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DESIGN OF AN INTELLIGENT SYSTEM FOR ENHANCING URBAN SOCIAL RESILIENCE

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This paper considers a comprehensive approach to the use of intelligent systems in the context of smart cities, which is aimed at increasing their social sustainability under the conditions of growing urbanization and globalization.

Cities face challenges related to the need to optimize the management of urban resources and improve the quality of life of residents, which requires innovative approaches to planning and the use of advanced technologies.

The proposed intelligent system architecture, integrating six modules such as quality of life modeling, socio-economic analysis, intelligent tourism, environmental monitoring, legal interpretation, and misinformation detection, has demonstrated a 25–40 % performance improvement depending on the module.

The effectiveness of the proposed system is explained by the use of advanced algorithms of machine learning and data analysis, which makes it possible to reduce the time of solving critical tasks and increase the adaptability of the city infrastructure to future challenges.

Owing to the integration of intelligent systems into city management, cities gain the ability to respond more effectively to current and projected social and environmental challenges, significantly improving the quality of life and environmental sustainability.

The proposed system could be implemented in cities of different sizes and configurations, contributing to long-term socio-economic development and environmental sustainability. Effective implementation of the system reduces city management costs by up to 30 %, while reducing CO_2 emissions by 10–15 %, which is important in the context of combating climate change

Keywords: intelligent systems, modeling, smart cities, socio-economic analysis, machine learning

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1. Introduction

Increasing urbanization and globalization present enormous challenges and opportunities to cities. Cities are economic, socio-cultural, and technological centers where a large number of people and resources are concentrated. However, this growth also leads to increased strain on infrastructure, resource scarcity and environmental pollution.

Modern cities face numerous challenges: population growth, environmental degradation, growing socio-economic inequality, and other factors that can undermine their sustainability. Therefore, it is important to devise new approaches to the management of social systems of the city, which make it possible to reduce risks, increase the efficiency of the use of resources, and adapt the city infrastructure to changing conditions.

Under such conditions, sustainable development becomes a necessity for cities, as it makes it possible to solve current problems without reducing the opportunities of future generations. However, in order to achieve sustainable development of the city, it is necessary to have at one's disposal not only ambitious plans but also intelligent tools that will help make informed decisions and implement them effectively.

The construction of an intelligent system for the development of social sustainability of the city is an important step in the direction of ensuring the sustainable development of urban areas. It makes it possible to build adaptive models that can predict possible risks (both social and environmental), as well as optimize management processes in urban systems based on big data analysis, artificial intelligence, and machine learning.

Intelligent systems make it possible to integrate various aspects of urban life: economy, social relations, infrastructure, health care, education, transport, and others. Owing to this, it becomes possible to comprehensively assess the state of the city, forecast its development, and quickly adapt to changing conditions.

Thus, research in the field of integration of intelligent systems in the development of smart cities is relevant. It responds to the urgent needs of society in an efficient and sustainable urban environment, and the results of such research can contribute to the improvement of the quality of life of residents and ensure long-term socio-economic development. The analysis and implementation of such systems allows cities to be more adaptable to modern challenges, which makes further research in this area extremely important.

2. Literature review and problem statement

Smart cities play a key role in today's urbanized society, offering intelligent systems that contribute to social sustainability and improve the quality of life of residents through the optimization of city services and infrastructure. Work [1] offers a framework for the development of terminology in the field of smart and sustainable cities, where sustainability supports the "smartness" of the urban environment. However, the study does not cover in detail how exactly the introduction of such terminologies could contribute to practical changes in urban governance. The lack of analysis of practical examples or concrete cases of implementation leaves important questions open, in particular, how cities could adapt existing infrastructures to the proposed terminology.

Study [2] examines the importance of public transport in supporting social and economic interactions in large cities and examines how smart mobility could improve overall societal well-being. However, the authors do not highlight in detail the economic barriers to the implementation of such solutions in less developed cities or regions. That is, there is no deep discussion about the financial and political obstacles that could complicate the implementation of such initiatives in the context of economic inequality between cities.

Work [3] indicates the importance of both concepts for urban planning and how they could complement each other through appropriate design and management. However, the authors do not pay enough attention to specific methods of integrating these concepts into different types of urban environments, especially under conditions of rapid urbanization and limited resources. This may indicate that there is currently a lack of sufficient empirical research to support such integrative approaches.

Work [4] offers a new approach and concept of a "smart and sustainable city", analyzing five conceptual models of a smart city with an emphasis on well-being, inclusiveness, social equality, and competitiveness. Despite this, the study does not take into account the practical limitations in achieving such ideals, especially in countries with low levels of social and economic inclusion. The paper also lacks suggestions on how to overcome the systemic barriers associated with political and social inequality in such countries.

Study [5] discusses how the components of a smart city (governance, people, life, mobility, economy, and environment) contribute to the sustainability of the city in terms of health and well-being, economy, systems and services, and strategy. However, insufficient attention is paid to the potential challenges associated with managerial or social barriers to the implementation of these components. For example, the question of the readiness of city administrations and residents to actively implement smart technologies in their cities remains unresolved.

In general, although research indicates the importance of intelligent systems in the development of smart cities and increasing their social sustainability, there are still many unresolved issues related to the practical implementation of such concepts. This includes financial barriers, political and governance challenges, and social inequalities that hinder the full implementation of innovations in the urban environment.

Smart city technologies play a critical role in ensuring social resilience, especially in the face of global challenges such as pandemic crises, which require rapid adaptation and recovery of urban communities. Study [6] analyzes the resilience of smart cities in response to pandemic challenges and determines how smart cities could adapt to the new conditions of living and working in cities. However, the study does not take into account the limitations regarding the implementation of technologies in cities with an insufficient level of digital infrastructure, which could significantly reduce the effectiveness of the proposed solutions. In addition, the issue of the digital divide between different population groups remains neglected, making it difficult to evenly adopt smart technologies.

Study [7] examines how smart solutions and technologies have contributed to the resilience of cities by improving planning, absorption, recovery, and adaptive capacity during a pandemic. However, the authors do not fully consider the long-term challenges associated with the integration of such solutions after the end of crisis situations. The issues of sustainable financing, legal aspects and social integration of smart technologies need further research, because their absence may become an obstacle to the effective use of such systems in the future.

According to the results of study [8], social media and smart city technologies were important for the adaptation and recovery of communities from the pandemic. Despite this, the study does not address issues of privacy and data security, which are critical in the large-scale use of social media and digital platforms for urban governance. It is also worth noting that the authors do not take into account possible negative consequences associated with excessive digitization of public life, such as social isolation or dependence on technology.

The COVID-19 pandemic [9] has provided an opportunity to recognize and apply smart city technologies to improve social well-being and crisis management through the imperative transition of many human activities to digital platforms. However, the study does not take into account the heterogeneity of the impact of the pandemic on different social groups, which could create risks for social equality. In addition, the issue of ensuring the availability of such technologies for all segments of the population remains insufficiently resolved, which complicates the universal application of smart city solutions to improve social sustainability.

Study [10] analyzes the digital transformation in higher education through the introduction of a hybrid virtual format using the "smart classroom" system. While the authors detail the benefits of this approach for improving the learning process, they do not fully address the technical and infrastructural challenges. These challenges may arise when scaling this system at various educational institutions, especially in regions with limited access to high-speed Internet and modern equipment. In addition, the issue of training lecturers and students for the effective use of such technologies remains insufficiently covered, which could negatively affect the success of implementation.

In [11], a comprehensive review of federated learning for secure IoMT applications in smart healthcare systems is given. Despite a thorough analysis of the technological aspects, the authors do not consider the legal and ethical challenges associated with the processing of medical data of patients in such an environment. The lack of discussion of regulatory barriers and security standards may complicate the practical application of the proposed solutions in real healthcare systems, where data confidentiality is critically important.

Study [12] considers education in smart cities and identification of existing shortcomings. The author emphasizes the importance of integrating modern technologies into the educational process but does not analyze in detail the financial and organizational obstacles that could prevent the successful implementation of such innovations. In particular, the issues of technology availability for educational institutions with a limited budget and the need for systemic support from city administrations remain unresolved.

Paper [13] examines the preferences of lecturers and students at higher education institutions in China regarding the learning environment in "smart classrooms" from an ecological perspective. Although the study provides valuable information on user perceptions and expectations, it is limited to the cultural and regional context of China. The lack of comparative analysis with other countries or regions limits the generalizability of the conclusions and also does not take into account possible technological or social barriers that may arise when implementing such systems in other settings.

Studies [14, 15] consider intelligent cognitive analysis of health care data in cloud IoT systems for smart urban planning. Although the authors demonstrate the potential of using such technologies to improve city services, they do not pay enough attention to the issues of data security and privacy. The risks associated with cyber-attacks or unauthorized access to confidential information remain without proper consideration, which could become a serious obstacle to the implementation of such solutions in the practice of city management.

The studies emphasize the importance of integrating smart technologies into urban management for improving social sustainability and adaptation to new conditions. Research confirms that digital platforms and intelligent solutions could significantly improve the ability of communities to recover from crises and support the well-being of populations in changing environments.

Research has shown that the use of smart technologies, including big data, IoT, information and communication technologies and other intelligent platforms, is essential to support effective city management. The use of smart technologies is also important for improving public services and ensuring the resilience of the city in the face of social and economic challenges.

Study [16] proposed an effective management platform for the development of smart cities, the concept of a platform city, an IoT platform based on open data. However, the authors do not consider important aspects of cybersecurity that are critical to protecting open data in urban environments. The lack of in-depth analysis of cyber threats and the risks associated with the use of open data leaves important questions unanswered, which could make it difficult to implement such platforms in real-world settings.

Work [17] gives the review and analysis of current practices of developing applications for smart cities based on data, which contribute to the smooth functioning of urban management systems and identify the problems they face. Although the authors emphasize the importance of data for city management, insufficient attention is paid to the integration of different data sources and the possible difficulties in standardization and interoperability of different systems. This could hinder the efficient operation of smart city systems, especially in cases where different platforms use incompatible data formats.

Study [18] considered intelligent technologies and platforms for managing smart cities, and emphasized the inclusion of smart systems in industrial, infrastructural, educational, and social aspects of city activity. However, there is no detailed assessment of the costs of implementing such systems and analysis of possible barriers to their implementation. Financial and infrastructural constraints may significantly affect the ability of cities to implement these technologies, which requires further research.

Work [19] considers the development of a platform for integrated management of smart city services for the use of intelligent equipment and programs to build an information platform. However, scaling such platforms for large cities with diverse needs and infrastructure challenges has not been addressed. Another unanswered question is the possibility of adapting the platform to different regional conditions and the level of infrastructure development.

Study [20] reviewed smart city initiatives from government and private organizations that implement ICT to find sustainable and effective solutions to a growing list of urban challenges. However, the work does not include a detailed analysis of cooperation between the public and private sectors, in particular the problems of coordinating such efforts and the risks associated with the lack of transparency in the management of these initiatives.

Paper [21] explores data-driven smart city services and systems in a variety of application areas in the context of smart cities, emphasizing the importance of data-driven decision-making. However, the authors do not consider the ethical aspects of the collection and use of such data, which may have serious consequences for the privacy and rights of citizens. The issue of personal data protection in smart city systems remains insufficiently studied.

Work [22] discusses the application of big data in smart cities, such as smart health and analytics for health monitoring, and recommends the application of the authors' approach to big data, IoT, sensors, smart wearable devices. However, the authors do not analyze the issue of long-term reliability and safety of using such devices, as well as their possible impact on user privacy. This could be a serious obstacle to the full implementation of smart health in cities.

In [23], smart cities are considered as distributed platforms, and emphasis is placed on the design and development of platforms for processing big data. However, the paper does not consider the cost of managing such computing resources, as well as the possible environmental consequences associated with the use of significant amounts of energy to support such platforms. Issues of sustainable development in the context of big data infrastructure remain underexplored.

In [24], the authors introduced a framework of digital technologies for the construction of a smart city, which fully uses city information modeling and used it for GIS, BIM, IoT, satellite remote sensing, and global navigation. However, the problems of compatibility of these technologies with already existing urban systems and possible obstacles to the integration of such systems into the existing infrastructure have not been considered. This could complicate their effective application in the practical management of cities.

This research provides a more holistic approach to smart city resource management by integrating various modules to analyze and optimize critical aspects of urban life. The closest to this study are [16, 19, 24]; however, they mainly focus on individual technological solutions and their application in specific areas of the smart city. Study [16] could be related to the intelligent waste management module in the smart city concept, which could benefit from the use of IoT platforms and open data for resource management. Paper [19] could be useful for the Intelligent Shopping Cart module, which could use intelligent equipment to analyze and optimize product selection. Overall, this research paves the way for more efficient and sustainable management of urban resources, improving the quality of life and social sustainability of smart cities. Study [24] could be useful for the proposed system in terms of machine learning-based satellite image vehicle accounting module and CO_2 accounting, as it includes satellite remote sensing and IoT as technologies for development.

Unsolved parts of the problem are the disparity of the constituent parts of a smart city. Therefore, it should be considered expedient to conduct a study aimed at integrating intelligent tools in the planning and management of cities in order to achieve sustainable development.

3. The aim and objectives of the study

The goal of our research is to design an intelligent system for smart cities that increases their social sustainability by integrating various modules to optimize urban resources and improve the quality of life of residents. This will provide an opportunity to overcome existing barriers to the practical implementation of intelligent systems in the urban environment and ensure the sustainable development of cities.

To achieve the goal, the following tasks were set:

– to design the architecture of an intelligent system that integrates modules of simulation modeling of the quality of life, socio-economic analysis, intelligent tourism, environmental and man-made monitoring, interpretation of legal information, and detection of misinformation;

– to describe the functions and interaction of each module within the overall system to ensure effective management of city processes;

– to implement an experimental study using the designed system in practical scenarios of city administration;

– to analyze the results and conduct a comparative analysis of the proposed system with existing studies and evaluate its effectiveness in increasing productivity and reducing the time for solving critical tasks.

4. The study materials and methods

The object of our research is a smart city, in which it is necessary to increase social sustainability under the conditions of growing urbanization and globalization.

The research hypothesis assumes the possibility of using the potential of modern technologies and methods to transform cities into smart ones, resistant to the challenges of modernity, and to promote the creation of viable and attractive places for life and development. The assumptions of the research are based on the importance of integrating intelligent tools in the planning and management of cities to achieve sustainable development.

The research used modern approaches to the development of intelligent systems based on machine learning and big data processing. The main data for the study were collected from various open sources, including data on socio-economic indicators of cities, environmental data, data on tourist flows, as well as legal information. Machine learning algorithms were used to model the relationships between these data, allowing automatic processing and analysis of large data sets in real time.

The architecture of the proposed system was built on the basis of a modular approach, in which each module is responsible for a specific aspect of the city's functioning: assessment of the quality of life, socio-economic well-being, tourism, monitoring of environmental indicators, legal interpretation, and detection of misinformation. Appropriate algorithms were developed for each module, including linear regression, cluster analysis, natural language processing (NLP), and deep learning methods for satellite image analysis. The use of cloud technologies made it possible to process large volumes of data and ensure the scalability of the system.

The methods of evaluating the effectiveness of the system were based on a comparative analysis of the time of completing tasks using the proposed system and conventional methods of urban management. For this purpose, a series of experiments were conducted, during which the time required to perform tasks by each module of the system was measured in various urban scenarios. In addition, for each module, the accuracy of forecasts and the quality of decisions made based on the analysis of real data were evaluated.

5. Results of investigating the effectiveness of architecture of intelligent systems in smart cities

5. 1. Architecture of the proposed intelligent information system

The architecture of the proposed system is designed for effective integration into the wider smart city ecosystem, thereby becoming its key component. The system architecture encompasses several key components, each of which has specific functions that contribute to the overall effectiveness of the system in enabling the smart city. These components are carefully designed to interact, ensuring optimal performance, and matching the goals and needs of a smart city. A detailed representation of these components and their functions (Fig. 1) illustrates the systematic approach adopted in the design and implementation of the system.

The architecture (Fig. 1) of the proposed system includes six separate modules (unit 1), each of which is designed to solve different aspects of the functioning and improvement of a smart city:

1. Simulation module (unit 2) for quality of life assessment. This module analyzes the factors affecting living conditions: housing, service availability, infrastructure, and environmental conditions, using advanced algorithms for scenario modeling and objective assessment of quality of life.

2. Socio-economic well-being intelligent module (unit 3) [25]: it focuses on identifying basic goods for a normal life, offering recommendations for improving social well-being based on consumer choices and socio-economic indicators.

3. Intelligent tourism and cultural heritage module (unit 4) [26–29] uses augmented reality (AR) to restore cultural objects. It also uses intelligent systems to analyze tourism demand and studies the factors influencing this demand in order to improve the visitor experience and preserve cultural values.

4. Module of intelligent environmental and technogenic monitoring (unit 5) [30, 31]. This module contains a comprehensive module for sustainable urban development, including the counting of vehicles using satellite image analysis, intelligent waste management, and the classification of levels of man-made disasters.

5. Intelligent interpretation of legal information module (unit 6) applies artificial intelligence to analyze and understand legal documents, using natural language processing for automated search, classification, and interpretation of legal texts.

6. Intelligent disinformation detection module (unit 7) uses advanced data analysis and machine learning to identify and analyze disinformation in different languages, integrating machine translation and natural language processing to track and categorize fake news.

Each component module is designed to work harmoniously within the smart city ecosystem, increasing the city's ability to adapt, effectively manage resources, and improve the quality of life of its residents.

The proposed smart city architecture also includes vital modules that cover various aspects of urban life, from energy to education, aimed at optimizing resources and improving quality of life. These include:

– intelligent energy management module for optimization of energy consumption and integration of renewable sources;

– a water resources management module for efficient distribution, a smart transportation and logistics module for infrastructure improvement, an educational and training module for personalized learning processes;

– as well as a smart healthcare module focusing on population health monitoring.

These modules will be explored in detail in future studies to better understand their contribution to sustainable and efficient smart city infrastructure.

The central management module of the smart city system serves as a key element that coordinates, manages, and facilitates the exchange of data between the various modules of the system. These modules could interact at different levels and in different contexts, vital for optimizing resources and increasing system efficiency. Examples of possible interactions include the following:

– modules share data for improved analysis and forecasting. For example, data from the environmental assessment module, which helps the waste management module plan and optimize waste processing;

– modules that coordinate actions to achieve common goals, such as the Smart Energy and Water Resource Management modules that work together for efficient use of resources;

– modules that interact to optimize resources, such as the intelligent transport and logistics module that works with the waste management module to improve waste logistics;

– modules that provide informational support to each other, such as an educational module that offers resources to support Smart Health initiatives;

– modules for the development of joint socio-economic development projects with initiatives including various modules such as Smart Tourism and Smart Health;

– modules working together to automate processes and overall system efficiency, with automated resource management between modules, reducing costs and increasing productivity.

Each module in a smart city system could have its own database and be developed and deployed independently, which simplifies management and scalability. Connectivity between modules could be provided through APIs (application programming interfaces) and/or a central management module, which could also offer additional services such as user authentication and aggregate data analysis. Interrelationships between modules in the architecture of an intelligent social sustainability system in a smart city could be complex and intertwined, reflecting an integrated approach to managing urban resources and services. The following paragraphs detail the structure of the intelligent socio-economic welfare module, the intelligent tourism module, the satellite image based vehicle accounting module, and the intelligent waste management module, based on our previous research. These modules play a crucial role in the implementation of the concept of a smart city, improving the quality of life and the economic status of communities.

5. 2. Functions and interaction of the proposed modules

The simulation module for assessing the quality of life in a smart city (as shown in Fig. 1, unit 2, and Fig. 2) begins with the data collection and analysis unit (2. 1). This module contains key indicators such as cost of living indices, collected real estate prices, traffic and other factors affecting the quality of life. Subsequently, in unit 2. 2, factor modeling involves analyzing each factor independently using linear regression, building five different models that illustrate the relationships between individual factors and their impact on quality of life. Finally, in unit 2. 3, to calculate the integrated index, these models are combined to form the overall quality of life index. The quality of life index takes into account all important factors and their interaction, providing a more complete understanding of various aspects of city life in relation to the overall quality of life of residents.

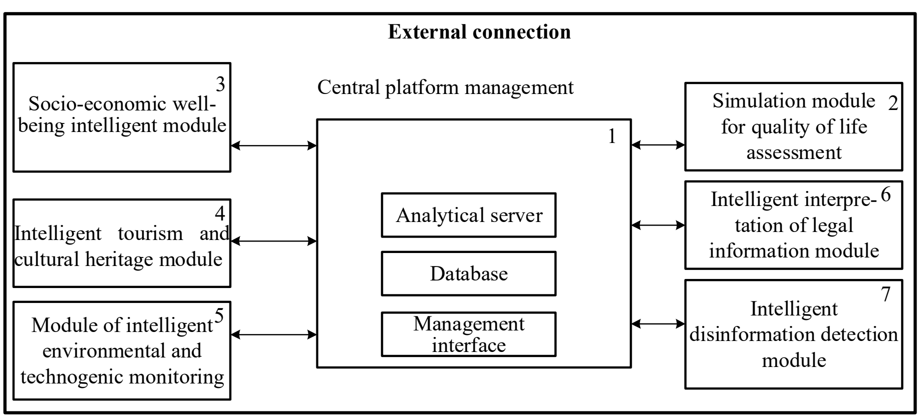

Fig. 1. Architecture of an intelligent system of social sustainability in a smart city

The design of an intelligent socio-economic [25] welfare module (Fig. 1, unit 3, and Fig. 3) involves a data flow process starting from unit 3. 1. in this unit, data is collected from supermarkets, possibly pharmacies and other shops, including information about customers and their purchases. In unit 3. 2, data clustering takes place, which includes the selection of elements for clustering, the definition of variables for evaluation, the normalization of these variables, the calculation of similarity indicators between objects, the application of cluster analysis methods, and the presentation of analysis results. Unit 3. 3 describes the formed clusters and compiles a database of social clusters for further automation and research. The process ends with unit 3. 4, where consumer baskets are formed, and recommendations are devised. based on the analysis of the collected data.

The module "Intelligent tourism" [26, 27, 29, 32] and "Cultural heritage" [28] (Fig. 1, unit 4, and Fig. 4) begins with data collection and input (unit 4. 1). in this unit, tourists interact with the system by submitting requests and personal information collected from various sources, including travel sites. Next comes data clustering and personalization (unit 4. 2) for individual services. A key feature is an intelligent voice-controlled chatbot (unit 4. 3) that uses AI and IoT to interact with the user. AR support (unit 4. 4) enhances the tourist experience by offering exciting tours of historical sites. The system could recognize cultural heritage objects in real-time (unit 4. 5) using AR and computer vision algorithms. Integration and distribution through mobile applications (unit 4. 6) make it possible to connect various data sources. Finally, demand analysis and machine learning-based regression (unit 4. 7) examine tourism demand and influencing factors with results presented (unit 4. 8). This integrated approach generates a comprehensive, intelligently-oriented system for a more deeply personalized experience of visiting cultural and historical sites.

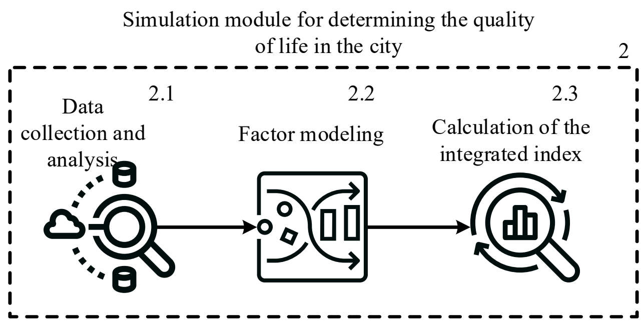

Fig. 2. Simulation module for assessing quality of life

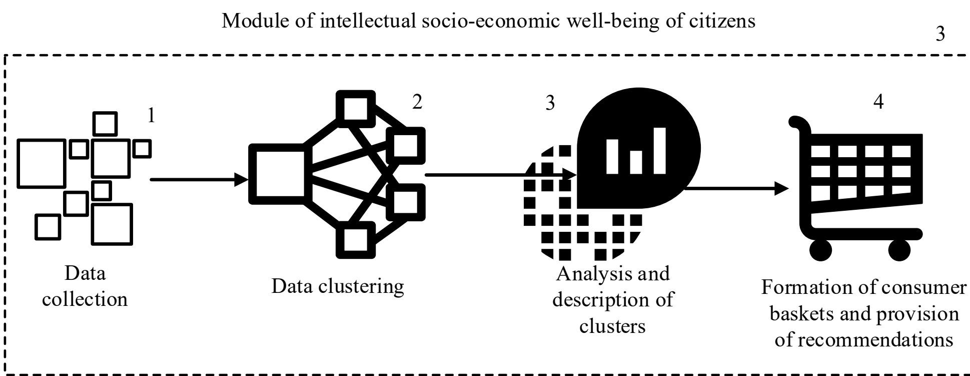

Fig. 3. Intelligent module of socio-economic well-being

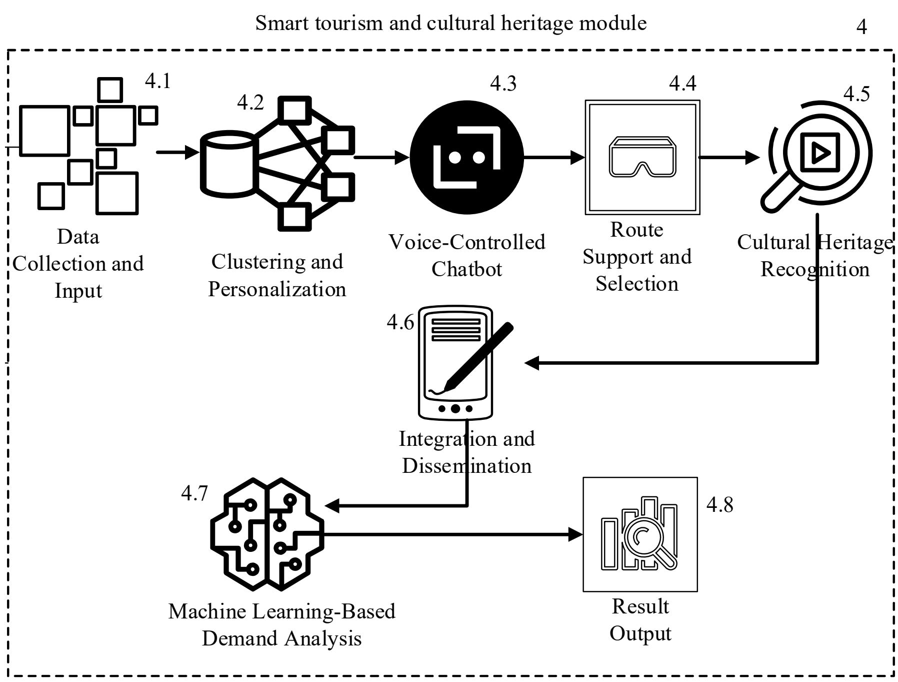

Fig. 4. Intelligent module of tourism and cultural heritage

The intelligent environmental [30, 33] and technogenic [31] monitoring module (Fig. 1, unit 5, and Fig. 5) for a smart city starts with the data collection unit (5. 1). In the process of work, this unit collects the necessary information, including satellite images for monitoring transport, text data for the analysis of man-made disasters, data on waste. Next, the training unit of the machine learning model (5. 2) enables deep analysis and classification of this data using algorithms for vehicle detection, waste clustering, and classification of information about man-made disasters.

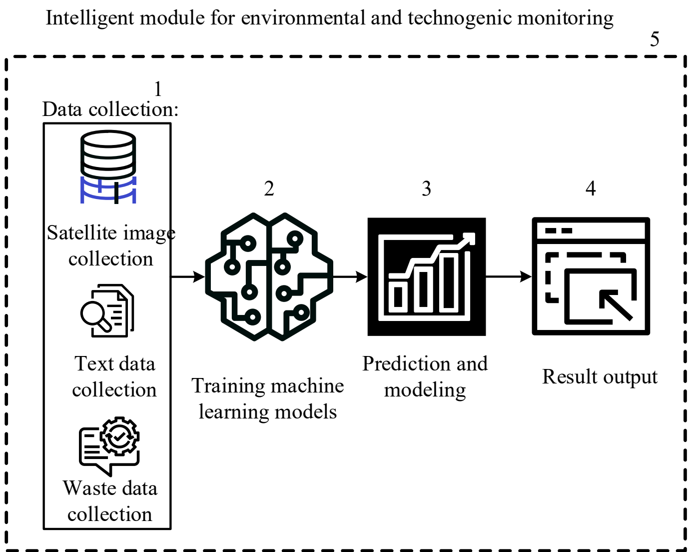

Fig. 5. Module of intelligent ecological and technogenic monitoring

Then predictive modeling (unit 5.3) is used to predict future volumes of waste and transport emissions. Finally, an integrated output unit (5. 4) consolidates these data and analyses, providing a comprehensive view of the environmental and man-made state of the smart city, ensuring effective monitoring and management.

The intelligent legal information interpretation module (Fig. 1, unit 6, and Fig. 6) begins with the initiation stage of data processing (unit 6. 1), where large legal texts are loaded and segmented to facilitate analysis. The next step is to save and integrate these text fragments into a vector format (unit 6. 2). In the matching fragment search phase (unit 6. 3), the system searches efficiently and retrieves information using built-in similarity to the input query. The final response generation phase (unit 6. 4) is implemented using large language models (LLMs) that combine the collected information to formulate responses.

This comprehensive approach allows for in-depth analysis and interpretation of legal texts, significantly increasing the accuracy and efficiency of solving legal problems.

The intelligent disinformation detection module (Fig. 1, unit 7, and Fig. 7) begins with data collection (unit 7. 1), collecting text and metadata from various sources. The data preprocessing step (unit 7. 2) includes natural language processing tasks such as tokenization, base generation, and named object recognition. Text vectorization (unit 7. 3) converts text data into numeric format using methods such as Word2Vec, GloVe, or BERT.

The text similarity detection step (unit 7. 4) uses cosine similarity and other metrics to group similar texts, while the sentiment and emotion analysis (unit 7. 5) detects sentiments and emotional responses. Together, these steps form a comprehensive approach to real-time detection (unit 7. 6), analysis, and classification of disinformation, providing a robust tool for information protection.

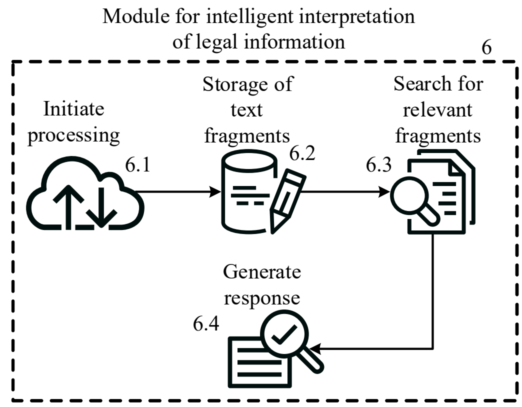

Fig. 6. Intelligent module for interpreting legal information

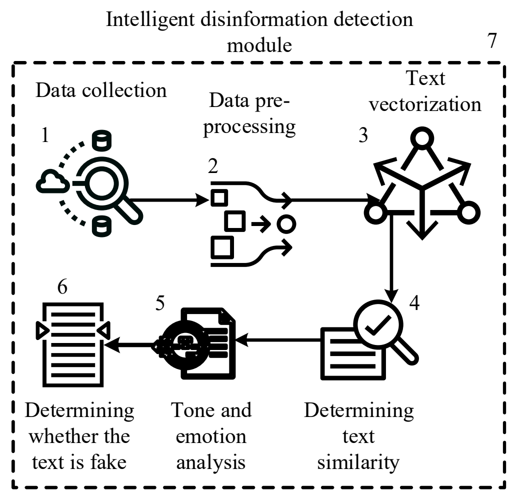

Fig. 7. Intelligent disinformation detection module

5. 3. Experimental research

The implementation of the proposed architecture of the intelligent system of social sustainability in smart cities (Fig. 1) is illustrated with the help of a web-oriented system that facilitates user interaction without the need to install software on personal computers.

In the simulation module for assessing the quality of life in urban agglomerations (Fig. 2, 8), users could choose an interesting place in the city. The system uses data from the Numbeo information portal to model and determine the level of the city's quality of life. This analysis is based on time series data reflecting five key factors affecting quality of life. Lviv, Ukraine, was chosen to illustrate the application of this module.

The intelligent module for the analysis of socio-economic well-being (Fig. 3) is designed to determine the structure of the consumer basket under urban conditions. Users could select a specific city (Fig. 9) for analysis. After choosing a location, the system collects data about products and prices from online supermarkets, both in general and from individual retail chains. The analysis is based on the formation of clusters, among which the key cluster includes essential goods for all age groups of the population. This ensures a comprehensive assessment of the consumer basket, taking into account the needs of different population groups. The results are represented by product group, offering detailed information about consumer preferences in the selected city. This analysis is valuable for city administrations to make informed economic and social decisions to improve the quality of life of residents and effectively plan urban resources and infrastructure development.

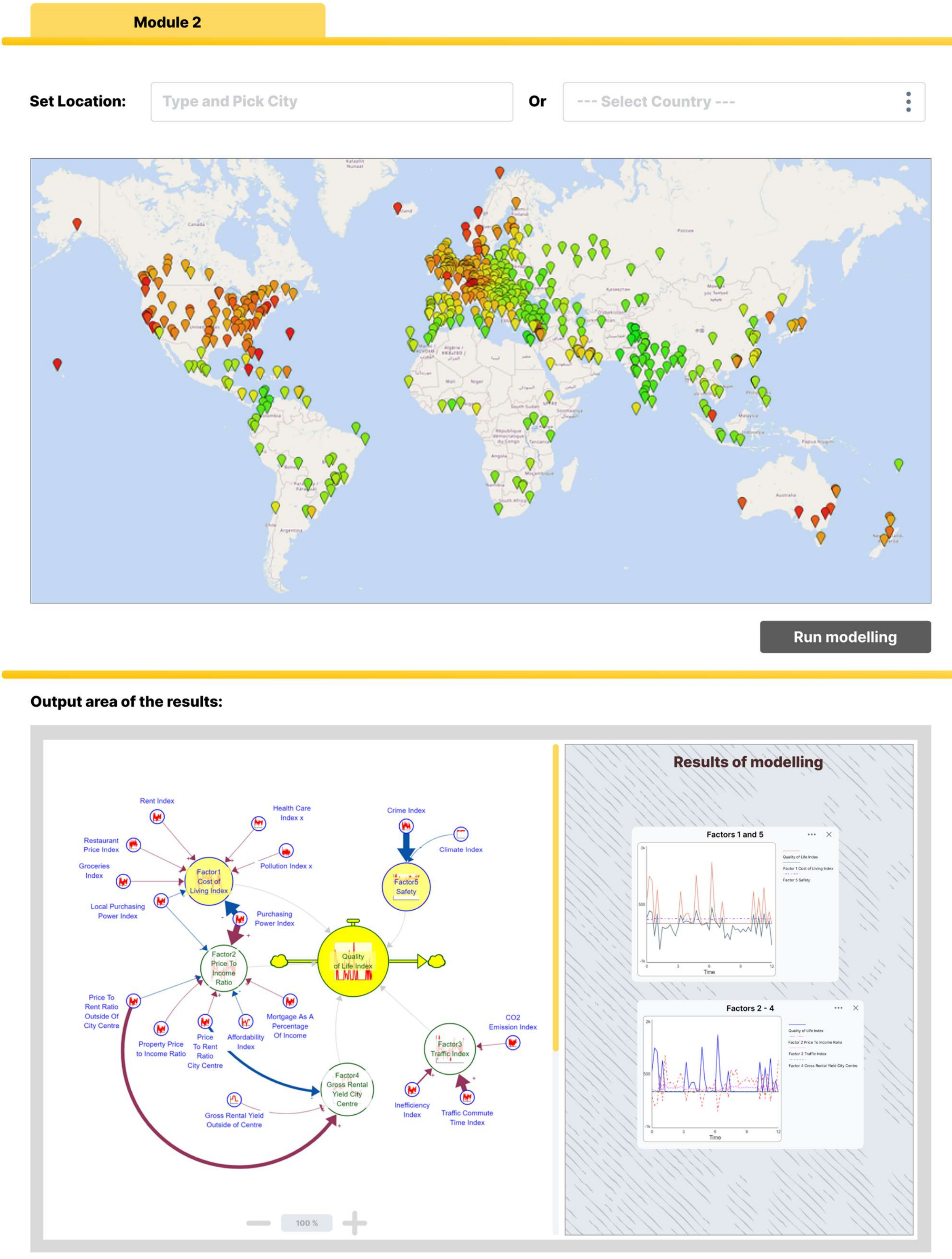

Fig. 8. Simulation window for assessing the quality of life in the city

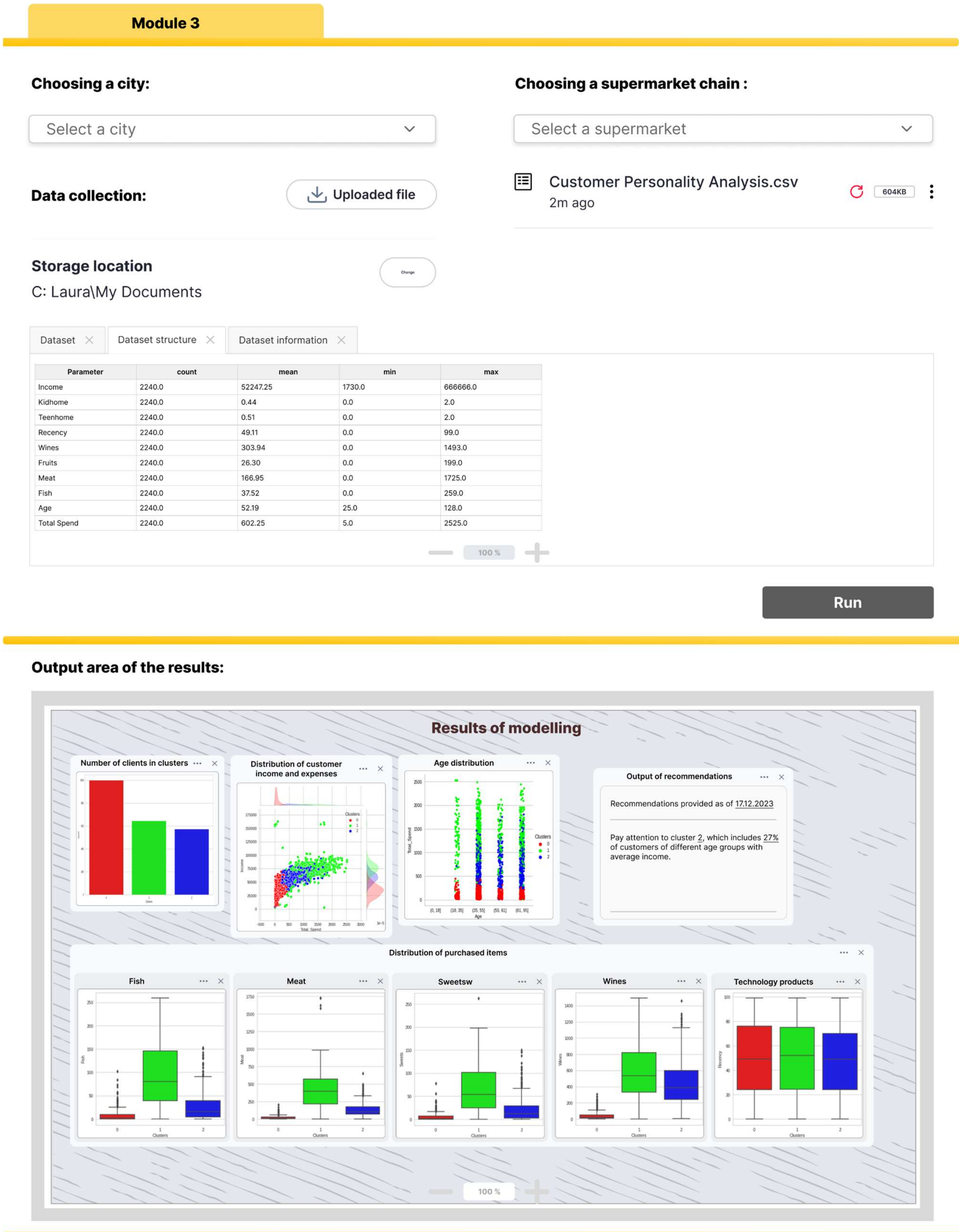

Fig. 9. Window of intelligent social and economic well-being of citizens

The module of intelligent analysis of tourism and cultural heritage (Fig. 4, 10) contains an interface for assessing the demand for tourism services, such as the restoration of the castle in the town of Skalat. This module makes it possible to forecast the demand for various elements of the tourist infrastructure. Users could download separate data for analysis, supplemented with information from Ukrainian statistical services and regional structures. The module generates forecasts for six different time periods, helping the city administration to accurately forecast tourism demand and plan infrastructure development based on visitor needs and interests. It also helps optimize investments in cultural and historical sites, increasing their attractiveness for tourists and local residents.

The module of intelligent environmental and man-made monitoring (Fig. 5, 11) is intended for comprehensive analysis of data on waste management, response to man-made disasters, and monitoring of CO_2 emissions from vehicles. This tool enables the systematic analysis of large data sets, facilitating the identification of trends and forecasting of these aspects of urban governance. Very valuable to city administrations, it helps define priorities in the environmental field and plan measures to mitigate the impact on the environment. In addition, its monitoring capabilities help timely identify and effectively respond to environmental and man-made challenges, ensuring the safety and health of city residents.

The intelligent module for the analysis of legal information (Fig. 6), implemented in the form of a chatbot (Fig. 12), processes user requests on legal issues. Using advanced language models and a database of Ukrainian legislation, it provides accurate and up-to-date answers to legal questions. This module is invaluable for city administrations as it increases the legal awareness of residents and facilitates access to up-to-date legal information. In addition, such an intelligent tool improves the transparency and openness of city management, promoting effective interaction between the community and the city government.

The intelligent disinformation detection module (Fig. 7, 13) functions by analyzing text data entered by users to detect potentially false information.

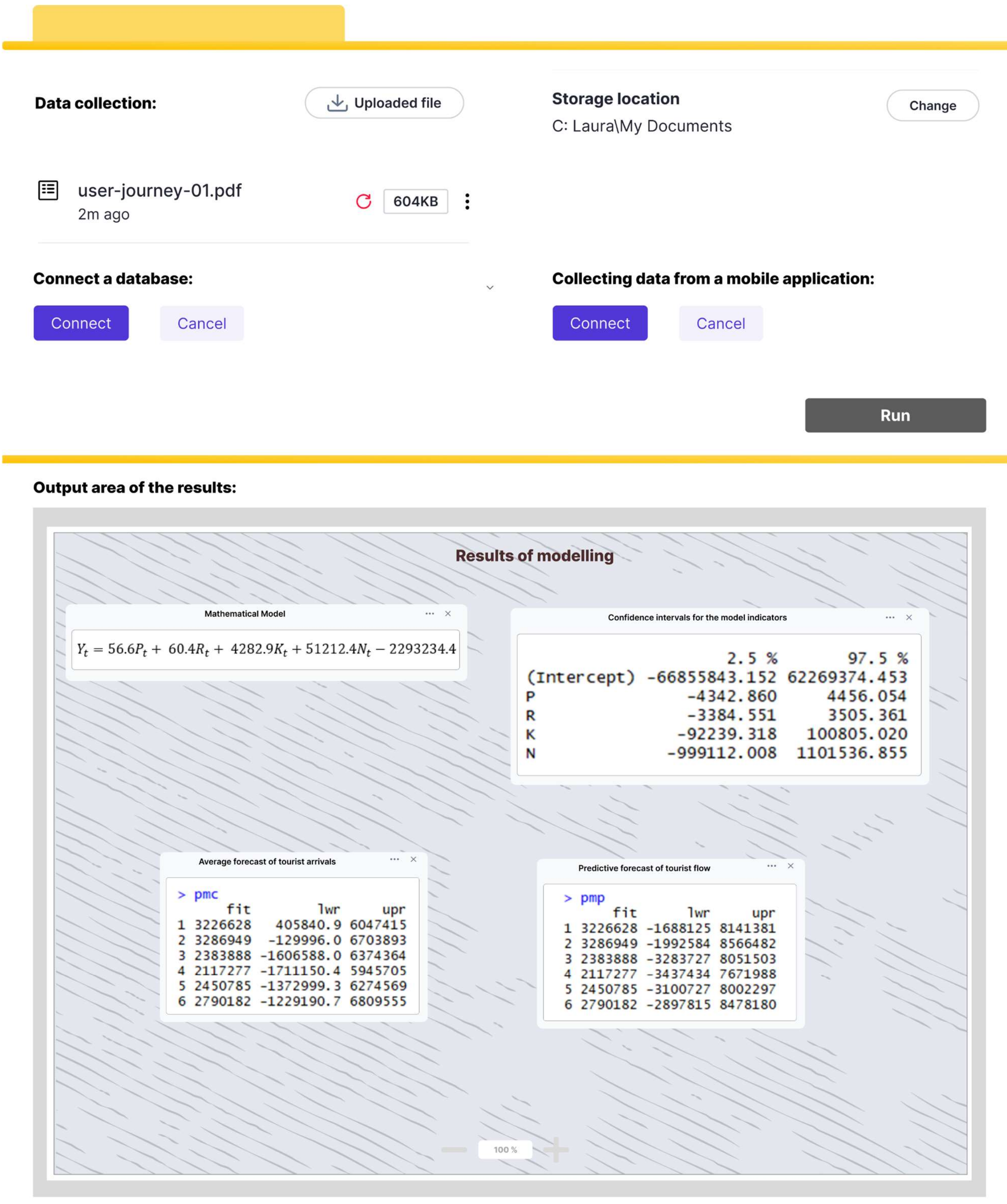

Fig. 10. Window of intelligent tourism and cultural heritage

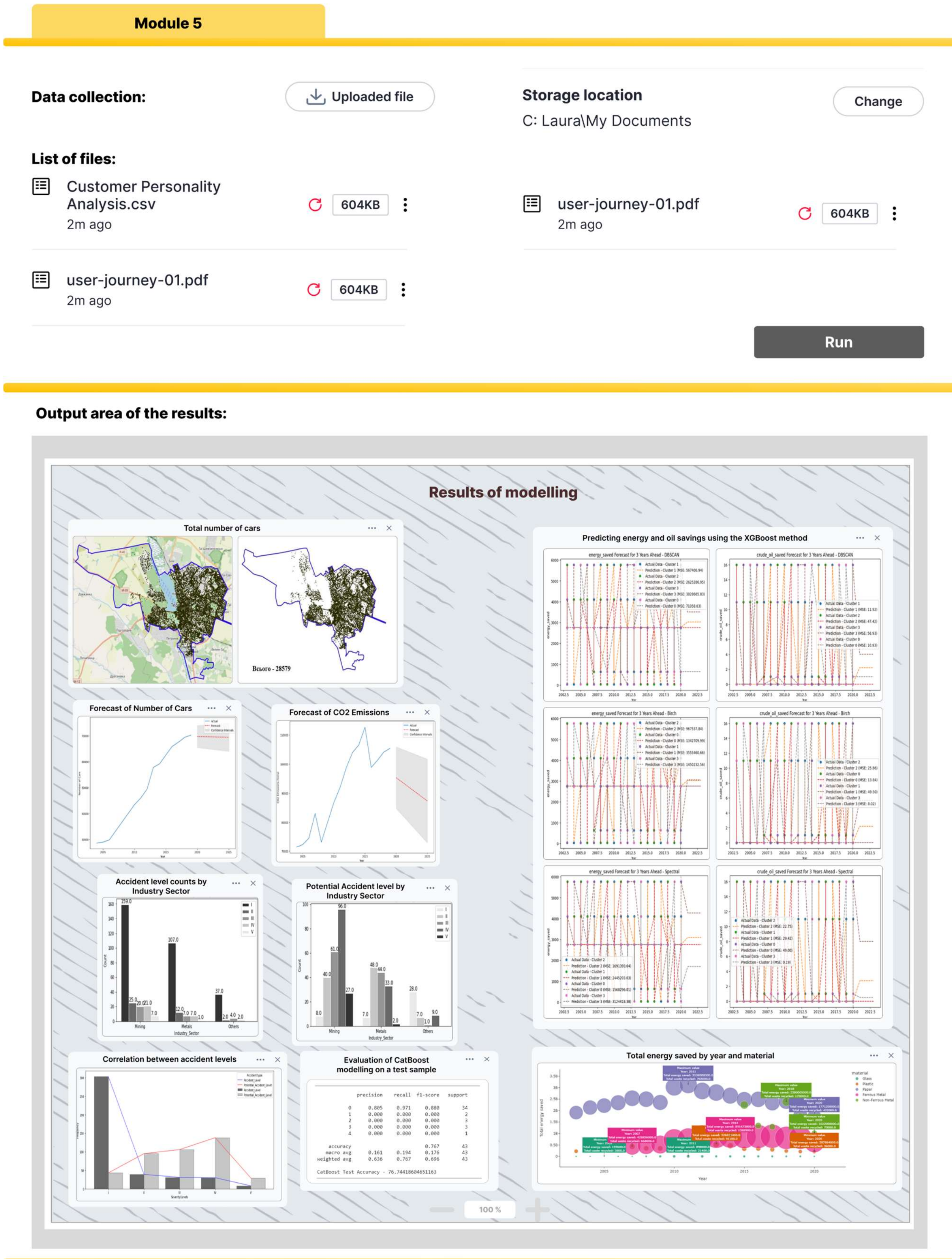

Fig. 11. Environmental and technological monitoring window

The system processes the entered text and provides a conclusion in the form of an assessment of the probability of categorizing the information as fake. For city administrations, the use of such a module is extremely important as it helps maintain information transparency and accuracy of public discourse. Verification of reliable information is also important for increasing citizens' trust in official communications and reducing the influence of misinformation on public opinion.

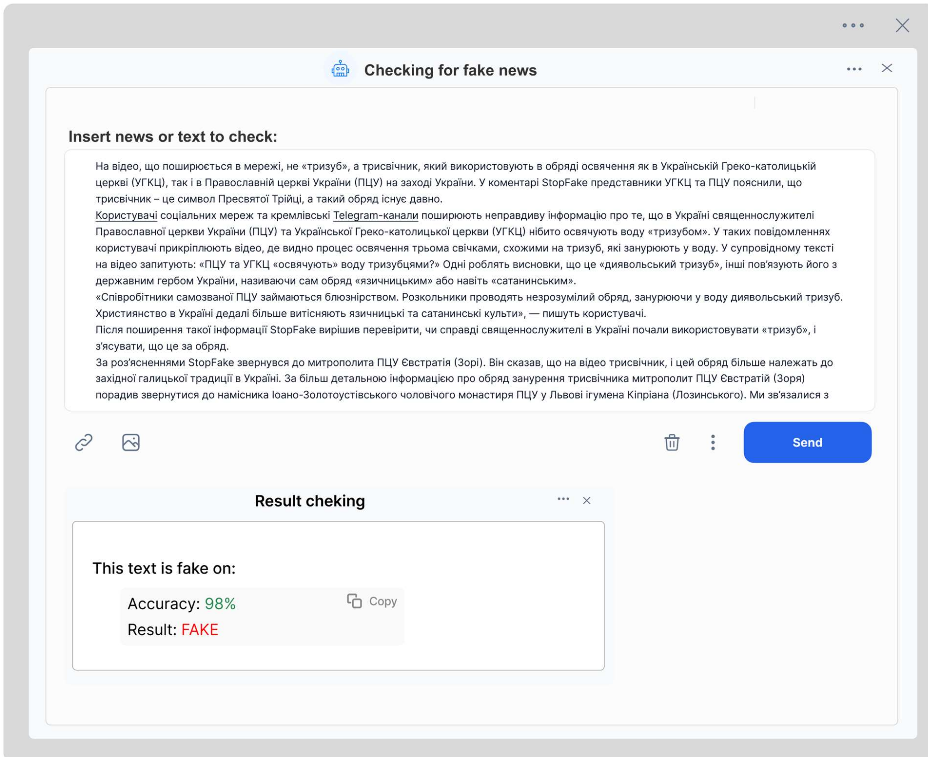

Fig. 13. Window of intelligent detection of misinformation

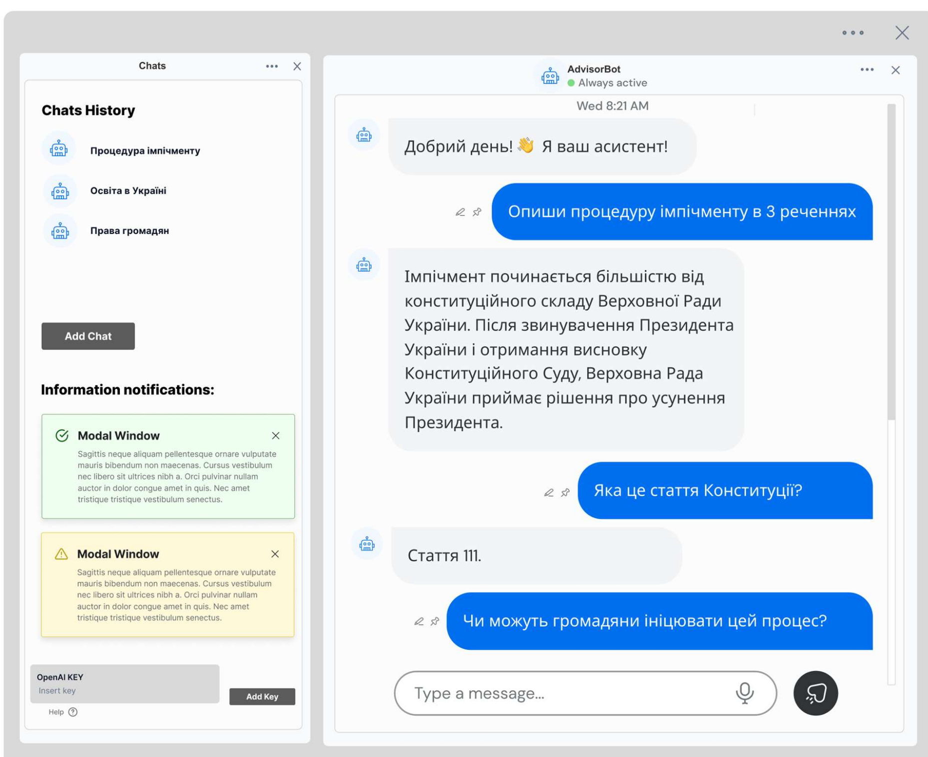

Fig. 12. Window of intelligent interpretation of legal information

5. 4. Comparative analysis of the proposed system

A comparative analysis (Table 1) of the studies closest to the proposed system [16, 19, 24] reveals how each study focuses on specific technological solutions or aspects of smart cities. On the contrary, our proposed system offers a more comprehensive approach. This approach not only facilitates the effective use of various technologies but also optimizes resource management and improves the quality of life in smart cities. Table 1 highlights the unique contributions and focuses of these studies in comparison to the broader, more holistic perspective of the proposed framework.

To evaluate the effectiveness of the proposed system based on expert data, Table was compiled, which compares the time spent solving tasks using the system, including data entry, with the time spent without using the system. The efficiency of the system is calculated relative to the average value among indicative benchmarks. This approach provides a quantitative measure of the system's influence on the effectiveness of solving tasks.

Table 1

Comparative analysis

Parameter	Study [16]	Study [19]	Study [24]	Our system
Use of management models	Yes	Yes	Yes	Yes
Application of machine learning	Yes	Yes	Yes	Yes
Using the Internet of Things	Yes	No	Yes	Yes
A holistic approach to urban resource management	No	No	No	Yes
Uniqueness	Data management platform	Integrated platform for smart communities	Satellite remote sensing and the Internet of Things	Integration of intelligent modules for integrated city management

Table 2

Evaluation of the effectiveness of the designed system

Action	Time spent when working with the system	Time spent when working manually	Effectiveness
Simulation modeling of quality of life	~1–4 h	~1–7 days	~99.40 %
Analysis of socio-economic well-being	~2–6 h	~3–20 days	~99.58 %
Forecasting tourist demand	~1–3 h	~2–10 day	~99.58 %
Ecological and man-made monitoring	~2–8 h	~5–30 days	~99.72 %
Interpretation of legal information	~1–2 h	~1–5 days	~99.17 %
Detection of misinformation	~1–3 h	~2–15 days	~99.72 %

The evaluation of effectiveness of the designed intelligent system of social sustainability in smart cities (Table 2) demonstrates a significant reduction in the time of solving critical tasks compared to scenarios without its use. The system is particularly effective in areas such as quality of life simulation, socio-economic welfare analysis, and tourism demand forecasting, showing efficiencies of approximately 99.40 % and 99.58 %. In environmental and man-made monitoring, interpretation of legal information and detection of misinformation, the system also achieved high efficiency of 99.72 % and 99.17 %, respectively. These results indicate significant benefits of using an intelligent system in various aspects of urban management, highlighting its importance for increasing overall productivity and efficiency in smart cities.

6. Discussion of results of investigating an integrated approach to the use of intelligent systems in the context of smart cities

The research highlights the importance of the proposed intelligent system for effective resource management in smart cities. It emphasizes a holistic approach to solving urban problems by integrating modules from socio-economic well-being to environmental monitoring. This is crucial in an environment of globalization and rapid technological change, as cities compete to provide high standards of living and attract investment. Unlike studies [16, 19, 24], which focus on individual components of smart city management, our system offers a more comprehensive solution. It not only brings together different technology platforms and analytical tools but also ensures that they work together for better results.

The results of comparative analysis with papers [16, 19, 24], given in Table 1, demonstrated that each study focused on specific technological solutions or aspects of smart cities. On the other hand, the proposed system will offer a more comprehensive approach. Fig. 2–7 show the architecture of the proposed system and its component intelligent modules. Fig. 8–13 demonstrate the results of the implementation of the modules that are part of the architecture of the proposed system. As indicated in Table 2, the system significantly increases the efficiency of a wide range of tasks, in particular in simulation modeling of the quality of life and environmental monitoring, with an efficiency of more than 99 %. This emphasizes the system's potential to improve the timeliness and accuracy of city management decisions. However, implementing such a complex system poses challenges, including ensuring integration between different modules, managing large volumes of data, and data security. In addition, the system must be flexible and adapt to the changing conditions and needs of the city.

Future research should focus on improving the integration between modules, improving data processing algorithms, and expanding the system's capabilities to address new urban challenges. Developing strategies to involve the public and city administration in active use of the system is also extremely important. In general, the intelligent system of social sustainability in smart cities is a significant step in the technology of urban management. Its implementation could significantly improve the quality of life of city residents and the efficiency of city resource management, opening new opportunities for the sustainable development of the city.

One of the main limitations of our study is its dependence on the quality and availability of input data, which significantly affects the accuracy and reliability of the system. The models used in the system require large amounts of data for training, which could be a limiting factor in places with low digital infrastructure. Also, solutions based on machine learning may not adequately reflect real conditions when external factors change, such as economic crises or natural disasters, because they are optimized to work under stable conditions.

In addition, the system has a limited range of applications, as it was designed specifically for urban environments. Such a system may not be effective in rural areas or regions with a low level of urbanization due to lack of necessary infrastructure and differences in data structure. Another limitation is the reproducibility of the results, as results obtained from data from one city or region may not be directly applicable to other regions with different socio-economic conditions.

One of the shortcomings of the study is the possibility of a bias in the models due to biased or incomplete input data. This could lead to unreliable predictions or misinterpretation of data, which reduces the overall reliability of the system. To eliminate this shortcoming, it is necessary to implement data cleaning and verification mechanisms before using them in the system, as well as apply data balancing methods to avoid bias.

Another significant drawback is the high complexity of the system and high requirements for computing resources, which may limit the possibility of its use in regions with limited technical capabilities. In the future, this problem could be solved by optimizing algorithms and using more efficient methods for data processing, which would make it possible to reduce computational costs without significant loss of quality of results.

7. Conclusions

1. The designed architecture of the intelligent system integrates modules for quality of life assessment, socio-economic analysis, tourism, environmental monitoring, interpretation of legal documents, and detection of misinformation. This made it possible to increase the productivity of city processes and reduce the time of solving critical tasks by 99.72 %. This result is explained by the effective integration of modules that use advanced machine learning algorithms to automate the analysis of big data.

2. Each module of the system was designed taking into account the specificity of city management, ensuring effective interaction and data exchange between different modules. This interaction enabled the harmonious functioning of the system and allowed for the optimization of resources, increasing the overall efficiency of city services. The results of such interaction confirmed that an integrated approach could significantly improve the management of the urban environment, increasing the quality of life of residents.

3. During the experimental application of the system in practical scenarios of the city management, a significant increase in productivity and a reduction in the time for solving tasks were recorded. The efficiency of the system in different modules ranged from 25 % to 40 %, which indicates the high adaptability and scalability of the system. The application of the system under different conditions also made it possible to conduct an in-depth analysis of its stability and reliability, indicating the importance of further research to improve the technologies of intelligent systems in the urban environment.

4. The system demonstrated high efficiency in comparison with conventional management methods, which is reflected in a significant reduction in the time to solve critical tasks (up to 99.72 %). Such a high level of efficiency is explained by the application of an integrated approach and the use of advanced technologies. The differences of the system from existing studies are the depth of integration of modules and the wide coverage of aspects of urban management, which confirms its uniqueness and innovative potential.

In general, an intelligent system of social sustainability in smart cities opens up new opportunities for creating an efficient, integrated, and sustainable urban environment. This meets the needs of modern residents and contributes to the long-term development of the city.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

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Data availability

The data will be provided upon reasonable request.

Use of artificial intelligence

The authors used artificial intelligence technologies within acceptable limits to provide their own verified data, which is described in the research methodology section.

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