption analysis, population estimation, and visibility gradients assessment. The subsection highlights the comprehensive DCP approach with LiDAR data processing software (*iQ City CCM*) and urban geosituational analysis.

Case Study Second - Kharkiv: a perspective of geomarketing within the "Digital Kharkiv" project as a routine GIS one. This subsection delves into the integration of geomarketing into the "Digital Kharkiv" project. Geomarketing plays a pivotal role in mapping socioeconomic elements tied to market interactions. "Digital Kharkiv," primarily sourced from *OSM* data, is lauded for its versatility in urban studies during peacetime and war. The text urges exploration of geomarketing within "Digital Kharkiv" in the context of post-Russian aggression rehabilitation, particularly in optimizing humanitarian object placements. Changes in geomarketing potential pre- and post-invasion in various city districts have been analyzed, highlighting areas with stagnation and those witnessing growth due to population resettlement.

Case Study Third - Dnipro: implementation of a typical GIS-project for analyzing provision of the city population with public transportation infrastructural networks. This subsection discusses the implementation of the "Digital Dnipro" project as part of the DCP framework. The project focuses on analyzing the provision of public transportation networks in the city of Dnipro. It utilizes data from *OSM* to create a virtual model of the city, which includes attribute information for urban objects. This subsection also highlights the impact of war on urban planning and the need for sustainable updates to adapt to changing conditions.

Conclusion. This section summarizes the key findings and takeaways from the research on DCPs in Ukrainian cities like Kharkiv and Dnipro. It highlights the importance of an urbogeosystemic approach in implementing DCPs effectively. The study emphasizes the flexibility and efficiency of the relevant GIS tools in urban research and transformation.

Keywords*: "Digital City" project, urbogeosytem ontological model, urbanistic environment, global coverage maps, interface and functionality of desktop software, user's cases of application, typical (routine) GIS-project, web tools.*

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Introduction to the research problem. Continuing rapid urbanization of the twenty first century has ushered in a period of time, where cities are at the forefront of global transformation. For the time being, more than half of the world's population resides in urban areas, and this trend is expected to intensify in the coming decades [1]. The modern cityscape is characterized by its complexity, dynamism, and the ever-increasing challenges posed by issues such as congestion, pollution, resource scarcity, and social inequality. In response to these challenges, cities around the world have embarked on a transformative journey, seeking to harness the power of digital technologies to create smarter, more sustainable, and efficient urban environments. This can be provided through so called *Digital City Projects* (DCP) [2-9].

According to general understanding, DCPs are designed to create various digital models of smart cities that are more efficient, sustainable, and livable. Such projects after reaching their ultimate state can represent usage of a number of advanced technologies such as the Internet of Things (IoT), big data analytics, and artificial intelligence to improve urban services and infrastructure. These projects aim to create a more connected and responsive urban environment that can adapt to changing needs and demands. The key dominant feature of the DCP subject, a digital city itself, is that this entity is a complex system associated with particular social, economic, ecological, and demographic urban conditions and changes [10]. The general frameworks for any solution in Urban Studies that is expected to be made on the DCP-basis include building real-time connectivity between non-physical (virtual) and physical objects titled as *a dynamic digital twin* [9,10].

We have already attempted to prove in our quite a few previous publications, that the introduced in it the urbogeosystemic research approach implemented within the Urban Remote Sensing (URS) frameworks can hardly be overvalued in a perspective of the contemporary urban studies [11-13].

In 2003, the First Earth Observation Summit issued a declaration to establish the ad hoc international Group on Earth Observation (ad hoc GEO). The GEO plan introduced the concept of the Global Earth Observation System of Systems (GEOSS) and delineated nine areas of its societal benefits [14]. Subsequently, numerous publications have contributed to the GEO Strategic Plan, with a notable example being a book on remote sensing for sustainability [15].

Since 2016, GEO has initiated the "Global Urban Observation and Information" Initiative, which sets forth six main objectives to be achieved by 2025 [16]. The distinctive characteristics of contemporary urban development have posed several challenges that demand innovative technological advancements in urban studies. These challenges and innovations can be summarized like follows:

- With the rapid evolution and transformation of the urbanization process, the study of urban systems has become increasingly intricate.
- The proliferation of cities and the rapid expansion of urban territories, particularly in developing nations, present significant challenges.
- Regions experiencing rapid urbanization with extensive construction projects are on the rise.
- The need for precise terrain models for urban planning and related spatial data processing is evident.
- The requirement for effective automated building surveys to assess the quantity and quality of architectural changes over time is recognized as an essential aspect of urban monitoring.
- Regular and precise environmental surveys of key cities in regions with extensive remote sensing data analysis are indispensable.

The advanced methodological concept of the *Digital City* has emerged as a pivotal component of this urban transformation briefly introduced above. Digital Cities are those entities that employ advanced technologies and data-driven solutions to enhance various aspects of urban life, including transportation, healthcare, education, governance, and public services [17]. These cities leverage information and communication technologies (ICTs) to optimize resource allocation, improve decision-making processes, and enhance citizen engagement. By doing so, they aspire to create urban environments that are more livable, economically vibrant, and environmentally sustainable [18].

As it has followed from all stated above, the implementation of Digital City initiatives is not limited to a particular geographic region; it may become a global phenomenon. In the context of *megalopolises* – large, interconnected urban regions typically characterized by a high population density and economic activity – the adoption of digital technologies becomes even significantly more critical due to the scale and complexity of urban challenges [1]. Megalopolises often serve as economic engines, cultural hubs, and centers of innovation, but they also face unique challenges related to infrastructure development, resource management, and social integration. These challenges are normally absent in other urban areas, which are of smaller scale.

The main **research objective** of our paper is to estimate, while basing on our urbogeosystemic approach’s latest updates, the performance of some Digital City projects in the urban studies of megalopolises, with a specific focus on the cities of Kharkiv and Dnipro in Ukraine. Before the war both Kharkiv and Dnipro represented prominent urban centers within the country's eastern region and had been actively pursuing digitalization initiatives as part of their urban development strategies. The horrific events caused by the Russian aggression altered everything to the worse. Nonetheless, by conducting few detailed case studies of these cities, we aim to shed light on the impact, challenges, and opportunities associated with Digital City projects in these megalopolises in the post-war period of their rehabilitation.

The previous works done. While overviewing the existing background of the selected research topic, we simply can't avoid to delineate in it the following constituents: 1) *the rise of Digital Cities* as some branched version of the Smart Cities category; 2) accumulating *Challenges in Megalopolises*; 3) at least briefly *the Ukrainian Context* should be taken into account.

The rise of Digital Cities. The emergence of Digital Cities can be traced back to the mentioned broader concept of *Smart Cities*, which gained momentum in the early 21st century, and it also was a subject of our particular research within the frameworks of the multifunctional approach, which combined our urbogeosystem (UGS) theory with the URS technique for LiDAR (Light Detection And Ranging) data processing. [19].

Smart cities leverage data and technology to enhance the quality of life for their residents while promoting sustainability and economic growth. Digital technologies such as IoT, AI, data mining, and blockchain have played pivotal roles in enabling smart city solutions [20-22]. The realm of Smart Cities, which accepts it as a complete synonym of a Digital City category, has seen a surge in publications in recent years, resulting in the challenge of selecting essential core elements amidst a plethora of definitions. Notably, innovation emerges as a prominent key element within this approach [23]. The key components of this comprehensive review of Smart Cities' definitions encompass various facets:

- "A city well-performing in a forward-looking way..." [24, P. 8];
- "A city that monitors and integrates conditions of all of its critical infrastructures" [25];
- "Connecting the physical infrastructure, the IT infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city" [26];
- "Combining ICT and Web 2.0 technology with other organizational, design, and planning efforts to identify new, innovative solutions to city management complexity, in order to improve sustainability and livability" [27];
- "The use of Smart Computing technologies to make the critical infrastructure components and services of a city more intelligent, interconnected, and efficient" [28].

The Digital City category actually extend the principles of smart cities by placing a strong emphasis on the integration of ICTs across various urban domains, exactly as it underlines meaning of *the spatial extent*. These initiatives seek to create a seamless and interconnected *urban ecosystem* where data flows freely between different sectors, enabling real-time monitoring, analysis, and decision-making. The ultimate goal is to improve the efficiency of urban services, enhance urban governance, and empower citizens to actively participate in shaping their cities [29, 30].

Accumulating Challenges in Megalopolises. Megalopolises have been often referred to as "urban corridors" or "super-cities," are unique in their spatial and demographic characteristics [31]. They are characterized by extensive urban sprawl, high population densities, and a complex web of economic, social, and environmental interdependencies. While megalopolises offer unparalleled opportunities for economic growth and cultural exchange, they also face significant challenges related to infrastructure, transportation, housing, and social cohesion [32]. The Digital City projects in megalopolises must navigate these complexities. They must address the specific needs and dynamics of these densely populated urban regions while striving to achieve the overarching goals of sustainability, resilience, and inclusivity [8, 33]. Understanding the performance of such initiatives in megalopolises is crucial for policymakers, urban planners, and researchers seeking to develop effective strategies for the digital transformation of urban territories [34].

The Ukrainian Context. Ukraine – our country at the crossroads of Eastern Europe, has been undergoing a profound transformation since gaining independence in 1991. Its urban centers, including Kharkiv and Dnipro, have played pivotal roles in this transformation. These cities have not been only economic and industrial hubs, but also centers of culture, education, and innovation. In recent years, Ukraine has recognized the importance of digitalization as a key driver of economic growth and social development. The government has initiated various programs and policies aimed at promoting the digital transformation of cities. Kharkiv and Dnipro have been at the forefront of these efforts, implementing Digital City projects that encompass a wide range of urban domains, from transportation and healthcare to e-governance and public safety. All mentioned positive changes and innovations have been implemented until the Russian aggression ruined very much and threw us back in time for the decades. Nonetheless, taking into account the perspectives of the post-war rehabilitation, it would be reasonable to mention and implement in this current research at least those our own developments and conclusions, which had a strong regional aspect and referred to urban digitalization: 1) estimation of the local commuting in Kharkiv region [35]; 2) provision of a GIS-project though some testing parcels in Kharkiv [11], 3) establishing the strong theoretical background as the urbogeosystemic approach (UA) to the Smart City concept implementation with the URS [36]; 4) a delineation of *geographical situations* in the urban environments of selected cities, including Kharkiv [37].

At its core, UA is a comprehensive framework that conceptualizes cities as dynamic, interconnected systems and recognizes that modern cities are complex, multifaceted entities influenced by a multitude of factors, from environmental conditions to socioeconomic dynamics [11-13]. An urbogeosystem sees urban environments as living organisms, where every element, whether natural or artificial, plays a role in shaping this city identity.

Exposition of the main research material. ***The performance of the theoretical urbogeosystemic approach and its UOM in the provision of practical Digital City projects.*** While mentioning the Smart City concept above, we meant, that it has gained prominence in recent years, which was driven by the need for sustainable urban development and efficient resource management. In our previously completed attempts we outlined that the central issue of this concept is notion of an "ontological model of the urban geographical system" (UOM) (Fig. 1), which would serve as the linchpin connecting various aspects of a Smart City [36].

We have proved in the relevant implementations of the urban environment digitalization, that such ontological model would not be merely a theoretical construct, but a practical framework that underpins the development of a Digital City Project [11, 13, 37].

The UA, while a powerful theoretical construct, finds its practical manifestation in the UOM. This model is already mentioned linchpin that translates UA principles into actionable plans for both regional, and local Digital City Projects. It does so by defining the key components and relationships within a Smart City, providing a structured roadmap for urban planners and policymakers.

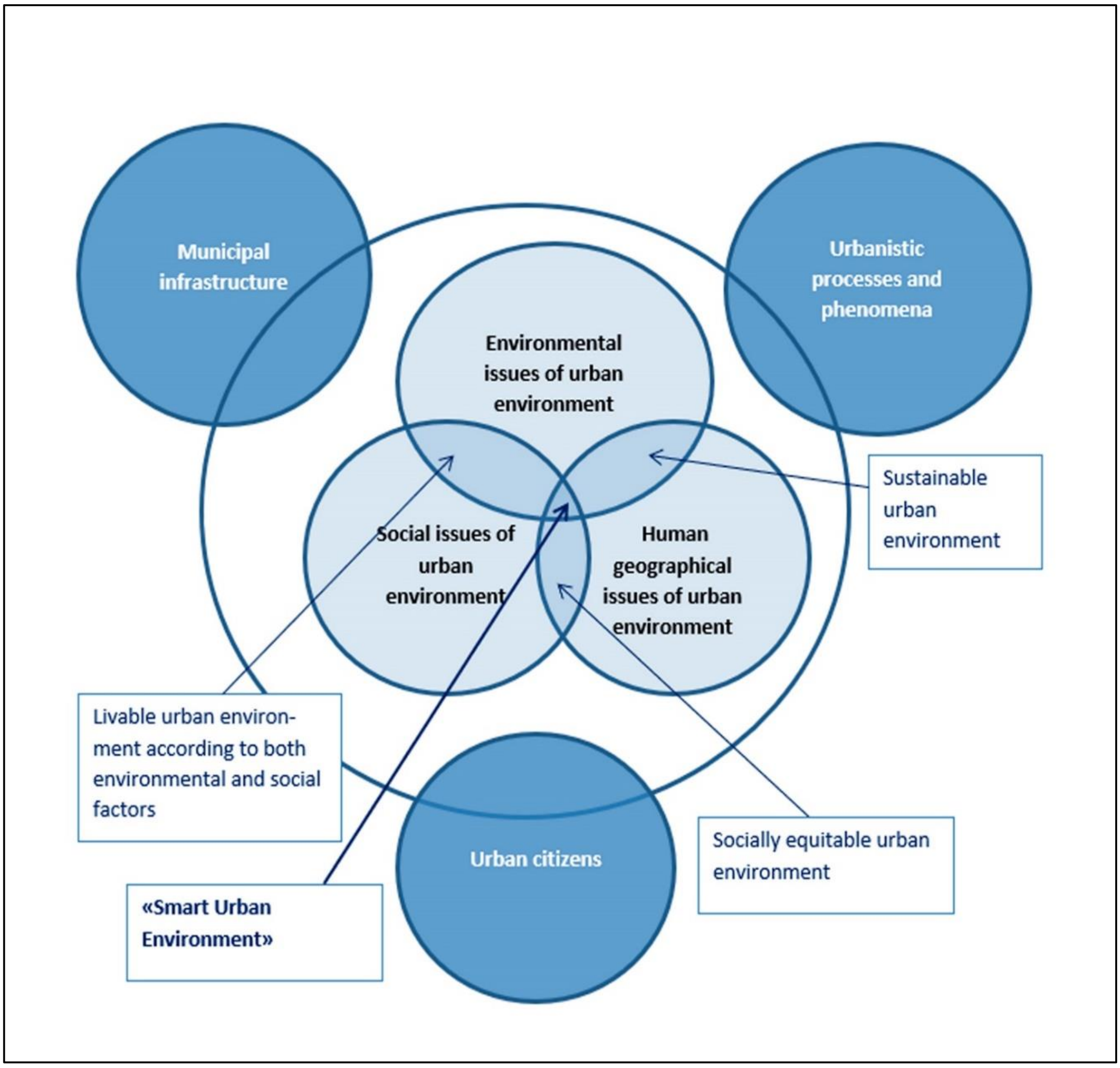

Fig.1. The structure and content of an ontological model of the urban geographical system [36, P. 106]

We conceived of the UOM as a kind of trinity tripod that draws strength from and fosters intercomnecttions among all three of this model constituents: urban citizens, municipal infrastructure, and urbanistic processes and phenomena. Together, these components enable the sustainable operation of a city, which can be evaluated as "smart operating" based on various existing criteria. Furthermore, the UOM aids in defining the core aspect of the Smart City concept within its geospatial perspective—the position of the "smart urban environment" in the broader hierarchy of environments related to a Smart City [36].

The basic modeling structure shown on the illustration above models aligns with the "cities as systems of systems" theory, positing that an urban entity branched into three levels (macro-, meso-, and micro-) comprises multiple subsystems [38]. The practical implementation of the DCP can commence by creating a simulation model for a selected city. This simulation model draws from urban remote sensing data in general [39], or LiDAR (Light Detection and Ranging) surveying results in particular [40], as well as the constituents of the global map coverages like *Open Street Map* can be involved together with broad range of remote sensing data [41, 42]. Once a computer model of the city is generated as a digital city project, preferably adhering to 3D City GML standards, the structure of the conceptual UOM of an urbogeosystem, as illustrated above, serves as the optimal architectural design for this Digital City simulation. If the "smart urban environment" occupies a central role in this targeted UGS construction, numerous technological, environmental, and socio-geographical solutions, made on the path to DCP implementation, should align with the hierarchy outlined in this UOM (Fig. 1). The UOM is that key, which translates UA principles into actionable plans for Digital City Projects. It does so by defining the mandatory components and relationships within a Smart City, providing a structured roadmap for urban planners and policymakers.

Key tenets of the UA / UOM application for the practical Digital City projects:

- *Holistic planning*: Digital City projects benefit from a holistic planning approach inspired by the UA/UOM. By considering the interconnectedness of urban systems, planners can make informed decisions that maximize efficiency and sustainability. The UA / UOM unity, with its component analysis, ensures that no facet of the city is overlooked;
- *Data-driven decision-making:* The UA /UOM's emphasis on intelligence aligns with the data-centric nature of DCPs. The UA / UOM helps structure data collection and analysis efforts, enabling evidence-based decision-making. This is particularly crucial in optimizing resource allocation and enhancing urban services;
- *Citizen-centric solutions:* engaging urban citizens in DCPs is a core UA / UOM principle. The UA / UOM unity facilitates the creation of digital platforms and interfaces that empower residents to provide input, access information, and participate in the governance of their city. This democratization of urban planning enhances the project's practicality and acceptance;
- *Infrastructure integration:* The UA / UOM guides the integration of various urban infrastructure components, ensuring that they work harmoniously to support the smart urban environment. This not only improves operational efficiency, but also enhances the overall quality of life for city dwellers;
- *Sustainability and resilience:* Sustainability, as a key tenet of the UA / UOM, is woven into the fabric of Digital City projects guided by the urbogeosystemic model. These initiatives prioritize renewable energy, efficient resource use, and environmentally friendly practices. Moreover, they incorporate resilience strategies to withstand unexpected environmental and social challenges, such as natural disasters, or pandemics, as well as hostilities.

Case Study First - Kharkiv: A feasible perspective of a full-format DCP implementation. Populating the Digital City project with data from Open Street Map. This perspective can be implemented in a real Digital City project, basing on the methodology introduced in the previous section of this paper as well as taking into account some other our developments. While representing a unity of UA / UOM, we actually attempted to establish a background, according to which a digital city may be a formalized model of a real city, encompassing all its structural elements and key objects that can be represented in a GIS as a collection of 2D and 3D primitives. Essentially, a digital city can *be more, than a typical GIS project*, where various layers describing specific spatial objects within a particular city are not only loaded and organized, but affiliated with the Building Information Models (BIMs), in this way reaching the state of CIM – City Information Models [43]. Nonetheless, if we possess only a “routine GIS project” for a city in our disposal, we should accept, that fundamental layers of a digital city include boundaries of districts/census tracts, roads, public transportation lines, essential natural features, and land use types – all this would correspond to the *Municipal Infrastructure* block of the UOM (Fig. 1). Additionally, depending on the specific research context, supplementary features such as residential buildings, hospitals, fire stations, service facilities, industrial and recreational facilities, parking lots, subway stations, key traffic pathways of peoples and gods, and more other ones can be also loaded into a DCP, but already with respect to the *Urbanistic processes and phenomena* block of the UOM (Fig. 1). In other words, these can be any vector objects with a spatial reference and the attributes within a specific extent of the geographical space, what strongly corresponds to the urbogeosystem theory [11, 13, 19].

Because of the capability of the full-format GIS platforms to be connected to online spatial data repositories, the users no longer need to load all available data covering the studied city into a DCP. It is sufficient to load only immutable base layers and a set of situational layers that may be required to study specific urban processes and phenomena [36]. Obtaining such layers for a digital city can be accomplished using specialized tools for querying the opened databases. An example of such a tool could be the web-based tool called *Overpass Turbo*, which allows users to filter and download any available data from the *OpenStreetMap* (OSM) global maps for any territory through special API queries and export them in *.GeoJSON* format, which can be read by a GIS platform [44]. In a similar way, even innovative databases of open-source benchmark datasets can be generated, as a given example of power distribution network modeling [45] or straightforward converting OSM data into land cover / land use maps [46].

Through *Overpass turbo*, a user can make queries to specific urban objects in a given city and, if necessary, filter them as be based on specific attribute characteristics. The ease of interacting with the database is facilitated by the convenient organization and systematization of spatial data in the *OpenStreetMap* coverage. All spatial objects have a set of tags (attributes) that describe the object's classification. Tags are represented as *key-value pairs*, which provide descriptions for each individual object. For example, a pair like *"landuse: commercial"* describes a commercial land use object. Tags in OpenStreetMap are generally standardized and categorize objects into specific classes, which are common for all objects associated with a shared tag. For instance, objects with the 'highway' tag may be categorized into primary, secondary, tertiary, motorway, trunk, residential, and so on.

With knowledge of the tags employed to describe the objects of interest in *OpenStreetMap* and the categories, into which they are divided through *key-value* pairs, we can use *Overpass turbo* to download any objects by constructing a simple query using *Overpass QL*, a specialized query language of this global map coverage. To simplify this task, *Overpass turbo* provides a *Query Wizard* tool, where you only need to input a correct expression using *key-value* pairs and standard auxiliary operators such as *'=', 'is', 'in', 'or', 'not', 'and'*, etc. The tool will automatically generate the correct query according to the expression and load all the specified data into an interactive map window, which can then be exported in *GeoJSON* format.

Further we attempt to go through a clear sequence of steps for downloading necessary data from *OpenStreetMap* using *Overpass turbo* for the purposes of building a full-format DCP for Kharkiv and gathering specific objects as examples of this project completion. We have composed the following chart and apply to it further as to a strategic scheme, which implements the UOM presented above within some particular segment of a DCP completion – its data aggregation by *Overpass Turbo* (Fig. 2).

Suppose, while aggregating a DCP, we need to download *a point layer of hospital*s in the city of Kharkiv. To do this, the following steps should be provided according to Fig 2.

Firstly, we need to find out the tag that can be used to filter hospitals. To do this, a user can go to the *openstreetmap.org* map and use the *Query Features* tool to click on a hospital within the city boundaries of Kharkiv. After this action, a side panel will open on the current page, listing all objects within the selected area. Among these objects, a user needs to find and select a required point feature – that hospital (Fig. 3). Then, a table with all tags related to the selected object will appear on the side panel in this web-interface. It is possible to use these tags to make a query to the database through *Overpass turbo* to download into a DCP this spatial feature immediately. However, since it is necessary to download all hospitals in the city, we need to choose a generalized tag from the presented tags for all hospital objects. In this case, it can be the *'building'* tag with a value of 'hospital'. With this information, a user can now formulate a query by *Overpass turbo*.

Secondly, to construct a query to the spatial database, on the *Overpass Turbo* page, a user needs to click the *Wizard* tool. Next, in the *Query Wizard* window, based on the available information, a user has to enter the following expression: *'building=hospital in Kharkiv'* (Fig. 2). This query will retrieve all spatial features with the tag *'building: hospital'* within the city of Kharkiv, i.e., all the hospitals in this urban area within the official boundaries of the city. Then, a user can immediately click the *"build and run query"* button, after which, after some time, all the relevant features that were queried will be displayed on the map.

Thirdly, to download the selected features to user's local computer, in the *Overpass Turbo* window, a user needs to click on the *Export* button, and in the window that appears, it will be necessary to click *download* next to the corresponding spatial data format in the drop-down list, for example, *GeoJSON*. As a result, the requested data will be downloaded to your computer.

Fourthly, the final step in populating the digital city's model with the data is to directly add the downloaded features to the existing DCP (Fig. 3). In addition to spatial location, the downloaded hospital features may also contain a range of proficient attribute information entered in *OpenStreetMap*. If necessary, the added features can be further reprojected, sorted, and filtered depending on the specific project require-

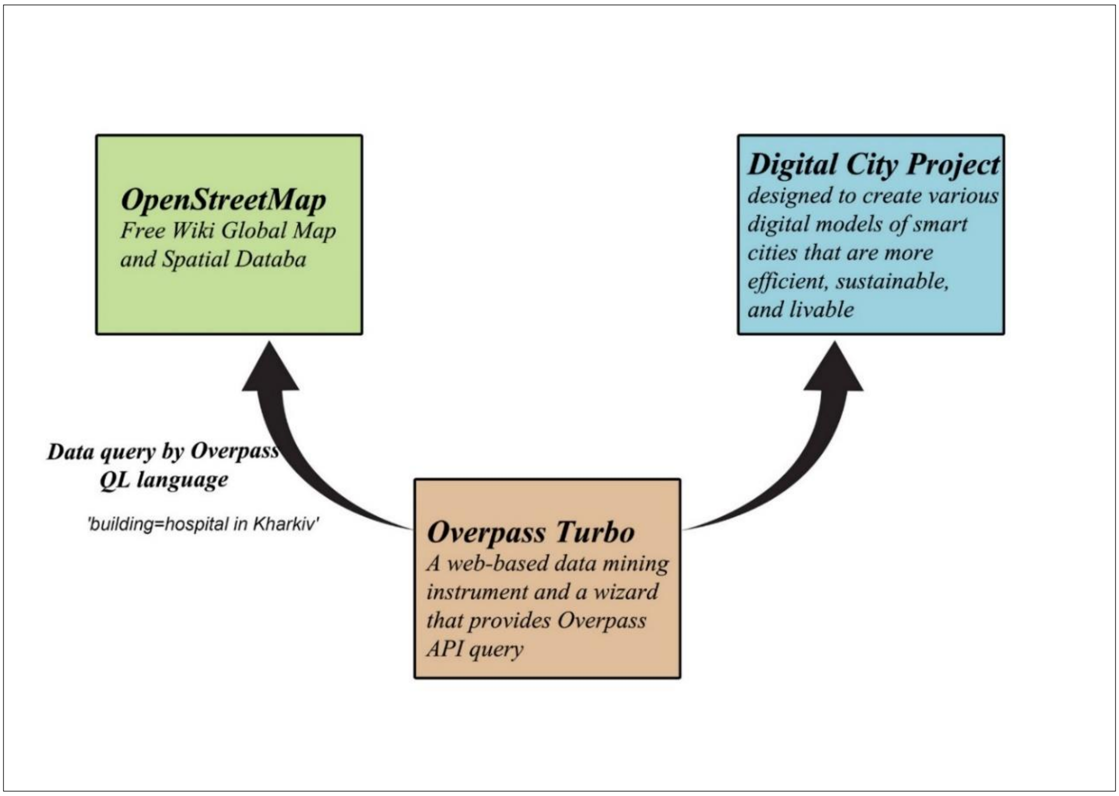

Fig. 2. The aggregation of a Digital City project from the OSM data sources by applying *Overpass Turbo*

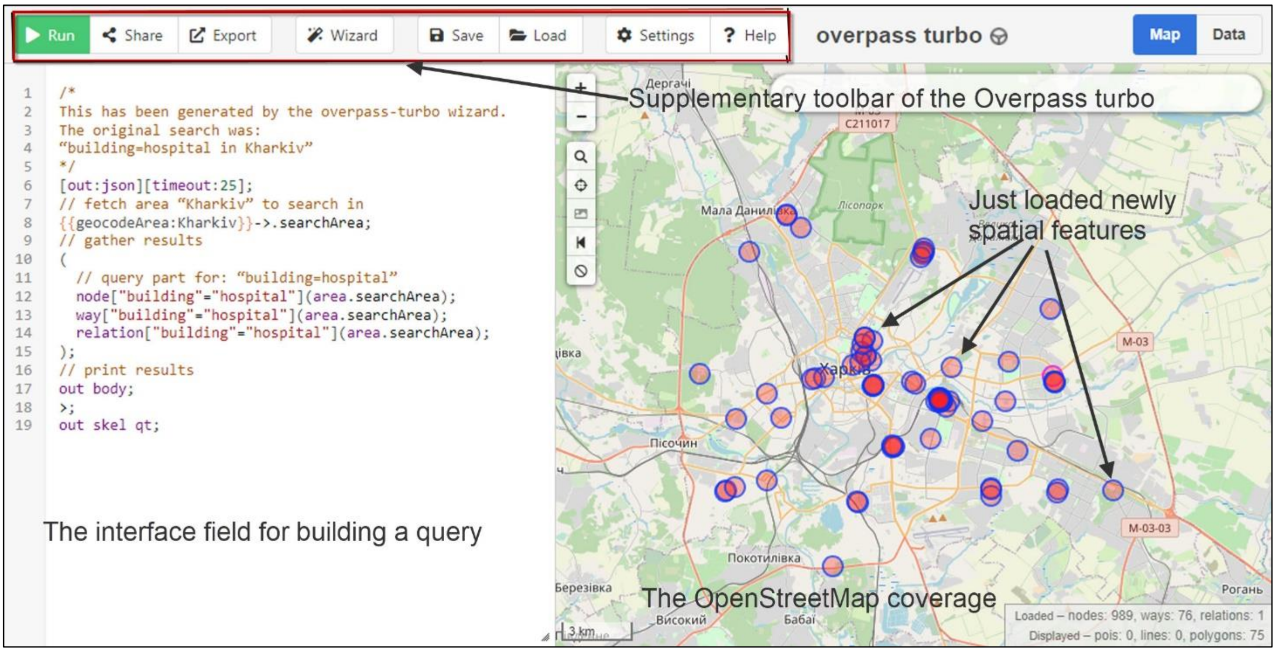

Fig. 3. The *Overpass Turbo* interface, while aggregating a Digital City project of Kharkiv: creating a feature layer of hospitals

ments.

Similarly, using the described above procedures, a user can download any spatial features affiliated with a given urban territory, and which are available in *OpenStreetMap*, thereby shaping this DCP. For more convenient use of the project, its layers can also be organized and categorized in a certain way (e.g., public transportation lines, service facilities, energy facilities, etc.) by the selected GIS platform.

OpenStreetMap is just one of many sources of spatial data for creating a digital city. To populate the project with data, you can use GIS tools such as address geocoding, digitizing satellite images, aligning global coverage maps, importing CSV tables containing object coordinates, and many others. Additionally, spatial data of various origins can be loaded into the digital city, which can be reformatted and combined with existing base layers [12]. For example, information about building geometries (sizes, heights, shapes, etc.) obtained from LiDAR surveys can be vectorized and loaded into the project.

Aggregating a DCP by LiDAR data processing. First of all, at this benchmark of our text it is necessary to make one step back to the Digital City project's ultimate goals, and update them according to Lidar technique of Urban Remote Sensing involvement.

We accept that the *urban digitalization* can be provided by a specially elaborated formalizing technique for describing a set of physical, social, and legal infrastructures, that can be *simulated by a Digital City project* referred to above. That both modeling, and modeled project is a tool available for both city residents, and its municipality for the aims of efficient governance that transform a city into an intelligent one. It is *the main ultimate goal* of this DCP.

The second goal is to elaborate *key robust indicators* for evaluation of the DCP performance due to ensuring the efficiency of a given municipality, urban services, and a quality of city residents' life. According to this the project of digital city must provide efficient planning and predicting for "what-if" scenarios in: urban economy, environment, and energy; emergency response, recreation, safety, sanitation and solid waste disposal; telecommunication and transportation.

The third ultimate goal is to include into the DCP those urban components that represent *the information technologies and telecommunications (IT&C),* what allows not only to use effectively infrastructure, but also to provide stronger integration of all dimensions of a smart / digital city.

The fourth goal, which actually has to be achieved as the first one in a temporal perspective, is to simulate by LiDAR data processing the common building types, their formation, and changes as the various set of models: the basic building models (a "box" model), parametrized models, prismatic models, low-polyhedral models (LPM), and high polyhedral models (HPM) [47].

LiDAR data and derivative results of their processing can significantly expand the possibilities of the DCP in addressing numerous tasks of Urban Studies. Basing on LiDAR data, it is possible to create a simulation model of an urban environment consisting of discrete models of city expansion within its development. Such a model can serve as the foundational layer of the Digital City project, to which other data obtained from various data collection sources can be integrated by entering them into corresponding attribute tables or by creating separate layers of these data in the appropriate geographic projection.

An important aspect of involving LiDAR data into building a DCP is the ability to automate this project features' classification. As a result, objects within the city, identified during LiDAR surveying, can be categorized into specific thematic classes, such as buildings, various types of trees, and elements of infrastructural networks. This property of LiDAR data enables digitization and inventory of all static urban features that would be subject to LiDAR surveying in a given real city [48-50]. Each feature can be assigned a unique identifier and a specific tag linking it to other features of the same type.

The most appropriate usage of LiDAR data in the Digital City project is the visualization of building models in the form of generalized, low-polygon models in the *CityGML* format. *LOD1* (Level of Detail) and *LOD2* are optimal levels of detail for such models. These models convey all the essential characteristics of buildings necessary for performing basic GIS operations while imposing a relatively low computational burden compared to more complicated and detailed models. From *LOD1* models, information about building height, approximate volume, as well as a general understanding of urban density and vertical planning can be obtained. *LOD2* models can significantly refine the mentioned characteristics and facilitate the identification of building types.

Based on the properties of buildings extracted from *CityGML* models, reproduced by the software, in which development two of the authors participated, and these models correlated with additional attribute data, the DCP for Kharkiv can implement the following various user's scenarios [12, 37, 51] (Fig. 4, ***A-C***).

We mean, first of all, already elaborated and partially implemented user's scenarios: assessing building energy consumption with a volume of consumed energy per a building (Fig. 4, ***A***), estimating the population distribution by an inhabitants' number per building (Fig. 4, ***B***), and analyzing the visibility gradient in the urban space (Fig. 4, ***C***).

All these scenarios employ the information about building geometries obtained from LiDAR data. E.g., population estimation assumes an approximate correlation between the volume of residential buildings and the expected number of inhabitants. Energy consumption estimation involves a similar correlation but with the energy consumption level of a given building, further calibrated with the information about a building age and the number of floors. In the visibility analysis, the processed LiDAR data provide a model of a given extent of urban environment, allowing the calculation of the visible volume of urban space from a given observation point.

The information generated through the implementation of these user's cases is not only a valuable outcome of urban studies, but also serves as highly valuable input for solving various other tasks of GIS-analysis within a project of the digital city using additional data layers from different sources. For exam-


A
Colors legend (kWh/m²a):
0 - 40 A
40 - 80 B
80 - 120 C
120 - 160 D
160 - 200 E
200 - 240 F
Over 240 G
N278
Tongerseweg
Bankastraat
Karimatastraat
Billitonstraat
Soerabajaweg
B
Colors legend (residents):
0 - 10
10 - 25
25 - 50
50 - 100
100 - 200
200 - 300
Over 300

Fig. 4.

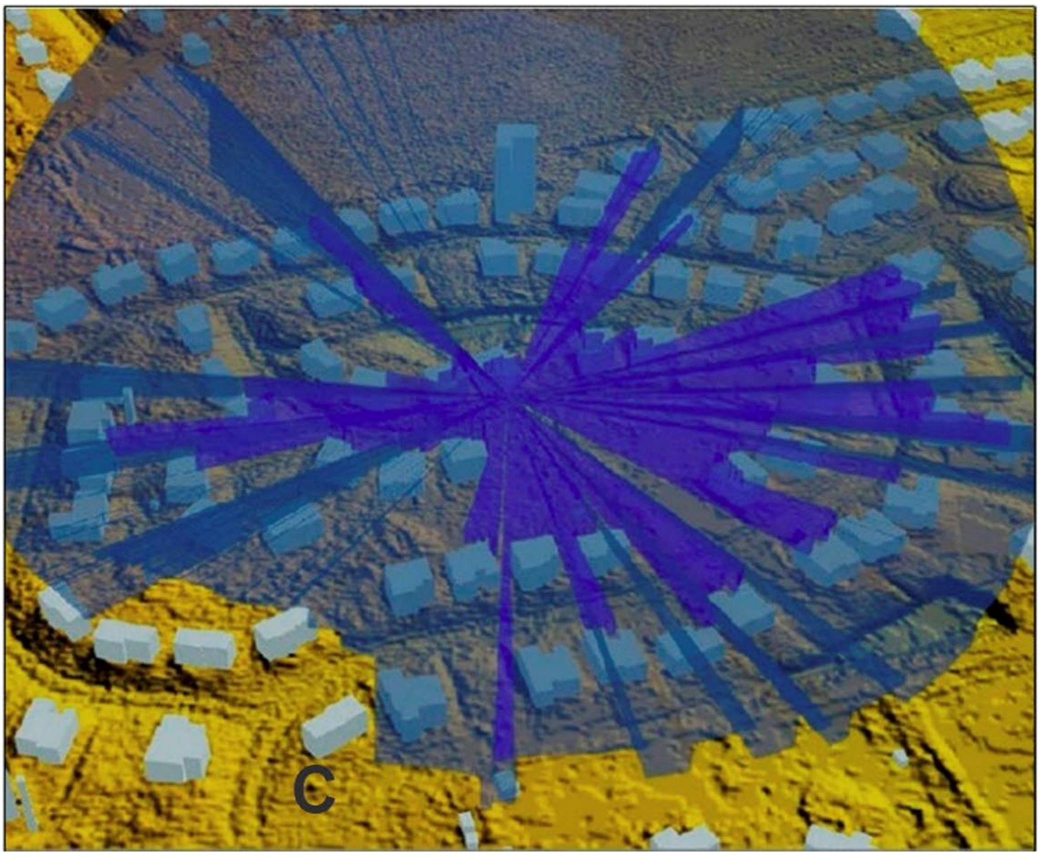

Fig. 4. The user's scenarios that can be implemented for Kharkiv's DCP in the *ELiT* web-software [12, 13, 47]: ***A*** – a user's case of energy consumption per building (according to the legend); ***B*** – a user's case of population estimation with building geometries – by a number of residents per building (according to the legend);); ***C*** – a user's case of visibility modeling in urban environment

ple, this information can significantly enhance the capabilities of geospatial marketing analysis, aid in identifying urban planning issues, assist in optimizing urban services, and support the planning of new districts and infrastructural networks, what is considered in the following sections of this paper.

The original software of the Digital City project completion with the results of LiDAR data processing. Loading derivative information from the LiDAR data processing into the digital city project can be achieved either through the direct extraction and modeling of buildings in specialized software, if it supports such functionality, or through importing a .*CSV* table containing information about building height, volume, and its coordinates to a GIS platform. This table should be obtained from an application that processes LiDAR data and extracts discrete building models from point clouds. A relevant example of such software can be the *iQ City Change Management (CCM)* application developed by one of the authors of this paper. The desktop software designed for the Windows operating system, utilizing *C++* and *Python* tools for its algorithmic core, along with *C# MS .NET* for user interface solutions, was created between 2012 and 2018. This development was primarily led by the first author of this paper and was carried out as a non-commercial project without any external financial support. This software product made its initial debut as the author's creation in an academic paper that presented findings from urban studies involving LiDAR data processing in the Kharkiv region [11]. The most recent update to this software occurred in 2019, involving the adoption and rewriting of the algorithmic core to use *C++ 11* and *Python 3.7*. The *CCM* software possesses a user-friendly interface, that is governed by various *Managers* (*Project, File, Layer, Processing, View, Processing,* etc.) (Fig. 5).

Upon launching the *CCM* software, a user has an option to either browse recent projects by selecting *File => Recent Projects*, or initiate a new one. When starting a new project, a user needs to configure project parameters in the *Project Preferences* section. This includes selecting a suitable projection from the various projection categories supported by *CCM* to match a geographic location of the data being used. Additional settings can be adjusted in various sections of the *Project Preference* dialog, starting with the *General settings*. A user should complete the project setup and proceed to import raw. *LAS* files. In the subsequent steps, within the High Polyhedral Modeling frameworks, a user should perform *BE (Building Extraction)* and *CD (Change Detection)* functionali-

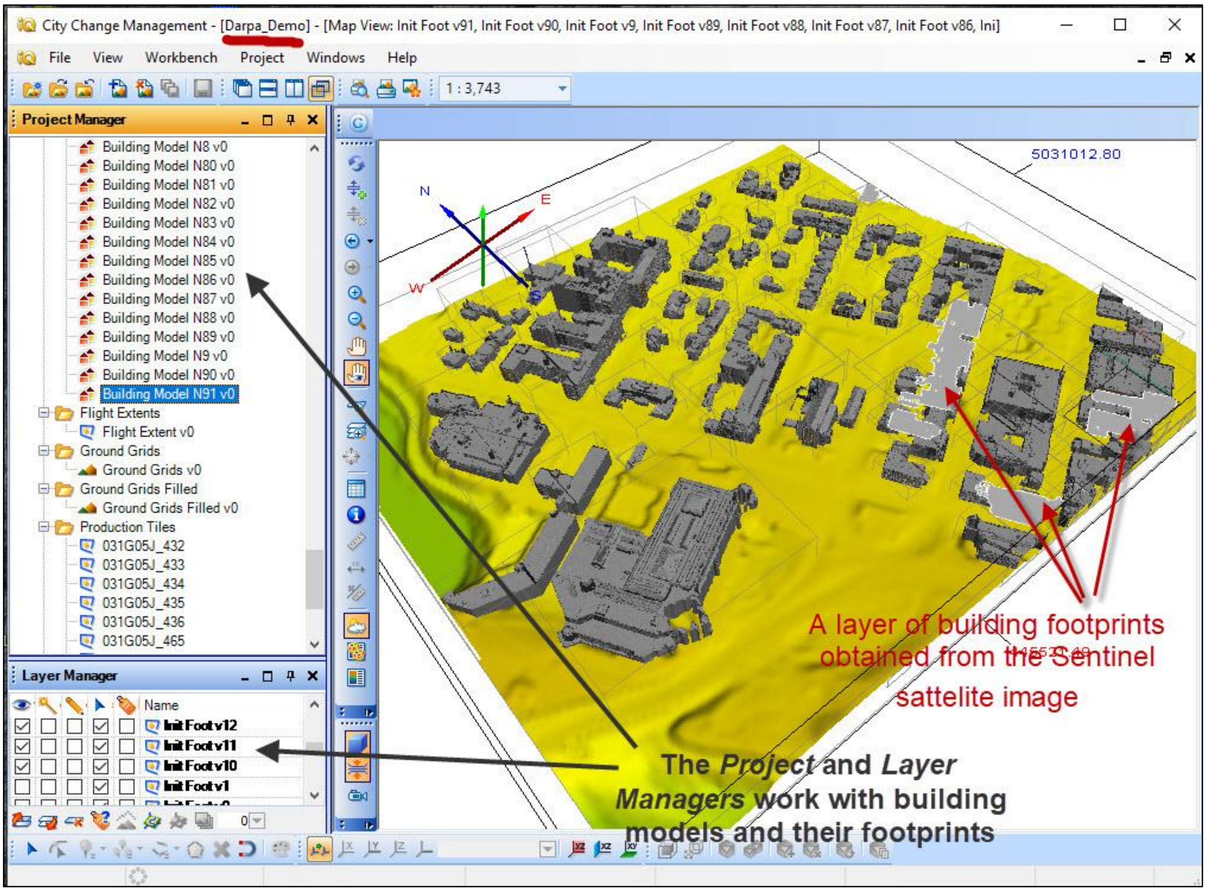

Fig. 5. Implementation of *t*he *DARPA* (https://www.darpa.mil/) challenging LiDAR project in the *CCM* interface

ties in a sequence. This begins by accessing the *Workbench* menu, which invokes the *Building Extraction Technology* tool. All three options available through this tool facilitate HPM building detection, building extraction, and the identification of changes in urban features, saving the results as *.OBJ* and *.ThreeDFM* files. Thus, this software application features the key functionality for extracting and HPM-modeling of buildings from input *.LAS* files. The result of this data processing is a set of discrete building models with geographic references and an attribute table containing information about each constructed building model, including its area, volume, height, and coordinates.

In the mentioned way, while applying several years ago for a research grant from the *DARPA* agency [52], we completed a testing task – a challenging LiDAR project due to modeling of some urban area in the United States. The results obtained proved high accuracy of the urbanistic environment reconstruction, what was determined by both high accuracy of the Airborne LiDAR data involved, and high recession of building models generated by *CCM*. Spatial location's accuracy of these models was estimated by comparison of the *CCM* delineated footprints with the building footprints extracted from *a Sentinel* satellite image (Fig. 5).

Upon a condition of provision an Airborne LiDAR survey for Kharkiv urban area, similar proficient results as in the project referred to above can be obtained. A *.CSV* table mentioned above can be exported from the *CCM* application in *.CSV* format and subsequently imported into a GIS project of the Digital City for Kharkiv as a layer of building centroids, generated basing on the attribute fields with the coordinates of each building. Such a layer would contain all the attribute information that has been calculated for the *CCM* building models. This information can then be transferred through spatial intersection to a layer of building footprints, previously imported, for example, from *OpenStreetMap*. Finally, with a layer of building footprints containing information about building height and volume, *LOD1* models can be constructed by extruding their height from the appropriate attribute field. The models obtained in this way can be used for implementing for Kharkiv, at least, those three user's scenarios described above (Fig. 4, ***A-C***). It is exactly that feasible perspective of a full-format DCP implementation for Kharkiv, what has titled this section of our paper.

A urban system or urban sprawl? Geosituational analysis within the Digital City project. Once, while examining modeled characteristics of the actual urban environment and its urban geosystem, we defined their models as quasi-rasterized and quasi-vectorized ones, correspondingly [13]. We also referred to the essence of real objects both models represent – physical environment of a real city (modeled by *the urbanistic environment*) and sets of separate features in it (simulated by the UGS). We attempted to explain that research and developing steps *Initial / Derivative data =>Urbanistic environment=>Urbogeosystem* could be provided within the frameworks of the functionality of raster-vector transformations in a full-format GIS-platform. Applying this routine GIS-functionality and analyzing results of this application can be one from two, although sophisticated, but efficient functional procedures, which can assist to answer the question: if an examined city rather belongs to *an urban system*, than to *urban sprawl* [53]. Another such delineating procedure is *the geosituational analysis* within urban areas [37].

In addition to the model of the urbanistic environment and the UGS model the Digital City project is one too. It can be considered as a comprehensive model of a city, consisting of numerous vector layers of urban features filled with various attribute data describing quantitative and qualitative characteristics of these features. These characteristics can be visualized on a map using various methods of GIS-map building: thematic mapping, buffer zones, 3D models, matrices, heat maps, and other results of the data visualization techniques. Such concentration of diverse data about the urban environment in a unified information space allows to detect and delineate the *urban geosituations* within this space. These entities can be accepted as the *third criterion* (after an urbogeosystem and urbanistic environment) due to definition of the main trend of the city development, as it was already emphasized above: either to an urban system, or to an urban sprawl. *An urban geographical situation* can be defined, as a particular *simulated* state and conditions of the certain spatial extent of the urbogeosystems. These state and conditions are, in their turn, determined by various *urban configurations*, which consist of a particular structure of city blocks and a number of other both static, and dynamic features of actual urban environment. Thus, in common meaning, an urban geosituation is rather a research construction and corresponds to the urbanistic environment category [13, 37, 51], while an urban configuration would rather relate to a straightforward view of this city physical space, either a static view, or a dynamic one. Both these views, in their turn, can be simulated by either *static*, or *dynamic geosituation.*

What is remarkable, that within the DCP multiple layers of the same these features can be created, while each would visualize different characteristics of these features. By switching between these layers, one can observe the redistribution of urban geosituations based on the specific attribute under this research. In this way, urban geosituations may only be discerned in a particular urban research context [37], while urban configurations, either sustainable, or unsustainable ones should actually physically exist within a city area.

A DCP would precisely enable efficient switching among these contexts, allowing the examination of various urban phenomena on the same features and recording diverse urban geosituations. Furthermore, using different data visualization methods within any city model from all those considered above, it would be possible to simultaneously represent the spatial distribution of various characteristics of urban features.

A united view of several such characteristics' distribution reveals fundamentally new urban geosituations, which become apparent only when GIS-layers are properly combined. For example, using a *heat map*, we can visualize the distribution of urban population density, overlay it with a layer of building footprints, thus indicating energy consumption levels for relevant buildings. Afterwards, a user can add a transparent layer of local climatic zones. This allows us to identify more precisely the most problematic areas of the city, for example in terms of population density and energy consumption, since the local climatic zones can provide insights into potential reasons, why some areas consume more energy than others. High energy consumption in the areas with a cold climate, for example, may be associated with low energy efficiency of buildings. If a similar level of consumption is observed in warmer zones, the reasons for such consumption may be miscellaneous and a subject to study. The population density map, in this context, may indicate whether the high energy consumption is caused by the residential buildings exclusively, or by other types of land use. Thus, by combining the visualization of different variables within the unified space modeled by the DCP, we can highlight qualitatively new patterns of urban geosituations, that might have been entirely different, had we excluded any one of these variables. A complete set of modeled *static geosituations* can be aggregated in this way. The more variables that can be visualized, the deeper the analysis of urban environments becomes, yielding more detailed urbogeosystem patterns and their properties. This is one of the main advantages of the DCP implementation in the context of geosituational analysis, the ability to integrate various parameters of the studied city by the GIS functionality and symbolize and visualize them.

In comparison with static geosituations an aggregation of a Digital City project by *dynamic ones* is rather a complicated issue, since we would need to apply to urban environment 1) repeated surveys based on 2) precise sensors and 3) reliable hardware platform. All this should be supported by efficient monitoring technique like the *Change Detection (CD)* technique provided by our *CCM* software.

The CD tool of *iQ City Change Management* relies entirely on the functionality of High Polyhedral Modeling – Building Extraction and has been designed to monitor architectural (geometric) changes within a city over a specified time frame. It accomplishes this by automatically comparing and analyzing two divided by a temporal benchmark sets of LiDAR point clouds. Thus, two datasets, the primary and the secondary ones, of a repeated LiDAR survey are normally processed. This tool identifies alterations in the positions and shapes of buildings as *3D models*. Our CD-method addresses all three fundamental aspects necessary for comprehensive 3D change detection as it was referred to in an advanced literature review: 1) aligning coordinate systems, 2) comparing spatial and spectral characteristics, and 3) representing and analyzing the detected changes [54]. Additionally, if we refer to the commonly used classifications of urban changes, which generally includes three primary categories – positive, negative, and no change, along with several subcategories – the two classes of building changes introduced in our approach as *Added* and *Removed* would correspond to partially detected cases in change detection, such as "new (part)" and "demolished (part)" as presented in these classifications [55, 56].

The *CCM CD* functionality had been applied to the open LiDAR data sources available for urban parcels and tracks in urban area of Tallinn, Estonia. All this allowed to delineate alterations in urban configurations mirrored by dynamic geosituations in selected urban parcels (Fig. 6).

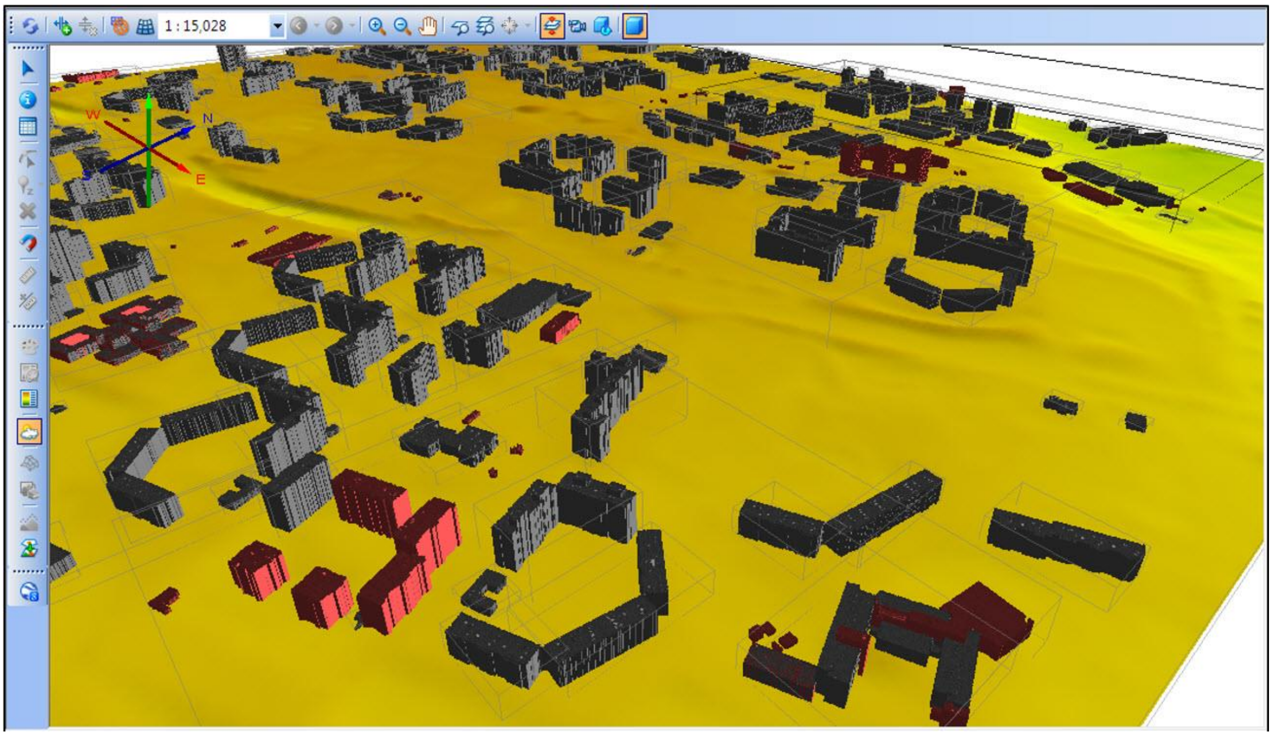

Fig. 6. The changes in urban configurations detected by *CCM* for the period of 2017-2021 for a given urban area (2 km * 2 km) in Tallin. Both added and removed changes depicted in **red**

Although this urban parcel is of an area, that is equal *4 sq. km* only, it can be quite representative one for outlining the *urban configuration => geosituation* research sequence. If there were detected up to fifty architectural-morphological changes, and more, than forty from them are *Added* one, it would be easily to make a conclusion about a general trend of local urban development on the base of the geosituational analysis only. Moreover, the *iQ City Change Management* produces an attribute table for all changes detected. If this table exported in *.CSV* format, and a result then vectorized in a point layer of changes' centroids, that allows, e.g., to provide a comparison of CD footprints with Open Street Map building footprints. The latter guarantees that representative visualizing, which would definitely delineate an existing *urban configuration => dynamic geosituation* sequence, while import of the *CCM* results into a full-format GIS give an opportunity of n extended spatial analysis provision (Fig. 7).

In the similar described way, if necessary LiDAR surveys are arranged, this technique of dynamic geosituation delineation can be applied for the Digital City project of Kharkiv, what for our city's past-war reconstruction and rehabilitation can hardly be overestimated.

If Kharkiv DCP is created once, it will not require constant drastic rebuilding with new data arrival. Instead, such data can be seamlessly integrated into existing attribute fields or object classes, while

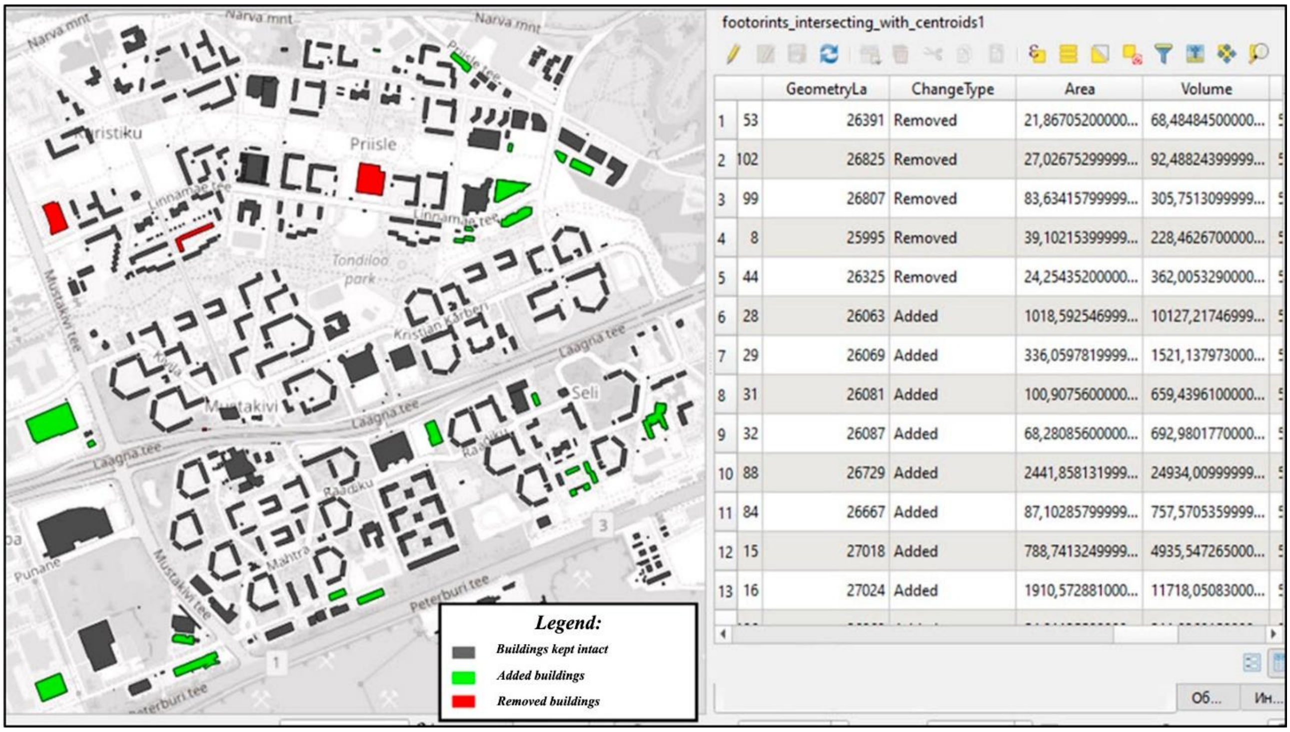

Fig. 7. The changes detected for an urban parcel Tallinn delivered from *CCM* to *QGIS* for *2D* visualization and extended spatial analysis

keeping project data intact. This allows the project to be regularly and easily updated with new data, which can be compared and tracked over time for changes in various urban parameters. These changes become evident in the presence of varying urban configurations, which would be mirrored in the geosituations.

Case Study Second - Kharkiv: a perspective of geomarketing within the "Digital Kharkiv" project as a routine GIS one. Such UOM's component as the socially equitable urban environment (Fig. 1) implies sustainable functioning of socioeconomic services in a given city. Such activity and discipline as the *geomarketing* can substantially contribute to it.

The geomarketing is a Human Geography discipline within the Marketing domain that is based on the study of the patterns of interaction between *the market entities* and *the target audience*, taking into account the *geographical aspects*. This interaction is determined by the geographic localization of the objects and their orientation towards a specific geographic context. Therefore, the primary focus of the geomarketing is the geographical mapping of those socioeconomic objects that are affiliated with market interactions [57].

It is necessary to emphasize, that the user's option for editing data in the virtual space of the DCP provides a significant advantage in territorial marketing research: population density, commercial areas, population movement patterns, and more. In that virtual GIS space that supports the DCP there are efficient opportunities for analyzing demographic data of the population, competitors, choosing the most favorable location, analyzing consumer behavior, planning the optimal route, market segmentation, and more. The key advantage of the "Digital City" project is the ability to perform such analysis based on open and up-to-date data [58]. In particular, this open access to data can contribute to greater transparency in the work of municipal authorities and commercial organizations in the urban environment. This may encourage the city's population to actively participate in decisions related to this city development.

Proceeding from all stated above, both in previous sections of our paper, and in this one, we suggest to examine the geomarketing approach implementation in a simplified approximation of a DCP - a typical GIS project called "Digital Kharkiv". It has been primarily combined on the base of the OSM data sources. The project contains geographic information that can assist in urban studies and consequent applied solutions both in the peacetime, and in the wartime (Fig. 8). For the time being, the "Digital Kharkiv" project contains information about various infrastructure objects, green areas, land use, buildings, and about some more urban features. From a geomarketing perspective, this information is extremely valuable for determining key parameters and measurements for provision of the geomarketing analysis.

Additionally, the project's advantage lies in the openness and currency of its data. Taking into account the tremendous military impact on Kharkiv upon the Russian aggression, especially at its beginning, it would be crucially needed to consider such a project's involvement in practical implementation of

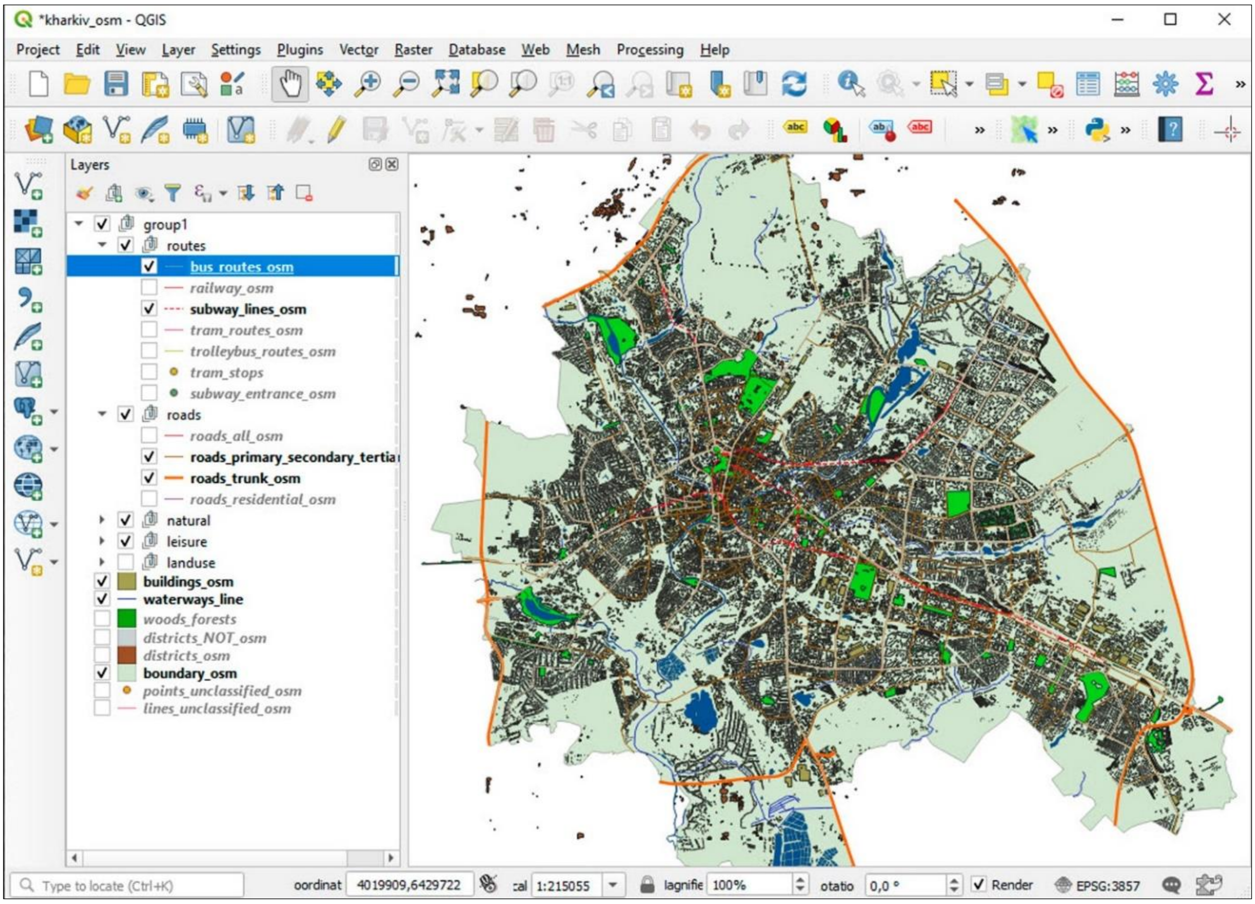

Fig. 8. The "Digital Kharkiv" project combined in the QGIS interface from OSM data sources and enhanced by derivative features obtained through GIS-operations

the necessary defensive and rehabilitating tasks within a perspective of "Digital Kharkiv". From the series of probable examples, we suggest to consider the placement's optimization of some *humanitarian objects* initiated by the Ukrainian government under the *"Resilience Point" project*. We intent to focus on the geomarketing aspects of their locational optimization. This methodology has been typically implemented within a specific spatial extent of the urban environment, defined within the context of the GIS project "Digital Kharkiv."

To perform a spatial analysis of geomarketing objects' distribution using a GIS, the *geocoding procedure* is required. Geocoding is the process of associating geographic coordinates (latitude and longitude) with data points on a map. In essence, it assigns and stores the *coordinate pairs, latitude and longitude*, to each object on the map that may be employed in geomarketing analysis. Similarly, coordinates are assigned to street names, public transportation stops, building addresses, park names, and more.

To perform geocoding, a database that stores addresses of urban objects is required. Global overview maps such as Google Maps and OpenStreetMap can be used as such databases. What is more, a geographic information system with a geocoding module is necessary. For this task, the *QGIS Bulk Nominatim* module was applied, which interacts with the *Nominatim OpenStreetMap* service to provide geocoding of addresses and reverse geocoding of coordinates. Its primary tool is Bulk Geocoding, which implements *mass geocoding* (huge data can be processed). One of the mass geocoding options is the *Geocode Table*, where either a *QGIS* database or a vector layer containing address information can be employed. For our task, we need to select the column in the loaded *Excel* spreadsheet that contains information about addresses, specifically their coordinates. The module attempts to find matches with existing information. It's essential to note the possibility of including detailed address information in the search. This allows adding information from the cloud storage, matching it with the coordinates. This obtained vector layer is the visualization of the required information about addresses. For further analysis, a user can apply to the existing OSM layers of the GIS project "Digital Kharkiv" (Fig. 8).

The described geocoding tools were used to import and digitize the addresses of both demolished buildings (Fig. 9), and "Resilience Points" (Fig. 10) in the city of Kharkiv. Both types of the features had been detected for the period from March to November 2022. The *Bulk GeoCoding* module was employed, which enabled the automatic digitization of

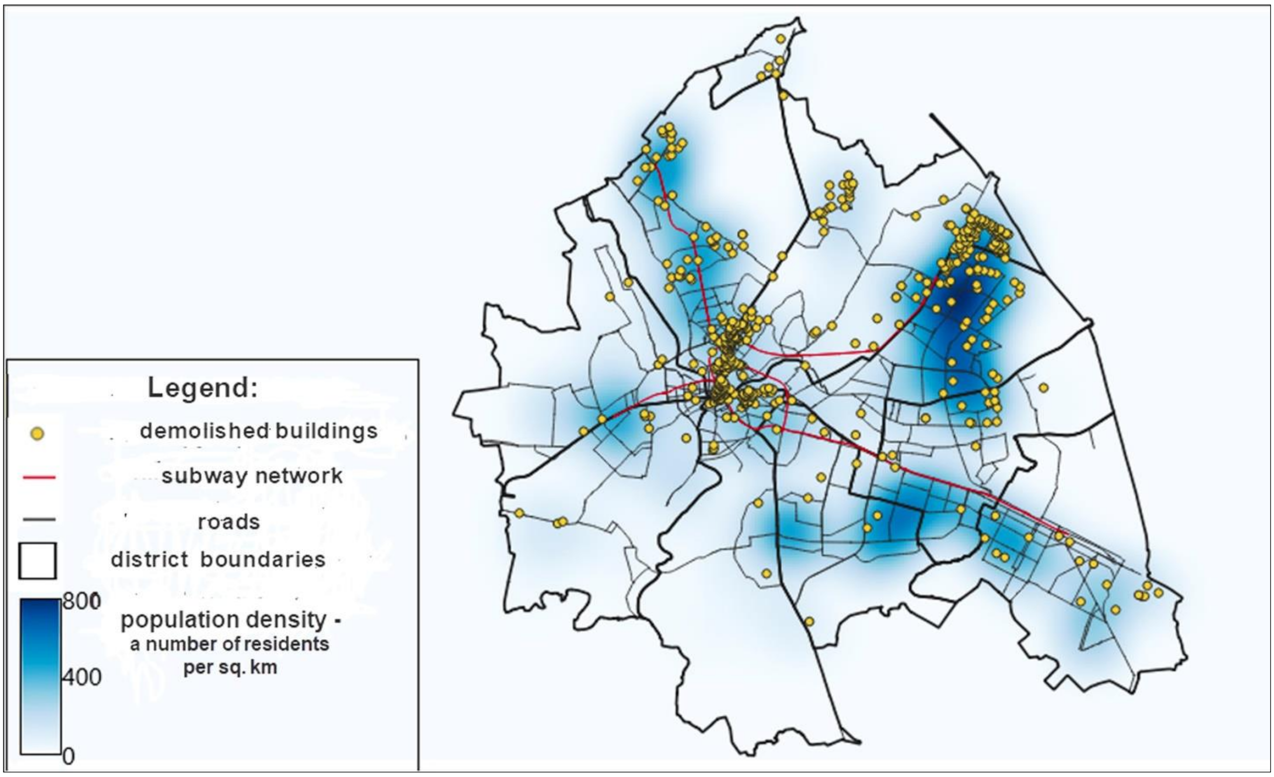

Fig. 9. A *Heat map* of population density in residential buildings and locations of demolished buildings in the city of Kharkiv during the period from March to November 2022 [59, 60]

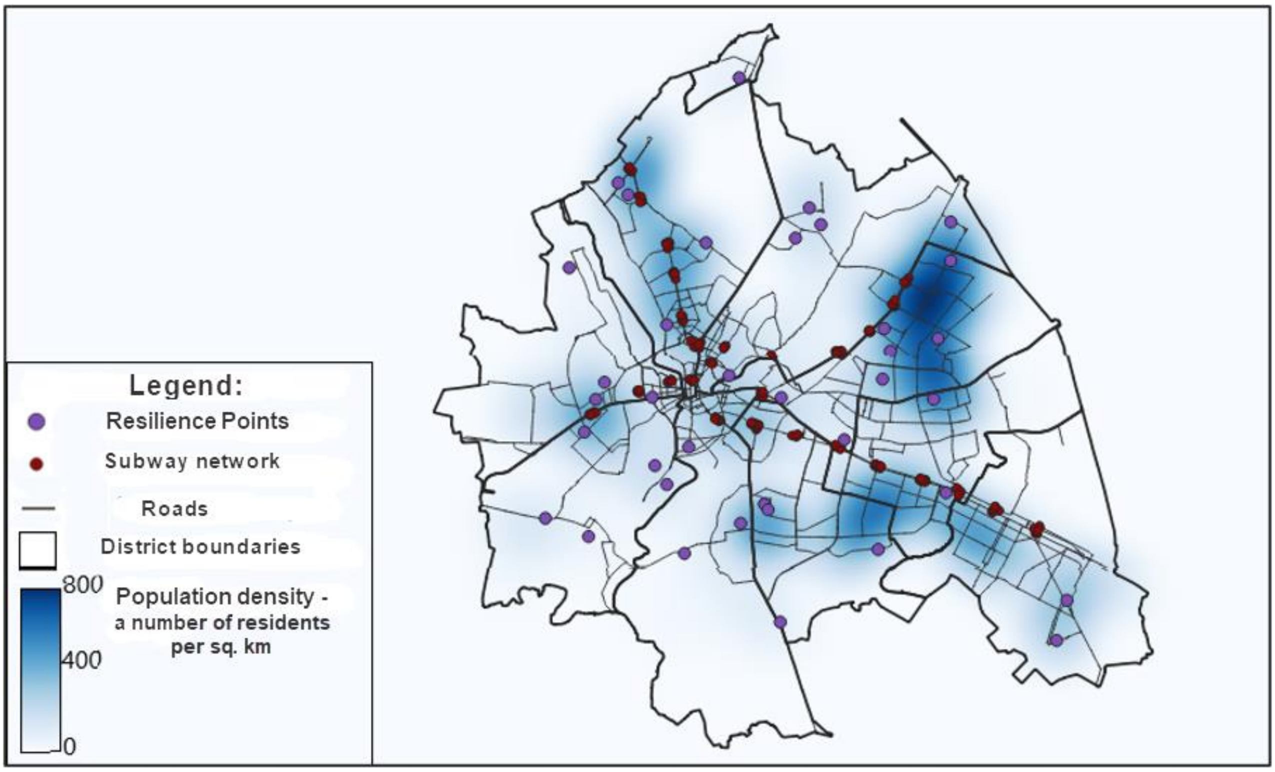

Fig. 10. A *Heat* of population density in residential buildings and locations of "Resilience Points" in the city of Kharkiv during the period from March to November 2022 [59, 60]

coordinate spreadsheets from an existing *Excel* table. This table contains data such as addresses, building types, and demolition dates. The data in this table were compiled from open government and public sources [59, 60].

Then, the *Overpass Turbo* web tool was used to query the OSM database for the residential buildings in Kharkiv. Using *Heat map* methods, a population density map has been created based on OSM buildings with *a weighting field* containing data on the number of apartments in each building. This field has a direct correlation with the population that can reside in residential buildings.

It is commonly known that upon the full-scale Russian invasion, the most impacted area in the initial war months was the *Northern Saltivka* city district. This area had the highest population concentration and residential buildings, what has been confirmed by the map (Fig. 9). The main characteristic of the visualized data is that the highest population concentration was observed in Northern Saltivka, while the highest number of demolished buildings was in the central part of the city. This was a consequence of the fact, that the center of Kharkiv was densely populated, but mainly consisted of low-rise buildings, while Northern Saltivka was a classic residential area. Summarizing, it is necessary to underline that significant factors affected the final locations of demolished buildings may include the course of events during the full-scale invasion (proximity of the occupation to the city's borders), the geographic location of objects, and historical aspects (age of building construction). Regarding the latter, it would be essential to focus not only on the density of construction, but also on its age. Historical buildings in the city center are more fragile than those built in the second half of the 20th century, as exemplified by the Northern Saltivka district (Fig. 9).

Analyzing the population density indicators in Kharkiv before February 24, 2022, it is necessary to emphasize, that the geomarketing potential of the territory mostly has shown negative development trends recently. For instance, due to the high population concentration, Northern Saltivka had the highest potential for the geomarketing areal activity. However, after February 24, it has demonstrated the definite signs of stagnation. Meanwhile, some urban territories have an increased potential for geomarketing strategies because they stay almost undamaged. First and foremost, this is related to to the southern districts of the city, where a significant portion of the population from the northern districts has resettled. Due to their security features and population growth in these areas, the restoration of social infrastructure (food establishments, shops) has been most active in the recent months.

The computer maps we have constructed based on the "Digital Kharkiv" project can serve as a basis for further research and humanitarian needs, such as identifying the most affected areas, determining objects that need to be restored urgently, forecasting demand, identifying gaps in the market where your products can be introduced. The overall potential of such visualization is high, given the convenience of using the project and the timeliness of the data. The data can be regularly updated and added based on real changes occurring in the city. Besides other techniques, these changes can be evaluated by exactly that LiDAR surveys, we mentioned in the previous sections of this paper.

Exactly on the base of computer maps mentioned, it is possible to conclude, that the placement of "Resilience Points" strongly correlates with several factors: security issues allocation, population density, access to sources of energy and water supply, road networks, and public transportation, as well as territorial constraints and others. The characteristic feature of the placement of resilience points is their proximity to major roads and subway lines, ensuring accessibility for the population. Most resilience points are located in the premises of schools and kindergartens, with some of them situated in the premises of the State Emergency Service and fire departments. These objects have priority access to critical infrastructure, guaranteeing access to sources of energy. Another essential aspect of their location is *the integrity* of these infrastructure objects.

Comparing the resulted computer maps, it can be easily to observe a pattern where access to "Resilience Points" in the Northern Saltivka district is rather limited (Fig. 10). This limitation is a consequence of the significant number of demolished buildings in this area. However, it is worth highlighting the fact that there are still not enough "Resilience Points" in the city in total, despite that fact, that besides the main resilience points in the city, there are numerous supplementary point locations with generators such as shops, cafes, gas stations, pharmacies, and bank branches. It's also necessary to note that there were those resilience points operated by responsible businesses, but which were mostly located in the city center, corresponding to these businesses' concentration.

Summarizing this paper's section, we can underline, that for the successful placement and operation of resilience points in wartime conditions, it's essential to carefully analyze all the main factors that can affect their effectiveness and accessibility to the population. The UA / UOM applications, explained in the methodological part of this text, in exactly this subject extent could be straight to the necessary point. Nonetheless, it is an evident objective of the future research attempts, while the provision of the standard GIS-approach with "Digital Kharkiv" may be an efficient practical solution for the time being.

Case Study Third - Dnipro: implementation of a typical GIS-project for analyzing provision of the city population with public transportation infrastructural networks. Consideration of building another typical GIS-project within the DCP frameworks, but for another urban location, Dnipro-City, has concluded this our research.

We have explored in this concluding case study the option of urban research in the city of Dnipro using its virtual model as a typical GIS-project, “Digital Dnipro”, also built primarily on the OSM data sources and enhanced by few derivative features (Fig. 11). That is the same research and development technique of the DCP implementation was applied, that had been used previously for “Digital Kharkiv”, as the previous section described it.

The *Overpass Turbo* and *Overpass QL*, both already referred to and discussed above, have been also employed in our third case study. Using the web-tools mentioned, we have revealed and exported data layers for the virtual representation of Dnipro in this selected sample of a Digital City project. For example, to obtain data about one of the key infrastructural networks - the main roads in the city of Dnipro, we have formulated the query as follows: *"highway = primary in Dnipro"*, obtained the resulted script with the *Overpass Turbo Wizard*, and what is more – received the necessary visualized results of our query (Fig. 12). Thanks to these tools, we have been able to combine the remaining parts of the virtual Dnipro’s project and obtain those derivative GIS-features our project lacked previously.

After uploading all the GIS-layers into the *QGIS*

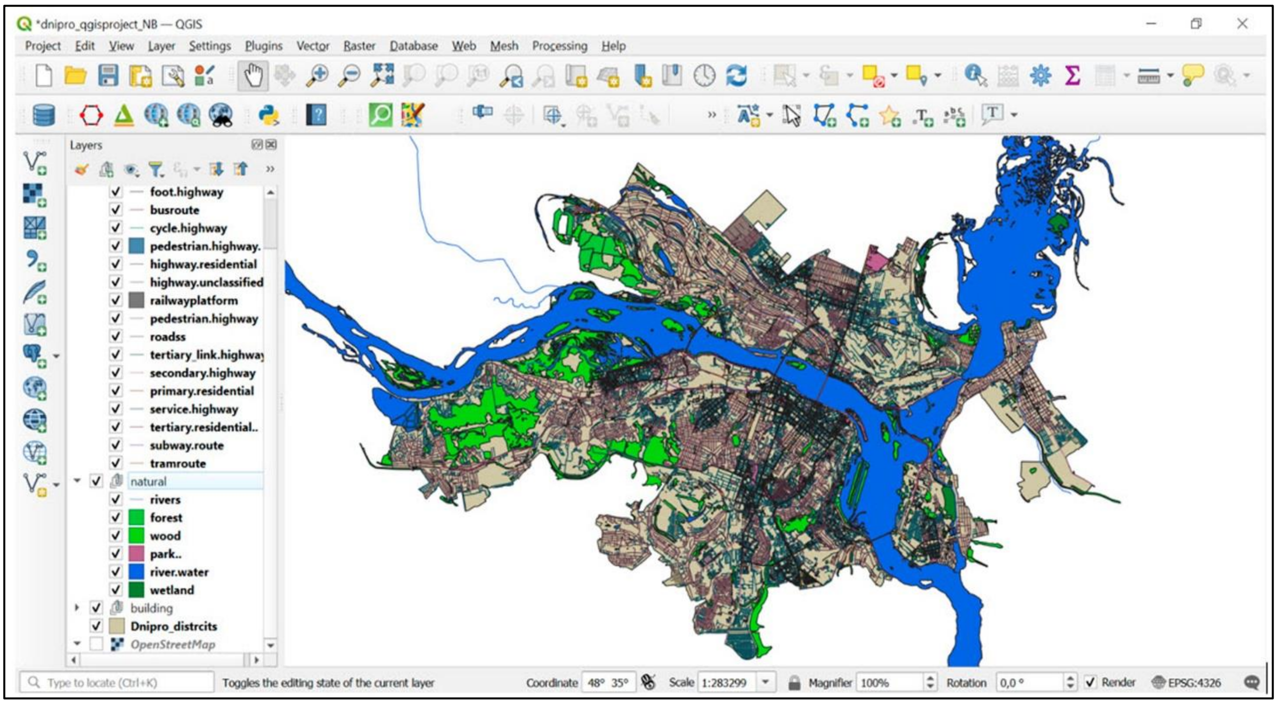

Fig. 11. The “Digital Dnipro” project combined in the QGIS interface from OSM data sources and enhanced by derivative features obtained through GIS-procedures

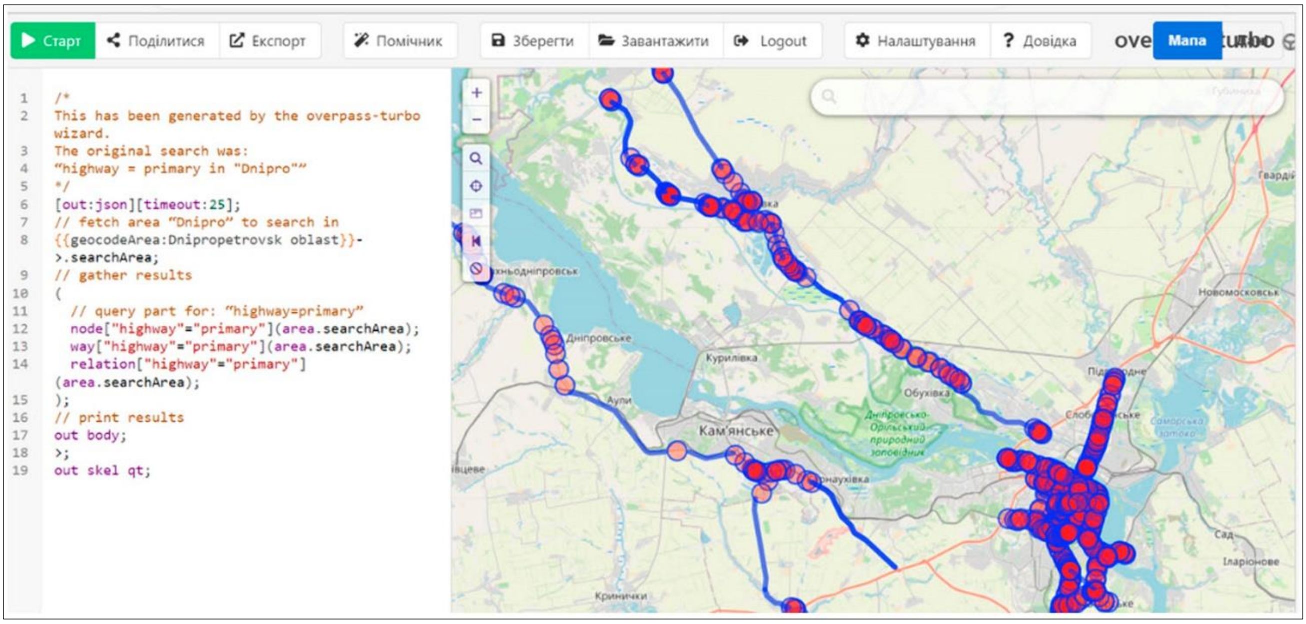

Fig. 12. The query script and corresponding visualized results for enhancing “Digital Dnipro” by one more infrastructural network layer

platform and saving them in *.SHP* vector format, we obtained a virtual model of an urban environment that enables a wide range of different research possibilities (Figure 11).

One of the advantages of using such a typical GIS project for urban research, as mentioned already for "Digital Kharkiv", is that it may contain detailed *attribute information* for all objects located on the map. This attribute information can be extended according to user's necessities. Thus, e.g., the *"Dnipro_districts"* layer contains attribute information for each district of Dnipro. For example, to analyze the current city's demographic situation, we had to add population attributes to respective polygon features of each district and visualize this attribute then. To obtain the necessary database information about various attributes we have referred to the external data sources - open available collections of information, as we did in the case of "Digital Kharkiv" [61, 62]. For a particular visualization in this case, we didn't apply to a het map approbated above, instead according to our research objectives we selected so-called *classified vector visualization.* To display population attributes on the map, we classified the vector data resulting in a map that visualizes population data for *each city district* (Fig. 13).

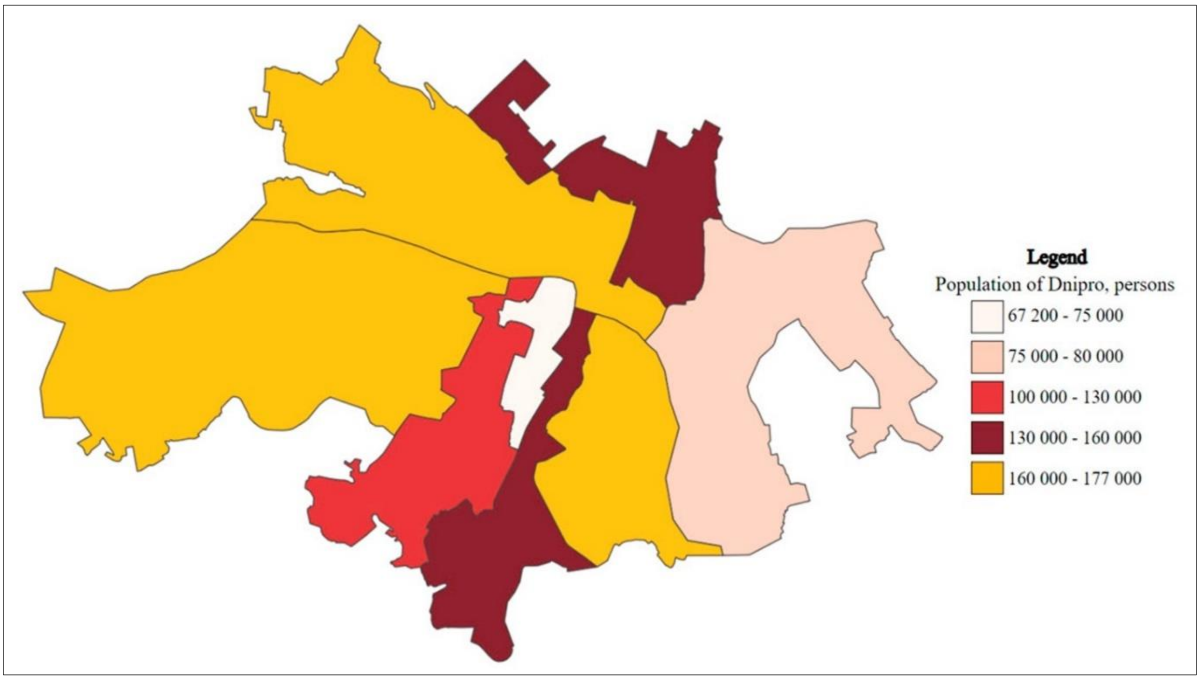

Fig. 13. Visualization of the population distribution in Dnipro on the base of the vector feature classification applied to the data from external sources [61]

On the base of this vector feature classification, it is possible to observe the highest population descending rank in the *Sobornyi District* (175,500 people), *Novokodatsky District* (161,026 people), and *Amur-Nizhnodniprovsky District* (160,123 people). Among the number of contributing factors, we should mention as a key one a particular segment of the transportation infrastructural network for each of these areas, as more accessible transportation tends to attract more residents. Another significant factor is the presence of the main employees of the industrial domain. Additionally, the availability of recreational areas should not be overlooked. Understandably, all these factors and conditions had worked before February 24, 2022 just as similar factor had done in a case of the urban area depicted by "Digital Kharkiv".

For further comparison with existing official perspectives of the city infrastructural network optimization due to public transportation necessities we have to rasterize, provide raster-vector transformation and add to "Digital Dnipro" the following official content of the future urban development perspectives (Fig. 14) [62].

It is obvious that the war has drastically altered all plans like this yet, but suggested in this text by us the general *urbanistic environment / urbogeosystem ontological model* approach to the DCP implementation should be kept intact, then it allows to provide necessary sustainable updates in urban planning. E.g., an extended "Digital Dnipro" project can be created exactly on the base of vector datasets from the view of Fig. 14 and obtained on this base derivative GIS-layers. The broad standard GIS-functionality exists for "Digital Dnipro" and "Digital Dnipro Extended" comparison within the plain of an existing transportation network and its development plans. We would easily take into account population density distribution and other factor to see, if the plans are grounded and realistic. After estimating with the proposed tools, we can be assured to correct the plans.

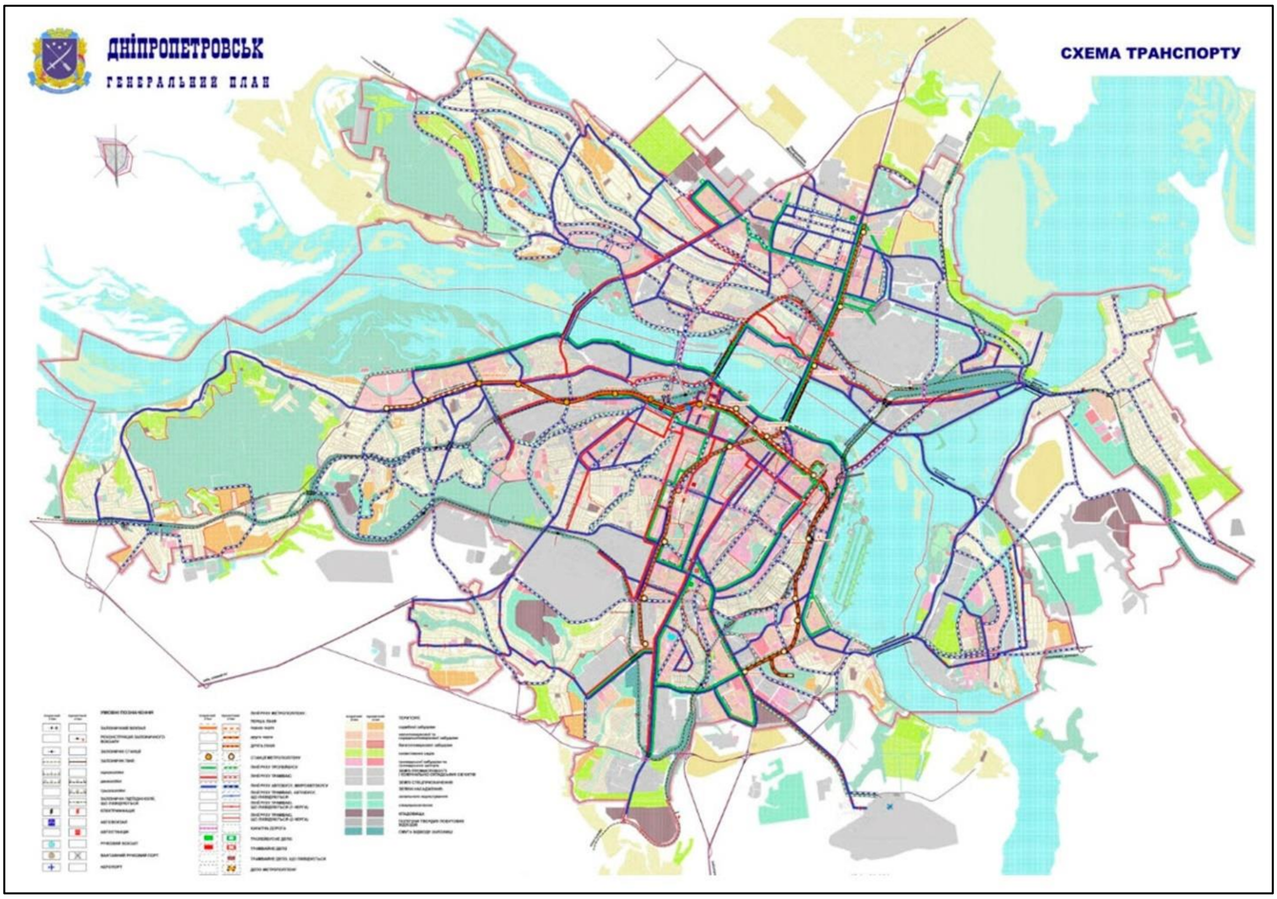

Fig. 14. The scheme of public transportation with a subway network in the General Plan of Dnipro-City urban development (a view of the original raster map) [62]

For example, it can be seen easily by comparing Fig. 13 and 14, that the transportation network had been planned proceeding from population spatial distribution, but the latter is expected to be drastically changed after the war. Thus, the general development plan for the city will be able to be easily corrected by the innovative GIS/DCP project "Digital Dnipro Extended".

Conclusion. Our research has delved into the dynamic and transformative realm of Digital City Projects within megalopolises, with a particular focus on Kharkiv and Dnipro cities in Ukraine. The escalating urbanization of the twenty-first century has propelled cities to the forefront of global change, demanding innovative approaches to address urban complexity and challenges. The concept of Digital Cities, an evolution of Smart Cities, has gained prominence, offering both data-driven, and model-driven solutions to enhance urban life. This study underscores the significance of the urbogeosystemic approach and the urban geographical system's ontological model as pivotal tools in shaping the practical implementation of DCPs. The research emphasizes the importance of regional context, acknowledging some unique challenges and opportunities that megalopolises present. The case studies of Kharkiv and Dnipro underscore the potential for digitalization to drive urban transformation, even in post-war rehabilitation scenarios. The use of both *OpenStreetMap* data, and processed LiDAR data for aggregating Digital City projects demonstrates the flexibility and efficiency of contemporary GIS tools in urban studies. The original desktop software developed by the authors for LiDAR data processing has proven its efficiency for urban studies. The geosituational analysis within the DCP offers a powerful tool for understanding urban configurations and trends. By integrating diverse parameters, the DCP serves as a dynamic platform for in-depth urban research.

Our paper has proven, that the application of the geomarketing within the Digital City project's framework emerges as a powerful tool for urban planning, enabling a detailed examination of market interactions and socio-economic services. This approach, combined with geocoding procedures, provides invaluable insights for decision-making in urban development. Moreover, the "Resilience Points" project within Kharkiv highlights the significance of strategic placement based on factors like accessibility, population density, and infrastructure integrity. The visualization and analysis facilitated by the DCP allow for informed decision-making in the context of urban resilience upon the military impact. In the case of Dnipro, the research demonstrates how a typical GIS project, "Digital Dnipro," mainly constructed using OSM data, can serve as a foundation for urban studies of city infrastructural provision. The incorporation of detailed attribute information empowers in-depth demographic and infrastructure analysis, supporting urban planning efforts.

Each from the separate subject section of our paper outlines the future research perspectives.

Ultimately, it can be concluded: the DCP framework stands as a versatile tool, adaptable to diverse urban contexts, offering a dynamic platform for decision-makers and researchers to explore, analyze, and strategize for resilient and sustainable urban futures.

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Значення проектів «цифрове місто» в урбаністичних дослідженнях мегаполісів (користувацькі сценарії на прикладах міст Харкова і Дніпра)

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Стаття розглядає методологічну й методичну послідовності впровадження концепції Проекту «Цифрове Місто» (ПЦМ) - від удосконалення і подальшого розвитку окремих теоретичних положень цієї концепції до переліку заходів щодо її практичної імплементації через засоби веб- та настільного програмного забезпечення. Ці програмні додатки працюють з унікальними результатами моніторингу міського (урбанізованого) середовища на підставі даних дистанційного лазерного зондування (лідарних даних). Метою статті є спроба виконати на підставі урбогеосистемного аналізу оцінку ефективності застосування ПЦМ як для теоретичних урбаністичних досліджень, так й для розв'язання певних актуальних соціально-економічних проблем міського довкілля, виявлених вкрай загостреними через російську агресію. У цьому зв'язку дослідження сфокусовано на урбаністичному середовищі мегаполісів Харкова й Дніпра. Представлене дослідження оцінює ефективність теоретичного внеску, що випливає із останніх удосконалень концепції урбогеоситем (УГС), в прикладну імплементацію низки проектів «цифрових міст». У цьому зв'язку розглядається й обговорюється перспектива реалізації «повноформатних проектів цифрових міст». Для таких рішень автори пропонують, що повноформатні ПЦМ повинні слугувати всеосяжними моделями реального (фізичного) міського довкілля, охоплюючи всі його структурні елементи та ключові об'єкти, виходячи за межі можливостей типового проекту ГІС. Останній, тим не менш, й це окремо підкреслюється, може вирішувати низку актуальних завдань міських досліджень. Щодо цього представлені інтерфейс й функціональність авторського настільного програмного застосування щодо обробки лідарних даних й 3D-моделювання міського середовища. Також розглядаються й пояснюються веб-інструменти роботи з картами глобального покриття (КГП). Останні виступають основними джерелами наповнення поточних практичних ПЦМ. У статті послідовно наводяться відповідні практичні рішення щодо користувацьких сценаріїв: 1) повноформатний ПЦМ Харкова, що реалізується на підставі його наповнення із КГП, обробки лідарних даних та геоситуаційного аналізу; 2) реалізація геомаркетингових досліджень на підставі ГІС-проекту «Цифровий Харків» з наголосом на оптимізацію розташування існуючої мережі укрить; 3) побудова ГІС-проекту «Цифровий Дніпро» як для аналізу забезпеченості транспортною мережею міського населення. так й для планування міського розвитку у післявоєнний час.

Ключові слова: *проект «Цифрове Місто», онтологічна модель урбогеосистеми, урбаністичне середовище, карти глобального покриття, інтерфейс і функціональність настільного застосування, користувацькі сценарії застосування програмного додатку, типовий ГІС-проект, веб-інструменти.*

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