ЦИФРОВАЯ УРБАНИСТИКА

Research Article

Oksana V. Savina✉
Candidate of Engineering Sciences, Senior Lecturer of Digital Technologies in Urban Studies, Architecture and Civil Engineering Department, Volgograd State Technical University (VSTU). 1, Akademicheskaya st., Volgograd, 400074, Russia;
e-mail: nov1984@yandex.ru; ORCID: 0000-0003-2276-5146

Artem A. Demin
Master's Degree student of Digital Technologies in Urban Studies, Architecture and Civil Engineering Department, Volgograd State Technical University (VSTU). 1, Akademicheskaya st., Volgograd, 400074, Russia;
e-mail: demin.artem2003@gmail.com

Kevin Grace Moupegnou Nzoussi
Candidate of Economics, Associate Professor of Economics Department, Melitopol State University (MelSU). 18, Bogdan Khmelnitsky ave., Melitopol, 72318, Russia;
e-mail: kevinnzoussi@gmail.com; ORCID: 0000-0003-1224-7425

Svetlana Yu. Katerinina
Candidate of Engineering Sciences, Associate Professor of Digital Technologies in Urban Studies, Architecture and Civil Engineering Department, Volgograd State Technical University (VSTU). 1, Akademicheskaya st., Volgograd, 400074, Russia;
e-mail: kat_svetlana@mail.ru; ORCID: 0000-0003-3836-753X

Vladimir V. Larin
Student of Digital Technologies in Urban Studies, Architecture and Civil Engineering Department, Volgograd State Technical University (VSTU). 1, Akademicheskaya st., Volgograd, 400074, Russia;
e-mail: cova4020@gmail.com

A DIGITAL ANALYSIS OF LAND PLOTS AND URBAN DEVELOPMENT PLANNING

Abstract. The relevance of the study is driven by the challenges of modern urbanization, such as infrastructure overload, social and environmental issues, which necessitate new tools for sustainable urban development. The article presents the development of a web application designed to automate the planning of development for individual land plots within the framework of comprehensive territorial development. A comparative analysis of existing software solutions (ArcGIS Urban, CityZenith, CityEngine) was conducted, revealing their limitations, including high cost and complexity of adaptation. As an alternative, the architecture and a functional algorithm for a web application are proposed and implemented. The application integrates data from the Public Cadastral Map and OpenStreetMap to analyze infrastructure within a 500-meter radius of a plot. The system automatically generates recommendations on permissible types of development based on Land Use and Development Rules. The application's operation is demonstrated through the analysis of plots in Volgograd, including functional and load testing. The developed tool offers practical value for municipal authorities, developers, and designers by optimizing the urban planning decision-making process.

Key words: comprehensive territorial development, cadastral data, infrastructure analysis, geographic information systems, Python, OpenStreetMap, web application, urbanized territory.

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Introduction

In the context of modern urbanization, where cities become centers of economic growth and cultural development, issues of rational use of urban territory are particularly relevant (Ratcliffe, Stubbs, Keeping, 2021; Masik, Sagan, Scott, 2021). Population growth and intensive urban development lead to global challenges: infrastructure overload, housing shortages, increased traffic flows, and environmental degradation (Torgashev, 2020; Bereitschaft, Scheller, 2020). These problems require a new approach to territory management that goes beyond traditional development methods (Milshina, 2021; Eltarabily, Elgheznawy, 2020). One of the key tools for solving these tasks is the concept of comprehensive territorial development (CTD), which allows for the creation of multifunctional, comfortable, and sustainable urban spaces (Azorin, 2024; Giles-Corti, Lowe, Arundel, 2020). CTD is a systematic process of urban territory development aimed at optimizing the use of land resources, modernizing infrastructure, and forming a safe environment (Erbyagina, 2021; Guseva, 2023, Popkova, Konev, Kanyukov, 2023; Ronchi, Arcidiacono, Pogliani, 2020). This approach integrates various elements of urban development: residential and non-residential objects, social and engineering infrastructure, creating a balanced environment (Kil, Filippov, Tatarintsev, 2022).

With the development of digital technologies in spatial planning, geographic information systems (GIS) have begun to play a special role (Parygin, Sadovnikova, Shabalina, 2017). They allow for the automation of infrastructure and transport accessibility analysis, modeling of various development scenarios, assessment of the environmental impact of projects, and the creation of digital twins of urban territories (Xia, Liu, Efremochkina, 2022). These tools significantly improve the accuracy of calculations and reduce the time required for design. An analysis of the existing process shows the need to automate key stages of land plot assessment for development planning, which will improve calculation accuracy, speed up analysis, and reduce the workload for specialists.

Within the framework of analyzing existing solutions for urban development assessment and CTD, three tools were considered: ArcGIS Urban, CityZenith, and CityEngine. These systems are used for modeling, analyzing, and visualizing the urban environment using modern technologies. The following criteria were defined for comparison, reflecting their functionality and applicability in urban planning:

- Determining the permitted use of a land plot: the system's ability to account for legal and regulatory restrictions on land use, necessary for complying with urban planning regulations;
- Determining the permissible development area of a land plot: the ability to calculate the maximum development area corresponding to established norms, which affects the economic efficiency of projects;
- Determining the development density of a territory: assessment of development density, which determines the sustainability and comfort of the urban environment;
- Integration with other systems: the ability to exchange data with external platforms and databases, enhancing the tool's compatibility;
- Development scenario modeling: the presence of functions for creating and analyzing various territory development options;
- Analysis of environmental/infrastructure impact: the ability to assess the impact of development on ecology, transport, and social infrastructure;
- Solution cost: costs associated with acquisition, implementation, and operation of the system, important for choosing an affordable tool;
- Configuration flexibility: the ability to adapt the system to specific tasks and project requirements;
- Use of real data: support for working with up-to-date urban environment data, ensuring analysis accuracy.

A comparative analysis of the solutions ArcGIS Urban, CityZenith, and CityEngine was conducted based on the specified criteria, and the results are presented in Table 1.

Table 1. Comparison of Existing Solutions

Criterion / Solution	ArcGIS Urban	CityZenith	CityEngine
Determining permitted land use	–	–	–
Determining permissible development area	–	–	–
Determining development density	+	–	+
Integration with other systems	+	+	+

Criterion / Solution	ArcGIS Urban	CityZenith	CityEngine
Development scenario modeling	+	+	+
Environmental/infrastructure impact analysis	+	+	+
Solution cost	–	–	–
Configuration flexibility	–	+	+
Use of real data	+	+	+

The conducted analysis revealed the strengths and weaknesses of modern solutions for CTD and urban development assessment. These tools have significant potential for planning and analysis; however, their use is limited by high cost and implementation complexity.

The developed system takes these factors into account, offering an affordable solution using open data and the possibility of integration with GIS, which allows for improving the efficiency of urban planning processes.

Conceptual Software and Information Solution for Digitalizing Development Planning of a Plot

Currently, the process of analyzing the development efficiency of land plots for CTD projects includes labor-intensive stages performed manually: input of plot information, collection and processing of data from heterogeneous sources (Public Cadastral Map — PCM, Land Use and Development Rules — LUDR), analysis of characteristics, matching the plot with the LUDR map, checking social infrastructure, and generating recommendations. To eliminate the shortcomings of this approach, such as high time consumption and the likelihood of errors, an automated process was proposed, presented in Fig. 1.

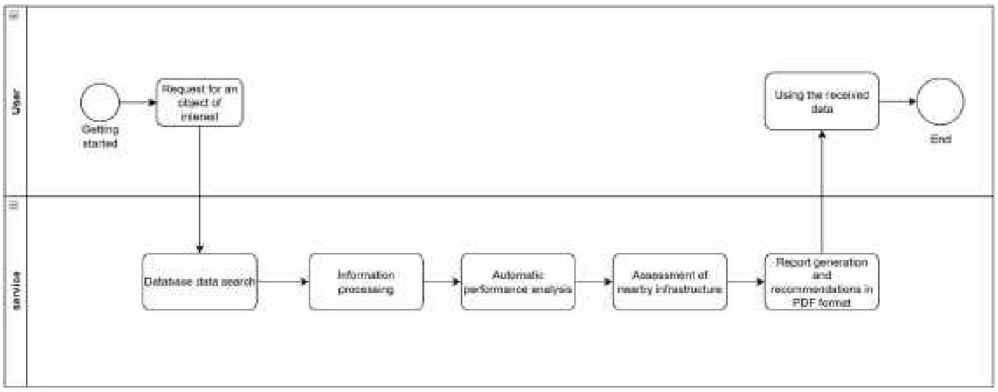


Fig. 1. Automated Process for Planning the Development of a Territory Plot

The new process begins with the user entering the cadastral number of the land plot. After that, the system automatically connects to the Public Cadastral Map (PCM) API to obtain the plot boundaries, area, and permitted use, and data on the surrounding infrastructure (roads, schools, stops) is loaded from OpenStreetMap (OSM). Regulations are extracted from the Land Use and Development Rules (LUDR). At the processing stage, the loaded data is checked for correctness, duplicates are removed, and it is converted to a unified format. The system identifies errors, such as discrepancies between PCM and OSM data. Next, the program calculates the plot area, and development restrictions (sanitary and protection zones) are checked based on the LUDR. Network analysis algorithms determine the distance to social infrastructure objects (schools, clinics, shops) and the transport network (stops). Based on this data, the system calculates the development coefficient (DC) to assess current use. Finally, the program suggests project options based on plot size, LUDR data, and the calculated DC. The analysis results are displayed on an interactive map, and a report is generated in PDF format.

To implement this process, a modular architecture was designed, built on a client-server model. The server side is implemented using the asynchronous Quart framework and the Python language. It processes user requests, interacts with Pynspd (for PCM) and Overpass API (for OSM), performs data analysis, and generates reports. SQLite database is used for caching and storing intermediate data. The client side is implemented as a web interface based on HTML, CSS, JavaScript using the Leaflet.js library for displaying interactive maps, as shown in Fig. 2.

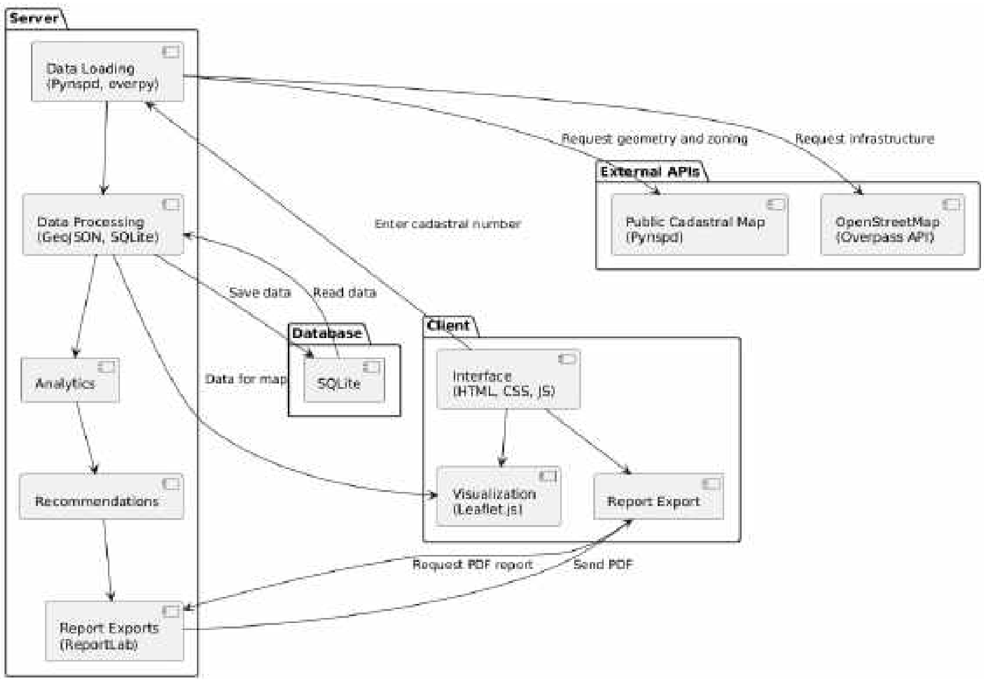


Fig. 2. Application Architecture

The decomposition of the server side includes a data loading module, responsible for obtaining plot geometry and LUDR zones via Pynspd, as well as infrastructure data via overpy; a data processing module, which converts the received data into GeoJSON format, normalizes it, and saves it to SQLite; an analytics module, performing analysis of infrastructure objects within a 500-meter radius of the plot; a recommendation generation module, generating development proposals; and a report export module, creating PDF reports using ReportLab. The decomposition of the client-side components includes an interface that provides input of the cadastral number and viewing of results. It also includes a visualization module, which displays the plot geometry, LUDR zones, and infrastructure objects on the map using Leaflet.js, and an export module, allowing the user to initiate the download of a PDF report. The developed architectural solution automates the analysis process, ensuring flexibility, scalability, and ease of maintenance.

Implementation and Algorithm of Operation

The application's server side, built on Quart, is the main element of the system, responsible for automatic information processing and recommendation preparation. SQLite database is used for data storage, including three main entities: land plots (*territories*), infrastructure objects (*infrastructure*), and recommendations (*recommendations*). Geodata is stored in GeoJSON format, ensuring integration with Geopandas and Shapely libraries for spatial analysis.

The developed algorithm covers the full cycle of operation — from the user inputting data to the preparation of recommendations and their display, which speeds up the process and improves the accuracy of the results. The process begins with the user specifying the cadastral number of the plot via the web interface. After entering the number, the system automatically requests data from various sources. Information about plot boundaries and Land Use and Development Rules (LUDR) zones is loaded via the Public Cadastral Map API using the Pynspd library. Data on infrastructure (schools, shops, stops) is extracted from OpenStreetMap using the overpy library and Overpass API.

The obtained plot data is analyzed using the Shapely library. The program determines the centroid of the plot (its geometric center) and creates a coverage area (buffer) with a radius of 500 meters around this point. At the next stage, the program identifies infrastructure objects within this buffer zone and classifies them. This classification includes social objects (schools, clinics, kindergartens), commercial objects (shops, shopping centers), transport objects (public transport stops), green zones (parks, squares), and residential buildings (apartment buildings). The sequence of steps performed by the application is shown in Fig. 3.

Based on data from the LUDR, plot area, and analyzed infrastructure within a 500-meter radius, the system generates recommendations. For example, it can suggest the optimal type of development (residential building, commercial object), point out a shortage of certain objects (schools, green zones), or confirm that the plot complies with its designated purpose. The analysis results are displayed on an interactive map implemented using the Leaflet.js library. The user can view the plot, the coverage area, and infrastructure objects. Furthermore, the system allows saving the results as a PDF report, created using the ReportLab library, which includes text, tables, a map, and recommendations.

The developed web application allows users to input data about land plots, analyze their characteristics, visualize information on a map, and receive recommendations. The application interface consists of two key components: a sidebar (for data input, management, and result display) and an interactive map (for visualizing plots, zones, and infrastructure objects). The visual representation of the main screen is demonstrated in Fig. 4.

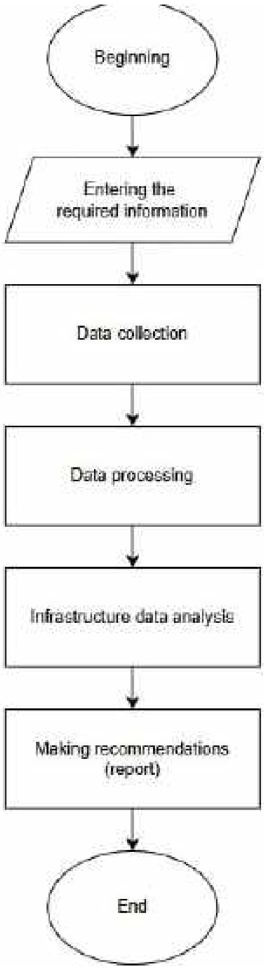


Fig. 3. Algorithm for Placing a Development Object

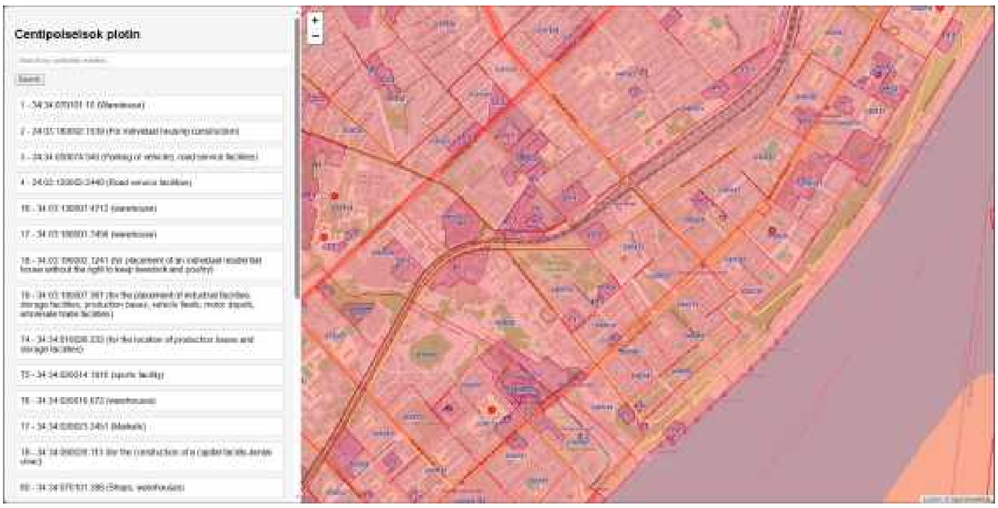


Fig. 4. Main Screen with Map and List of Plots

The main functions of the application include: searching for a land plot by cadastral number; displaying a list of available plots; visualizing the plot on the map (blue polygon) and the buffer zone with a radius of 500 meters (green circle). The map also shows cadastral blocks (red polygons) and Land Use and Development Rules (LUDR) zones (purple polygons) with labels of their codes and numbers. The system analyzes infrastructure within a 500-meter radius, generates recommendations (e.g., “Apartment Building” or “Add Kindergarten”), and allows exporting a report to PDF. Detailed information about the plot is presented in Fig. 5.

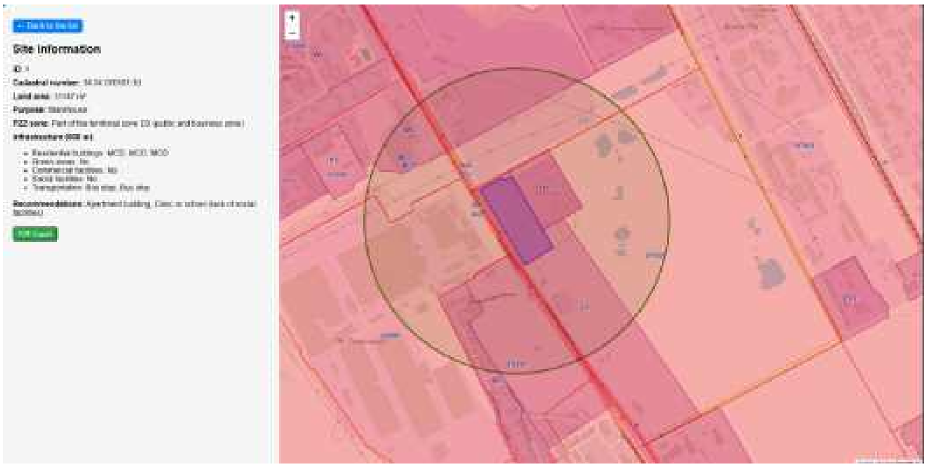
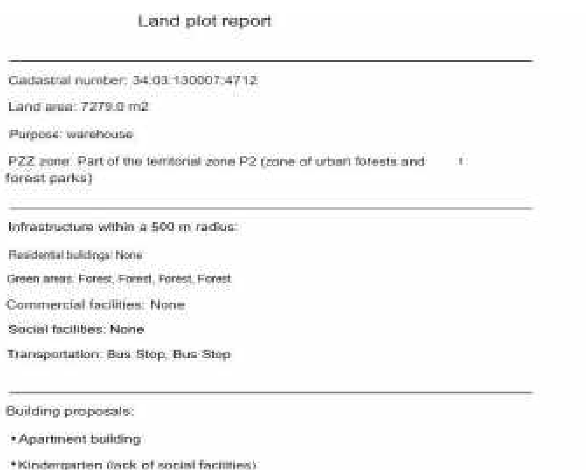


Fig. 5. Plot Information Screen

Functional testing was conducted to assess the system's performance and its compliance with requirements. Test scenarios were developed, including searching for and displaying a plot by cadastral number, analyzing the plot's infrastructure, and exporting a report to PDF. Functional testing confirmed that the system successfully implements all stated functions; all test scenarios were completed without errors. An example of a generated report is presented in Fig. 6.



Land plot report

Cadastral number: 34:03:130007:4712

Land area: 7279.0 m2

Purpose: warehouse

PZZ zone: Part of the territorial zone P2 (zone of urban forests and forest parks)

Infrastructure within a 500 m radius:

Residential buildings: None

Green areas: Forest, Forest, Forest, Forest

Commercial facilities: None

Social facilities: None

Transportation: Bus Stop, Bus Stop

Building proposals:

• Apartment building

• Kindergarten (lack of social facilities)

Fig. 6. Report in PDF Format

Fault tolerance testing was conducted to check operation in non-standard situations. Test 1 involved entering an incorrect cadastral number (e.g., “abc123”). Test 2 simulated a failure of an external service (Public Cadastral Map), where when entering a correct number, the PCM service is unavailable. Test 3 simulated 50 simultaneous requests for plot search and report export. Actual results showed that the system correctly handles incorrect data and failures, issuing error messages, and handles high load without crashing (average response time — 10 seconds).

General testing of the entire program was carried out on the “High Performance Computing Complex” deployed at the Department of Digital Technologies for Urban Studies, Architecture and Civil Engineering at Volgograd State Technical University as part of the implementation of the strategic academic leadership program “Priority 2030”.

Conclusion

As a result of the conducted research, an application for planning the development of a plot within an urbanized territory was developed and successfully tested. The created application is a tool that allows for a comprehensive analysis of land plots, assesses their potential for development, and generates substantiated recommendations considering urban planning regulations and infrastructure provision. The developed application takes into account the main stages of the existing CTD assessment process and allows optimizing the process of selecting the most effective project for territory development.

The potential scope of application of the developed system covers many areas:

- Municipal authorities can use the system for urban planning and land resource management;
- Developers and investors — for assessing the investment attractiveness of plots and selecting optimal development projects;
- Analysts and designers — for supporting the development of CTD projects.

Prospects for further development of the system include the following areas:

- Expanding functionality through the integration of additional data sources;
- Supplementing analytical data for forecasting economic efficiency, implementing machine learning methods for identifying patterns and optimizing recommendations;
- Creating a mobile version for operational access to the system from mobile devices;
- Adapting the system for analyzing large territories, for example, entire districts or cities, using more powerful databases such as PostgreSQL with PostGIS.

Acknowledgement

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Оксана Владимировна Савина✉

канд. техн. наук, старший преподаватель каф. цифровых технологий в урбанистике, архитектуре и строительстве, Волгоградский государственный технический университет (ВолгГТУ). Россия, 400074, Волгоград, ул. Академическая, 1;
e-mail: nov1984@yandex.ru

Артем Александрович Дёмин
магистрант каф. цифровых технологий в урбанистике, архитектуре и строительстве, Волгоградский государственный технический университет (ВолгГТУ). Россия, 400074, г. Волгоград, ул. Академическая, 1;
e-mail: demin.artem2003@gmail.com

Кевин Грас Мупегну Нзусси
канд. экон. наук, доцент каф. экономики, Мелитопольский государственный университет (МелГУ). Россия, 72318, г. Мелитополь, пр. Б. Хмельницкого, 18;
e-mail: kevinnzoussi@gmail.com

Светлана Юрьевна Катеринина
канд. техн. наук, доц. каф. цифровых технологий в урбанистике, архитектуре и строительстве, Волгоградский государственный технический университет (ВолгГТУ). Россия, 400074, г. Волгоград, ул. Академическая, 1;
e-mail: kat_svetlana@mail.ru; ORCID: 0000-0003-3836-753X

Владимир Вячеславович Ларин
студент каф. цифровых технологий в урбанистке, архитектуре и строительстве, Волгоградский государственный технический университет (ВолгГТУ). Россия, 400074, Волгоград, ул. Академическая, 1;
e-mail: cova4020@gmail.com

ЦИФРОВОЙ АНАЛИЗ ЗЕМЕЛЬНЫХ УЧАСТКОВ И ПЛАНИРОВАНИЕ ЗАСТРОЙКИ УРБАНИЗИРОВАННОЙ ТЕРРИТОРИИ

Актуальность исследования обусловлена вызовами современной урбанизации: перегруженностью инфраструктуры, социальными и экологическими проблемами, требующими новых инструментов для устойчивого развития городов. В статье представлена разработка веб-приложения, предназначенного для автоматизации планирования застройки отдельных земельных участков в рамках комплексного развития территорий. Проведен сравнительный анализ существующих программных решений (ArcGIS Urban, CityZenith, CityEngine), выявивший их ограничения, такие как высокая стоимость и сложность адаптации. В качестве альтернативы предложена архитектура и реализован алгоритм работы веб-приложения, которое интегрирует данные из публичной кадастровой карты и OpenStreetMap для анализа инфраструктуры в радиусе 500 м от участка. Система автоматически генерирует рекомендации по допустимому типу застройки на основе Правил землепользования и застройки. Работа приложения продемонстрирована на примере анализа участков в г. Волгограде, включая функциональное и нагрузочное тестирование. Разработанный инструмент представляет практическую ценность для муниципальных властей, девелоперов и проектировщиков, оптимизируя процесс принятия градостроительных решений.

Ключевые слова: комплексное развитие территорий, кадастровые данные, инфраструктурный анализ, геоинформационные системы, Python, OpenStreetMap, веб-приложение, урбанизированная территория.

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