MINISTRY OF NATIONAL EDUCATION
BUCHAREST TECHNICAL UNIVERSITY OF CONSTRUCTIONS
DOCTORAL SCHOOL

ABSTRACT
DOCTORAL THESIS

Usage of Geographical Information Systems as Local and Regional Development Analysis Tool

PhD Supervisor
PROF. DR. ING. PETRE IULIU DRAGOMIR
PhD Supervisor Cotutela
PROF. DR. ING. ANA-CORNELIA BADEA

PhD student
GAVRIȘ (DROJ) GABRIELA

Contents

Abstract

This doctoral thesis, entitled ”Usage of Geographical Information Systems as Local and Regional Development Analysis Tool ", investigates and substantiates the necessary transition of territorial management from static record-keeping methods to a dynamic digital ecosystem of spatial decision support systems (SDSS). In the context of accelerated urbanisation and new national legislative imperatives (Order no. 904/2023), the research proposes an innovative approach by integrating the rigour of precision measurements with advanced artificial intelligence, geostatistics, and computational modelling algorithms.

The central problem addressed is the fragmentation of administrative databases and the informational asymmetry that burdens urban planning processes in Romania. The thesis demonstrates that the minimum spatial data structure imposed by the current regulatory framework is insufficient for proactive management, necessitating evolution towards an extended ontological architecture capable of ensuring semantic and structural interoperability in accordance with the international standard ISO 19152 (LADM).

The research methodology is structured as a pyramid, progressing from multimodal data acquisition (satellite remote sensing, IoT sensors, Big Data, and VGI) to the generation of strategic knowledge. The central methodological innovation is the conceptual scheme that extends the minimum structure proposed by legislation and integrates complex cardinality relations and classes of smart objects, providing the technical foundation for the realisation of the Digital Twin of the region.

Experimental validation, conducted through a case study of the Oradea Metropolitan Area, was structured with the analytical and prospective studies necessary for updating urban plans as a benchmark:

1. Economic dynamics and territorial vitality: Using spatial data mining techniques and the Ripley's K function to model economic vitality at the level of administrative units.
2. Transport organisation and urban mobility
    - Analysis of mobility and efficiency of public transport
    - Analysis of the applicability of GIS technology in traffic and congestion tracking during road infrastructure construction works
    - Implementation of dynamic microsimulation in the SUMO platform for traffic forecasting for 2030 and 2040.
3. Ecological monitoring and urban microclimate:
    - Multicriteria analysis of the accessibility of green spaces: Comparative study between isotropic modelling and network analysis
    - Use of satellite remote sensing in monitoring anthropogenic risks and air quality: Case study – The impact of the COVID-19 pandemic in the Municipality of Oradea

  - Development of a protocol for decoupling climate noise from real urbanisation and modelling the Urban Heat Island (UHI) based on NDVI, NDWI, and NDBI indices.

4. Urban policies:
    - Multi-criteria spatial analysis (SMCDA) to support investment strategy development
    - Integration of geographic information systems and automatic valuation models into local fiscal policies, in order to ensure fiscal equity and predictability of budget revenues.

The research results confirm the hypothesis that the fusion of data from multiple sources eliminates subjectivity in territorial planning and optimises the allocation of public resources. The thesis concludes with a set of strategic recommendations for public administration, proposing various GIS-based tools for evidence-based governance.

In conclusion, the thesis demonstrates that the Geographic Information System represents the backbone of intelligent regional management, transforming from a visualization method into a predictive digital organism, essential for ensuring the balance between economic progress, social equity and environmental protection in the communities of the future.

Keywords:

Geographic Information Systems (GIS), Spatial Decision Support System (SDSS), LADM (ISO 19152), Digital Twin, GeoAI, Traffic Microsimulation (SUMO), Automatic Evaluation (AVM), .

1 Introduction

The contemporary global context is marked by accelerated dynamics that require a thorough reassessment of territorial management strategies. Climate change, socio-economic pressures, uncontrolled urbanisation, and demographic fluctuations – manifested as both rapid growth and severe decline in certain regions – can have catastrophic effects on sustainable development. Excessive urbanisation is often associated with significant negative environmental impacts, including the drastic reduction of green spaces, the conversion of agricultural land into built-up areas, and the fragmentation of ecosystems through the expansion of infrastructure and residential zones. (Kwartnik-Pruc & Droj , 2023)

The COVID-19 pandemic exposed the fragility of urban systems, revealing that cities worldwide were largely unprepared to manage the profound economic and social consequences of such large-scale disruption. This experience highlighted the urgent need for urban areas to build resilience and adaptability in the face of an uncertain future. (World Bank Group, 2021)

In this context, a comprehensive strategy and interdisciplinary collaboration are essential to address the challenges of urban planning effectively and objectively through the integration of digital technologies.

1.1 Defining the Problem

Although Geographic Information Systems (GIS) have demonstrated significant potential for streamlining administrative processes, the research identifies three fundamental deficiencies that hinder their strategic use in Romania's national context:

- • Data fragmentation and quality
- • Methodological inertia
- • Absence of advanced analytics models.

1.2 Research Hypotheses and Thesis Objectives

The general objective of the thesis is to develop and validate a geographic information system model to support local and regional development decisions by correlating geodetic rigour with the analytical needs of modern public management.

Objective 1: Design an extended geospatial data architecture in accordance with LADM standards (ISO 19152).

Objective 2: Implement multimodal acquisition and automated processing protocols using deep learning algorithms.

Objective 3: Model economic vitality and fiscal dynamics using spatial data mining techniques.

Objective 4: Design an automatic assessment framework (AVM/CAMA) to streamline local fiscal policies.

Objective 5: Analyse road infrastructure and assess the efficiency of multimodal accessibility.

Objective 6: Dynamically monitor network resilience under stress factors and forecast traffic through microsimulation.

Objective 7: Assess ecological vulnerability using spectral synergy and monitor the urban microclimate.

Objective 8: Operationalise the spatial multi-criteria analysis framework as a strategic decision support tool.

1.3 General Research Methodology

The research adopts a mixed-methods approach, integrating the quantitative rigour of geodetic measurements and mathematical modelling with qualitative analysis of development policies. The methodological process includes:

- **Documentation stage:** Analysis of the literature and the European (INSPIRE Directive) and national (Order no. 904/2023) regulatory frameworks.
- **Experimental stage:** Data collection from multiple sources, including ANCPI, Copernicus/Sentinel, SRTM, MERRA, OpenStreetMap, Google Maps, EMIS, and ANAF. Data processing was carried out using the QGIS (Quantum GIS) ecosystem, supplemented by ArcGIS Online (map viewer classic version), SUMO (Simulation of Urban Mobility) platforms for dynamic microsimulation of road flows, and Giovanni (NASA) for extracting atmospheric reanalysis indicators.
- **Modelling stage:** Application of spatial analysis, geostatistics, fuzzy logic, artificial intelligence, and multi-criteria spatial analysis algorithms.
- **Validation stage:** Testing the models through concrete case studies in the Oradea Metropolitan Area, evaluated in terms of administrative efficiency and the impact of the results on the decision-making process.

1.4 Structure of the Work

To examine the applicability of GIS systems in local development, this thesis is organised into six chapters, structured to ensure a logical progression from theoretical foundations to original contributions.

The first chapter serves as the introduction. It presents the need and opportunity to use geographic information systems as tools for local and regional development. The objectives and methodology of the research are also outlined.

The second chapter reviews the current state of knowledge, examining the evolution of GIS concepts, the INSPIRE legislative framework, and modern Smart City and Digital Twin paradigms.

The third chapter details data flow architecture and acquisition technologies, exploring the transition from conventional topographic survey methods to modern approaches for capturing reality, such as remote sensing, social sensing, and IoT sensors.

Chapter four describes the methodological and algorithmic tools employed, including geoprocessing algorithms, topological relationship theory (9IM), geostatistics, and multicriteria decision support models.

The fifth chapter forms the experimental core, presenting the analytical and prospective substantiation analyses for the Oradea Metropolitan Area, validated through the economic, investment, mobility, and environmental pillars.

The sixth chapter summarises the general conclusions, highlights the author's original contributions, and proposes future directions for implementing GIS as an autonomous decision-support tool.

2 Current State of Knowledge

The second chapter of the thesis examines the current state of knowledge, tracing the evolution of Geographic Information Systems from their primary function of data archiving to their role as analytical engines for urban and regional development. In a context often marked by spontaneous and chaotic urban morphogenesis, the research demonstrates the need for a transition to planning based on rigorous spatial evidence and advanced digital technologies.

2.1 Geographic Information Systems in Urban and Spatial Planning

Contemporary urbanisation is a direct response to shifts in economic paradigms, but its management requires a multidisciplinary approach. Geographic Information Systems are transforming this field through their ability to harmonise heterogeneous data flows (vector, raster, statistical data), converting intuitive decision-making processes into data-driven policies. (Worboys & Duckham, 2004)

In this context, public administrations serve as central pillars in territorial management, responsible for providing public services and optimising citizens' quality of life. Administrative activities are governed by a complex legislative framework, which regulates taxation, urban planning, construction, road infrastructure management, and, more recently, the structure of geospatial data.

2.1.1 Legislative and Technical Framework: INSPIRE Directive and Spatial Data Infrastructure

The value of a GIS as a decision-support tool lies not only in the amount of data it contains, but also in how effectively that data can be shared, combined, and understood across different institutions – a concept known as interoperability. This need led to the development of Spatial Data Infrastructure (SDI), a framework comprising the technologies, policies, standards, and expertise required to manage and distribute geospatial information.

At the European level, spatial data governance is guided by Directive 2007/2/EC (INSPIRE – Infrastructure for Spatial Information in Europe). Romania adopted this directive through Government Ordinance No. 4/2010, later republished as Law No. 190/2010, which established the National Spatial Data Infrastructure (INIS).

2.1.2 Legal Framework in Romania

The transposition of the INSPIRE Directive has enabled the creation of a harmonised spatial data infrastructure across Europe, with Romania actively involved in this initiative. The National Agency for Cadastre and Real Estate Advertising (ANCPI) is the designated authority responsible for coordinating the directive's implementation at the national level.

Within Romanian public administration, Geographic Information Systems have become essential tools for asset management and the issuance of official documentation. A significant regulatory development in this area is Order No. 904/2023, which mandates the use of GIS-compliant formats in the preparation of urban planning documents (PUG, PUZ, PUD).

2.1.3 Urban Information System

The evolution of contemporary urban planning, marked by dynamism and complexity, requires a shift from simple digital mapping to integrated spatial intelligence systems. Achieving controlled and responsible territorial management depends on the collection and harmonisation of large volumes of data (Big Data) from diverse fields: demography, economy, infrastructure, and environment. This challenge led to the development of the Urban Information System (UIS), defined as a GIS-based technology ecosystem optimised for automating the processes of analysis, modelling, and dissemination of urban information. (Geymen, et al., 2008)

Through the convergence of GIS, Big Data, and GeoAI, Urban Information Systems are evolving into platforms capable of supporting city-scale simulations and adaptive decision-making processes. This transformation positions the UIS as a central element of smart cities, contributing to the creation of resilient, sustainable, and citizen-centric urban spaces. (Mai, et al., 2025)

2.2 Geographic Information Systems in the Field of Traffic

The relevance of Geographic Information Systems in the transport domain stems from the inherently spatial distribution of transport and traffic data, combined with the need for multifaceted analytical approaches. However, the planning, design, implementation, and management of GIS-assisted traffic systems can only be achieved by organising and integrating all information about the transport and traffic infrastructure. (Droj & Droj , 2019) (Droj , et al., 2022)

The use of GIS-T enables urban planners to conduct advanced feasibility studies, validating how a proposed new structure will integrate into the existing ecosystem while respecting the principles of a smart city.

2.3 Modelling Reality through GIS Systems

Modern urban planning requires a dual approach to modelling reality: object-based modelling of physical elements and behavioural modelling. GIS systems enable the modelling of various aspects of reality to improve understanding of interactions between different features of the physical and social world. (Vanegas, et al., 2009)

2.4 The Evolution of GIS Concepts: from Relational Data Structures to Digital Twin Paradigms

The expansion of information and communication technology (ICT), together with the exponential growth in the volume of geospatial data managed and the accessibility of high-speed infrastructures, has facilitated a paradigm shift within GIS. These systems have evolved from simple databases to integrated platforms that harmonise geospatial information with remote sensing data, aerial photogrammetry, GNSS positioning systems, and virtual simulation models. The result is a detailed three-dimensional representation, characterised by multi-resolution, multi-scale, and spatio-temporal dynamism.

The peak of this evolution is the concept of the Digital Twin, which, unlike conventional 3D models, is a dynamic virtual replica of a physical or an entire urban system, continuously updated by data streams from IoT asset sensors, real-time telemetry, and remote sensing. The convergence of GIS with BIM (Building Information Modelling) plays a critical role at this stage, ensuring continuity of information from the level of detail of the constructive element to the regional geographical context. Thus, a Digital Twin is not merely a visual representation, but an ecosystem of temporally and spatially synchronised data, capable of simulating the behaviour of infrastructure under stress and supporting predictive "what-if" decisions. (Grieves & Vickers, 2017) (Sani & Rahman , 2018) (Ketzler , et al., 2020)

The fusion of Digital Twin modelling and intelligent management concepts transforms geographic information systems from a simple inventory tool into a living digital organism. This paradigm enables regional authorities to navigate the complexity of the modern urban landscape, ensuring sustainable development based on rigorous digital spatial awareness.

2.5 Conclusions

Originally an extension of computer-aided design (CAD) and automated mapping (AM), GIS has evolved into a versatile tool for spatial analysis and strategic planning. The field is undergoing significant transformation: traditional systems are shifting to 3D environments, integrating BIM capabilities, and adopting Digital Twin concepts for realistic simulations. This progress, together with the rise of Smart City and Smart Region initiatives, enables local and regional authorities to manage complexity more effectively, transforming raw geospatial data into a valuable resource for sustainable territorial development.

3 Data Flow Architecture and Acquisition Technologies for Implementing an Information System to Support Decision-Making in Local and Regional Development

The objective of this chapter is to analyse data acquisition, focusing on the transition from conventional topographic survey methods to modern paradigms of reality capture. In an era of information overabundance, the challenge lies not only in collecting data, but also in managing vast volumes of heterogeneous Big Data and extracting knowledge through artificial intelligence algorithms. The structure of this chapter examines the technological pillars of information systems: the computational framework, the geometric and legal foundation, the systematic observation of the territory, and the dynamic component of participatory urbanism.

3.1 The Big Data Paradigm and Artificial Intelligence in the Implementation of Geographic Information Systems

Geospatial data has evolved from conventional formats to the Geospatial Big Data domain, a concept defined by five fundamental dimensions (the "5 Vs"), each with specific implications for geodesy and urban planning: volume, velocity, variety, value, and veracity.

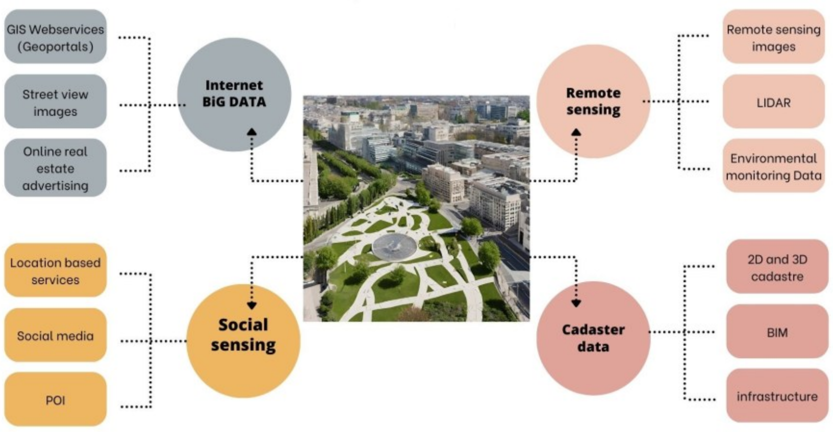


Figure No 1 Schematic representation of data sources (Droj , et al., 2024)

The shift to Web-GIS and mobile technologies has enabled real-time data sharing by providing online analytics tools and Location-Based Services (LBS). These utilise Global Navigation Satellite Systems (GNSS) to deliver critical insights into mobility, the real estate market, and the dynamics of human flows. The integration of data from social networks has led to the emergence of social remote sensing, adding a behavioural dimension to urban planning that was previously impossible to quantify using traditional methods. Deep learning algorithms provide efficient means of processing and analysing big data for tasks such as:

- Multi-temporal analysis and change detection: Automatic identification of urban sprawl (Zhang & Huang, 2018)

- Data fusion: Combining satellite imagery with Internet of Things (IoT) data to assess urban vitality and exposure to pollutants (e.g. PM2.5), according to the models proposed by Huang and Wang (Huang & Wang, 2020)
- Automatic land use classification: Extraction of the footprints of buildings and road networks with high accuracy. (Liu, et al., 2019)

3.2 Cadastre

Updating and maintaining cadastral registers within the complex architecture of modern cities requires a shift from traditional solutions based on CAD files, which are characterised by redundancy and isolation, to spatial database management systems (DBMS). A modern cadastral data model must comply with interoperability standards (ISO 19152 - LADM) to integrate legal, geometric, and temporal (4D) aspects. (ISO - International Organization for Standardization, 2012)(Shahidinejad, et al., 2024)

Recent research indicates that standardising real estate information is fundamental to sustainable urban management, facilitating informed decision-making in urban planning and infrastructure development. The integration of this standard ensures not only the security of property rights but also the efficient allocation of scarce resources in rapidly growing metropolitan areas, guaranteeing the uniformity and reliability of data used by appraisers, investors, and legislators.(Aydinoglu, et al., 2025)

3.2.1 Road Information System

Integrating main road features in a GIS environment enables the modelling of transport flows and the assessment of the technical condition of the network, providing vital support for maintenance management and regional investment planning. (Badea & Badea, 2021)

3.3 Using Photogrammetry Data in Urban Planning

Remote sensing has evolved from primarily military applications into a fundamental source of open data used across a wide range of fields. The ability of sensors to provide systematic data on the land surface has transformed various disciplines, including climate change analysis, natural resource management, disaster monitoring, and the assessment of land use dynamics. In modern urbanism, remote sensing offers a systemic perspective essential for understanding the morphology and functionality of urban spaces, which are marked by rapid dynamism and high structural complexity(Zhang, et al., 2019)

3.3.1 Characterization of Remote Sensing Data by Resolution and Sensors

To highlight phenomena relevant to understanding both current and historical situations, and to develop substantiation studies for urban plans and urban development projects, it is essential to use remote sensing data. Applications designed to support decision-making in urban development use complex, up-to-date, and historical spatial data that can be obtained quickly and inexpensively using satellite images. (van Maarseveen, et al., 2019)

3.3.2 Spectral Indices Used in Urban and Environmental Analysis

A well-established method for extracting quantitative information is the use of spectral indices, derived from mathematical operations applied to satellite bands (e.g. Landsat, Sentinel-2). These indices enable the transformation of reflectance data into biotechnical or environmental indicators. Numerous spectral indices can be used to analyse various aspects such as vegetation, water resources, snow, soil, fire, as well as the degree of pollution or climatic factors. (European Space Agency, 2023) (NASA)

3.4 Social Sensing – Crowdsourcing

The proactive involvement of citizens in producing geospatial data has become a strategic resource for various software applications, including risk management, traffic monitoring, and participatory urban planning. This phenomenon, supported by the proliferation of ubiquitous mobile technologies, was theorised by M. Goodchild in 2007 under the concept of Volunteered Geographic Information (VGI). VGI refers to the use of citizen networks as volunteer human sensors for creating, assembling, and disseminating geospatial data. Crowdsourcing approaches rely on digital platforms that combine real-time information, turning social media users into "social sensors". (Goodchild, 2007)

3.4.1 Mobility Monitoring

Crowdsourcing involves collecting geospatial information and data from a large group of people to highlight spatial relationships, either by users voluntarily answering a series of questions or by receiving real-time data from digital devices such as mobile phones. (Todd & Donihue , 2021) Community contributions to geospatial data acquisition, facilitated through crowdsourcing platforms such as Waze, Google Maps, or collaborative mapping projects like OpenStreetMap, have triggered a paradigm shift in territorial planning. This development enables urban planners and decision-makers to overcome the limitations of conventional statistical analysis by integrating real-time, updated spatial information flows to identify emerging trends and support public policies adapted to contemporary urban dynamics. (Indrajit, et al., 2019)

Recent research combining remote sensing data with social sensing technologies and advanced GIS systems has shown that human activities leave quantifiable traces on the electromagnetic signatures of urban elements. These can be correlated with behavioural data extracted from social networks to generate multidimensional models of "everyday urbanism".

3.5 Advanced Processing and Information Extraction

Due to the fragmented and heterogeneous nature of the urban environment, remote sensing data processing must go beyond classic pixel-by-pixel classification methods. Artificial Intelligence and Machine Learning algorithms are now used to automatically extract spatial patterns:

- Random Forest and Support Vector Machine (SVM): for high-precision land-use classification.
- Deep Learning: for automatic segmentation of buildings and road networks from VHR images.
- Geographically Weighted Regression (GWR): for modelling non-stationary spatial relationships between socio-economic and environmental factors. (Yu & Fang, 2023)

3.6 Conclusions

The review of the specialised literature highlights that the architecture of a modern information system for regional development cannot be limited to a single data source, and decision-making success depends on data integration. The rigour and accuracy of cadastral and road data must be harmonised with the spatial context provided by remote sensing and the social dynamism of crowdsourcing. The main conclusions are:

1. The evolution of GIS through the integration of artificial intelligence and autonomous GIS systems reduces the subjectivity of human analysts and accelerates response times in critical situations.
2. The transition to 3D Cadastre and ISO 19152 standards is imperative for the correct modelling of complex urban infrastructure.
3. VGI (Waze, OSM) data represents the "pulse" of the city, providing information about mobility and social behaviour that physical sensors cannot fully capture.
4. Correlating electromagnetic signatures with social media data opens new horizons in assessing quality of life at the local level.

4 Advanced Geospatial Analysis and Computational Modelling Methodologies

In a GIS environment designed for decision support, analysis algorithms are not merely drawing tools but serve as mathematical foundations that enable the decoding of complex relationships between infrastructure, population, and the environment.

4.1 Computational Paradigms in the Extraction of Knowledge from Spatial Data

In the "Geospatial Big Data" era, the volume of information collected through sensors, IoT networks, and distributed cadastral databases has surpassed the processing capacity of conventional statistical methods. To extract strategic value from these massive data flows, it is necessary to employ advanced Knowledge Discovery in Databases (KDD) techniques, in which data mining is the crucial step for identifying previously unknown and potentially useful patterns, associations, and structures (Zaharie, 2018). Unlike non-spatial data, georeferenced data exhibits intrinsic spatial dependence, manifested as spatial autocorrelation, which necessitates the use of advanced algorithmic architectures. The table below provides a systematic comparative analysis of classical data mining techniques and those specific to the spatial domain, highlighting the qualitative leap required in geodetic modelling.

Table 1 - Classical vs. spatial data mining: a comparative overview (adapted from - Anders, 2003)

	Classic Data Mining	**Spatial Data Mining**
Data definition	Simple predominantly alphanumeric and tabular.	Complex: multidimensional (2D, 3D, 4D), multi-scale, vector/raster.
Relationships	Explicit: arithmetic, logical sorting	Context-dependent: topological, metric, directional, dynamic, fuzzy
Data organization	Linear indexing or simple hierarchical structures.	Advanced spatial indexing (R-tree, Quadtree, geohash).
Operations	Local	Local, focal, regional and global.
Statistics	Context-independent	Spatial, geostatistical autocorrelation.
Output Data	Reports based on sets, logical associations	Spatial graphs, density, spatial clustering models.

Algorithms	divide-and-conquer, sort hierarchical structures, classic decision trees.	Minimum Bounding Rectangle (MBR), Spatial Indexing, Computational Geometry.
Classification	Identifying the class by numerical similarity	Supervised and unsupervised for remote sensing data or classification based on contextual vicinity.
Association and aggregation	Grouping by Identical Attributes	Location-based spatial aggregation, spatial relationships, computational geometry.

4.2 Spatial Analysis and Computational Data Modelling Methodologies

The main advantage of geographic information systems is their ability to provide a unified, detailed analysis of all managed data, including those with geocoded geometric characteristics, non-geometric or alphanumeric characteristics, and images.

Spatial analysis involves examining these data to model reality, enabling the detection of structural patterns, interpretation of temporal dynamics, evaluation of the feasibility of investment locations, and generation of predictive "what-if" models.

4.2.1 Image Classification

Image classification is a crucial process in analysing data collected by sensors mounted on satellites, aeroplanes, or other platforms in remote sensing.

4.2.2 Spatial Relations

Spatial relations form the basis of geospatial analysis processes and are implemented as spatial predicates within complex database queries. These relationships enable precise definitions of how geographic features are connected or correlated in space, allowing the extraction of objects that meet specific positional logic relative to a reference object (or query object).

Spatial relationships can be combined and integrated into spatial queries using logical operators (and, or, not) to extend and refine relationships, ensuring accurate and coherent interpretation of spatial data (Carniel, 2022)

4.2.2.1Topological Relations

4.2.2.2Metric Relations

4.2.2.3Directional Relations

4.2.3 Geoprocessing Methodologies for Vector Data

Geoprocessing operations constitute the algorithmic core of vector analysis. They can be logically classified by their effects on geometry and attributes, with direct analogies to set algebra. (Lwin & Murayama, 2025)

Family	Main purpose	Algorithms	Mathematical/Logical Analogy
Spatial filters	Extract/Crop	Clip, Difference	Filtering based on topological conditions
Logical Overlay	Combining information	Intersect, Union, Symmetrical Difference	Operations on sets (∩, ∪, Δ)
Shape Analysis and Aggregation	Proximity / Generalization	Buffer, Dissolve, Convex Hull	Analysis of the intrinsic properties of geometry

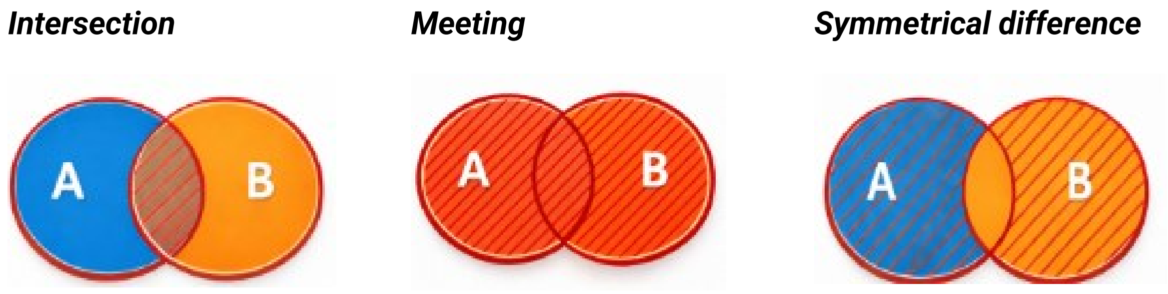
Table no. 1 Classification of geoprocessing operations

Spatial filters are operations that function as filters or topological templates, extracting sub-entities without creating semantically new geometries. Overlay operations recalculate the topology of the resulting network, generating new features whose attributes represent a combination of the source layers.

Surgery	Operation on Crowds	Logical description	Result
Intersect	**A ∩ B**	Creates a new layer that contains **only the common areas** between layers A and B.	The geometry is **A ∩ B**. The attribute table contains **the attributes from A and B**.
Union	**A ∪ B**	Creates a new layer that contains **all the geometries** in A and B. The boundaries are recalculated in the overlapping areas.	The geometry is **A ∪ B**. The attribute table contains the attributes from A and B, with null values where there is no overlap.
Symmetrical Difference	**A Δ B** or **(A ∪ B) \ (A ∩ B)**	Create a new layer that contains the areas that belong **to A or B, but NOT both at once**.	Geometry is **A Δ B**. The attribute table contains the attributes from A and B.

Table no. 2 Overlay operations

In the image below, we present a visual comparison of the three operations, with the results indicated by hatching.



Intersection ***Meeting*** ***Symmetrical difference***

Figure No 2 Visual Comparison Between Intersection, Meeting, and Symmetrical Difference Operations (Droj, 2009)

The geoprocessing workflow must include a rigorous topological cleaning step, based on defined proximity tolerances, to ensure that coincident boundaries are treated as a single mathematical entity.

4.2.4 Shape Analysis and Spatial Aggregation

Overlay operations use the relationships between different layers. Shape analysis and aggregation operations use the intrinsic properties of a single layer. They transform the layer to highlight a specific characteristic, such as proximity, a common category, or spatial distribution. (da Silva, et al., 2015)

Sub-family	The question he answers	Main Tool	What do they analyze? (Intrinsic Property)	Result
Proximity	"What's nearby?"	**Buffer**	Position and distance in space.	An area of influence.
Aggregation	"How can I group similar items?"	**Dissolves**	Membership in a category (defined by attributes).	A simplified, generalized layer.
Shape	"What is the footprint of a group?"	**Convex Hull**	Spatial distribution and expansion of a set of objects.	The outer limit of the group.

Table no. 3 Classification of Shape Analysis and Aggregation Operations

4.2.5 Geostatistics

Geostatistics is an advanced analytical framework for processing georeferenced data, integrating the location of entities as an intrinsic variable in the statistical model. Unlike conventional statistics, geostatistics quantifies and models the spatio-temporal structure of processes, based on the principle that variables in close proximity tend to exhibit similar values (autocorrelation).

A. Point distribution analysis using Ripley's K function

B. Spatial autocorrelation and hotspot analysis

4.2.6 Modelling Uncertainty and Imprecision Through Fuzzy Logic

Urban and regional planning often encounters phenomena with boundaries that are not clear-cut, but instead display areas of gradual transition (e.g. urbanisation, vegetation density, areas of economic influence). While classical Boolean algebra uses binary values (0 or 1), accurate modelling of empirical reality requires the use of Fuzzy Logic, as theorised by Lotfi A. Zadeh (Zadeh, 1965).

A. Fuzzy C-Means Membership Functions and Classification

B. Fuzzy Spatial Operations and Relations

4.3 Road Infrastructure Modelling in GIS - T

Most GIS systems work in Cartesian system, usually Euclidean space, where the distance between two objects is determined according to the relative positions calculated using the Euclidean distance. However, for traffic applications, this distance must be calculated along predefined trajectories specified by lines and curves – directed segments that define graphs.

GIS-T applications integrate updated geospatial databases of the street network with all traffic information, such as traffic signs, traffic lights, speed limits, traffic restrictions, maximum capacity elements, and points of interest, as well as a wide variety of real-time information, including accidents and traffic jams. (Wuest & Mioc , 2007) (Droj & Droj, 2020)

4.3.1 Routing Algorithms

Routing algorithms, once used only in specific GIS applications, have become among the most common uses of GIS technology and are now an essential feature of all modern devices. Determining the most efficient route to a destination is not only a primary concern for ordinary users but is also extremely important for emergency services. (Mitchell, 2005)

4.3.2 Determining the Minimum Cost Path

The minimum cost path for graphs without negative costs is determined by various adaptations of Dijkstra's algorithm.(Dijkstra, 1959)

4.3.3 Determination of the Maximum Flow

Using the Ford–Fulkerson method, traffic bottlenecks caused by node entry capacity exceeding the maximum flow can be identified to optimise traffic flow.

4.3.4 The Influence of Public Transport on Traffic

The population chooses its mode of travel, and thus its means of public transport, by considering geographical factors such as proximity to transport stations at both the point of departure and the destination, as well as factors such as frequency, travel time, congestion, and quality of services.

According to the urban economic model defined by Fujita and Ogawa, people usually choose their accommodation, workplace, and means of communication to minimise costs. To better understand what influences traffic, mathematicians Vincent Verbavatz and Marc Barthelemy developed a simple schematic model that captures the basic elements of the interaction between traffic and public transport. (Masahisa & Hideaki , 1982)

In conclusion, to reduce the number of cars in traffic, and consequently the number of drivers, it is advisable to reduce the time required to travel by public transport so that it is significantly shorter than the time spent travelling by car. This can be achieved by increasing the number of people with easy access to public transport and by reducing waiting times. (Verbavatz & Barthelemy, 2019) (Buchanan, 2019)

4.4 GIS Architecture as a Decision Support System in Regional Development

A spatial decision support system is a powerful digital tool designed to assist decision-makers in addressing complex spatial problems that lack clear structure.

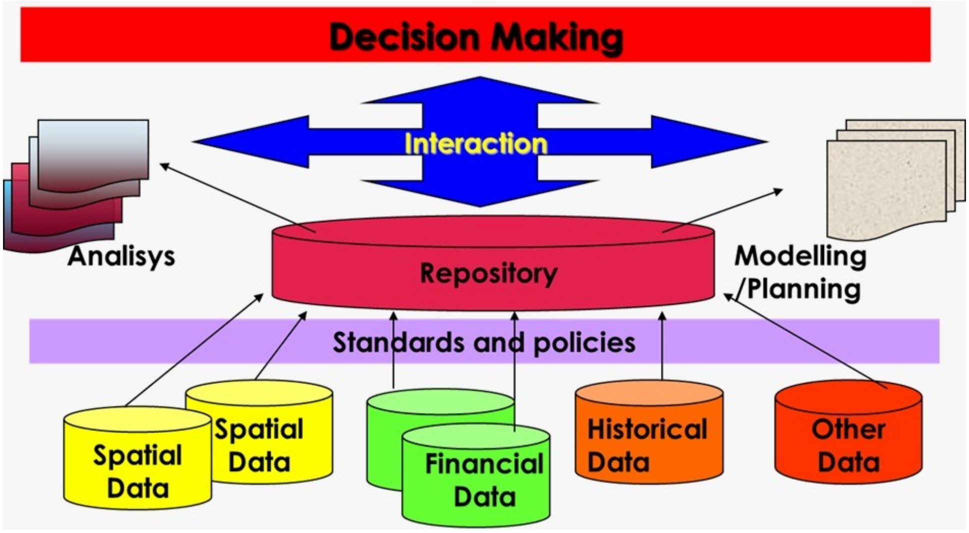


Figure No 3 Decision Support System Structure (Droj & Droj, 2010)

When applied to local and regional development, the system's architecture is based on three key elements that guide the transformation of raw data into strategic knowledge:

1. The database management system, which performs the semantic integration of geospatial data (cadastre, municipal networks, satellite images) with heterogeneous non-spatial databases (financial indicators, demography, public policies)
2. The Model Base and Analysis (MBMS) – the analytical core where spatial analysis, geostatistical, and multi-criteria analysis (MCDA) algorithms are integrated. (Malczewski & Rinner, 2015)
3. The dialogue and visualisation interface, which facilitates interaction between the decision-maker and the model, transforming complex mathematical results into accessible graphical and cartographic representations, thus supporting evidence-based governance.

The most robust multi-criteria analysis methodology in spatial decision optimisation is the integration of GIS with the Analytic Hierarchy Process (AHP), which decomposes complex problems into a hierarchical structure and transforms qualitative evaluations (expert opinions) into rigorous numerical weights. (Nguyen, et al., 2020)

The spatial multi-criteria analysis process involves a rigorous methodological flow, transforming geographical criteria into decision-making support through the following stages:

1. Definition of criteria to measure the degree of achievement of the proposed objective and restrictions:
    - Criteria that increase or decrease the suitability of a location such as proximity to utilities or road accessibility.
    - Boolean restrictions that exclude certain areas from analysis for legal or technical reasons such as protected areas, flood zones.

2. Standardising of the criteria by bringing them to a common comparability scale, usually the range [0,1]. This is done through transformation functions (utility scores), allowing the subsequent aggregation of heterogeneous data.
3. Determination of the importance of the criteria, by weighting, each factor is assigned a weight that reflects its relative importance in relation to the other criteria.
4. Aggregation of results by combining weighted criteria maps to obtain a final adequacy score.

The integration of multi-criteria analysis in the GIS environment transforms territorial planning from a reactive to a proactive and transparent approach, providing the mathematical rigour and flexibility necessary to manage conflicts of interest specific to sustainable development, and ensuring that administrative decisions are based on multidimensional and objective spatial analysis.

4.5 Conclusions

Integrating a spatial perspective with statistical information is essential to unify the data; otherwise, accuracy, consistency, and temporality may be inadequate.

Spatial analysis, like statistical analysis, relies on processes that can be programmed, but results may still be produced even when basic assumptions are unmet, incorrectly formulated, or when input data is incorrect or incomplete. Apparent accuracy does not guarantee correctness. To interpret results, for example from a geographic information system, it is necessary to understand the quality and timeliness of the input data, the algorithms used for data processing, and the limitations of the graphical displays.

5 Architecture of an Extended Urban Information System for Substantiating Territorial Development in the Oradea Metropolitan Area

This chapter presents the experimental foundation of the research, focusing on the empirical validation of the proposed methodological framework by operationalising an Urban Information System (UIS) for the Oradea Metropolitan Area.

5.1 Objectives of the Case Study and Regulatory Compliance Framework

The configuration of the information system begins with compliance with the new normative framework established by Order no. 904/2023. From a technical perspective, the case study adheres to the interoperability pillars defined by the legislation:

a. Spatial reference unit: All datasets are designed in the national Stereographic 1970 system (EPSG 3844), ensuring the metric accuracy necessary to correlate with the official cadastral plans.

b. Data format: Use of the GeoPackage container (GPKG) as an open standard, facilitating the exchange of information between institutions without loss of topology or attributes.

c. Semantic standardisation: Implementation of the HILUCS classification, enabling alignment of the functional zoning of the municipality of Oradea with European land use standards.

5.1.1 Identification of the Limits of the Minimum Structure and Proposal of the Extended Conceptual Scheme

Although Order no. 904/2023 establishes a data structure necessary for storage and visualisation, this minimum set is insufficient for the development of urban plans on GIS platforms, and even more so for a spatial decision support system.

The extended scheme proposed in this paper, shown in Figure 13, introduces a complex spatial ontology that goes beyond the simple representation of thematic layers, incorporating concepts such as multi-scale modelling, hybrid fusion (vector-raster), and real-time IoT integration.

The extended architecture of the system is organised on the following classes of objects and relationships:

A. **Classes of point objects and mobility nodes:** The nodes of the system are represented by the ends of street segments, transport stations, and urban facilities.

B. **Linear object classes and critical network modelling:** The extended system treats infrastructure as a complex topological graph. Streets are decomposed, through compositional relationships, into discrete street segments, allowing the attribution of dynamic properties. Municipal networks are modelled as intelligent linear entities, integrated with IoT pressure, flow, and fault sensors, facilitating predictive maintenance. The public transport network is also defined by linear routes correlated with the frequency and capacity of the means of transport.

C. **Classes of polygonal objects and multi-scale representations:** Spatial modelling includes the boundaries of administrative units, territorial reference units, generic classes of parcel and building type, as well as derived classes such as plots with or without buildings, parks, and classes derived from constructions: housing, public buildings, etc. We propose the implementation of adaptive multi-scale display logic for municipality-type entities or complex facilities: buildings, points of interest (POIs).

D. **Hybrid classes and spatial fields:** These manage phenomena with continuous variation by using raster-origin data (e.g. noise maps, pollutant dispersion, spectral indices) in correlation with the vector boundaries of administrative units and specialised zoning such as protected, functional, and fiscal areas.

E. **Integration of IoT flows and semantic attributes.** The extended system transforms physical entities into smart objects by integrating IoT sensors:

  - **Mobility:** Traffic sensors placed on street segments and real-time monitoring systems on public transport vehicles.
  - **Utilities:** Monitoring the status of networks (pressure, flow) for incident management.

F. **Non-spatial databases:** each geometric entity is related to the provisions of the Local Urban Planning Regulation (RLU) and the technical-legal specifications of the areas with special regime.

G. **Modelling Relationships and Topological Integrity**:

  - **Cardinality (1:1, 1:n):** Biunivocal associations (1:1) respectively hierarchical associations (1:n)
  - **Inheritance**: Used to specialize classes by facilitating the automatic propagation of common attributes.
  - **Composition and aggregation:** Defines existential dependencies ensuring database consistency in case of geometric changes.
  - **Topological Predicates (***Contain, Cross, Overlap***):** Used for implementing plan integrity rules.

Through this extended structure, the Urban Information System becomes a dynamic Digital Twin platform, capable of reflecting not only the present state of the territory (according to Order 904/2023), but also simulating evolution scenarios based on economic, environmental, and traffic data, thus providing the necessary support for analytical and prospective substantiation studies.

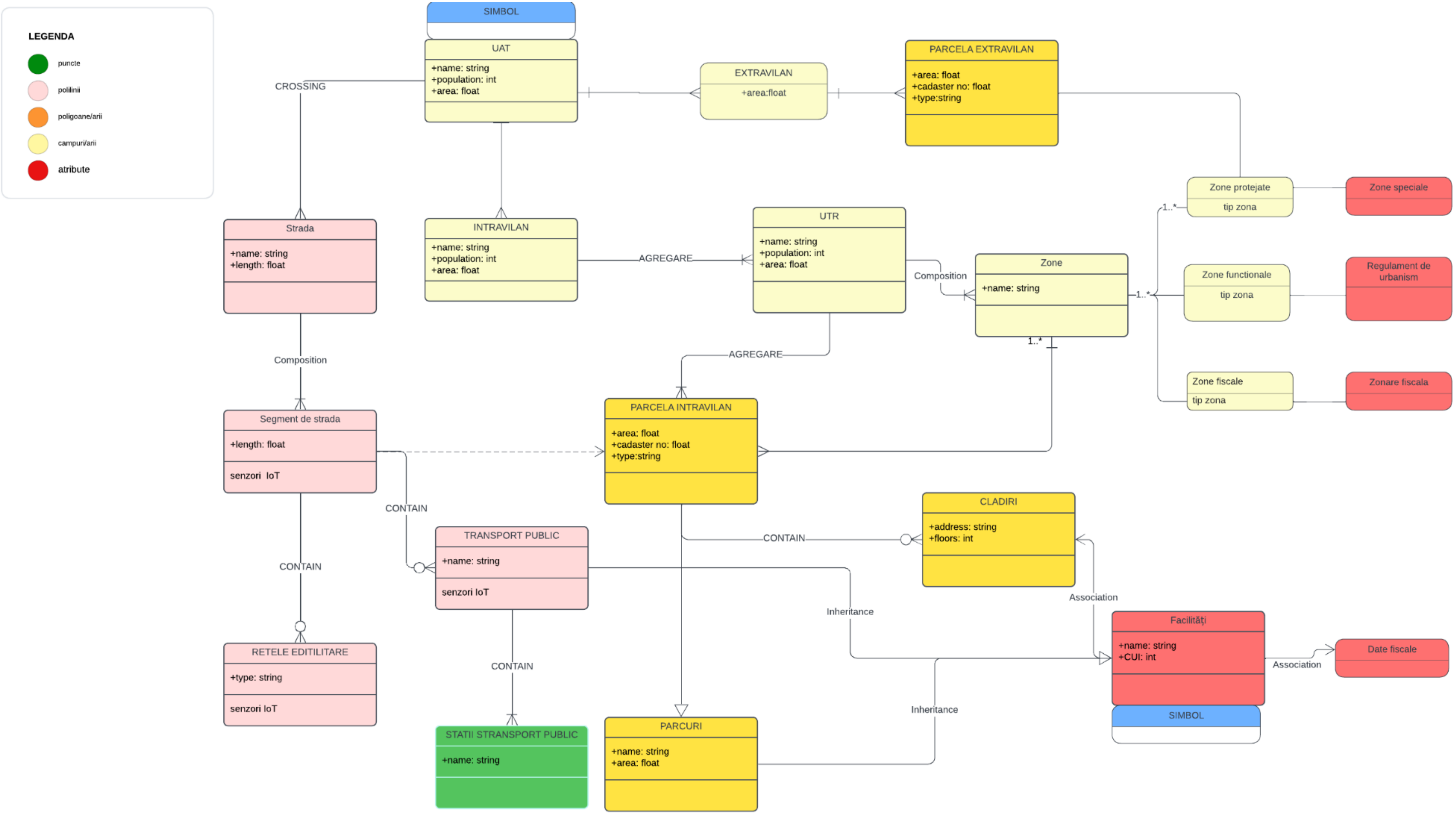


Figure No 4 The conceptual scheme of the minimum spatial data required for analytical and predictive studies (elaborated by the author)

5.1.2 Data Acquisition, Correlation and Integration Methodology

The methodological flow is structured on three fundamental levels:

A. **Acquisition and pre-processing:** The first stage involves collecting information from sources with varying resolutions and refresh rates, while ensuring compliance with the official Stereographic 1970 projection:
   - **a.** High precision data: Cadastral plans, administrative boundaries (UAT, intra-urban/extra-urban), and municipal networks obtained from ANCPI and/or the local administration.
   - **b.** Remote sensing data: Multispectral satellite image streams provided by the Landsat (NASA) and Sentinel (ESA) constellations, integrated into the system for generating spectral indices and analysing the evolution of pedo-morphological processes and land cover.
   - **c.** Real-time and social sensors component: Integration of crowdsourced data from Waze and OpenStreetMap (OSM) platforms, correlated with networks of IoT (Internet of Things) sensors distributed across critical infrastructure. These data enable the system to transition to a Digital Twin architecture, providing the ability to reflect the instantaneous state of transport networks and support operational decisions in urban management.

B. **Relational and spatial correlation of heterogeneous information:** The correlation process goes beyond simple data joining, aiming to build a complex conceptual model in which relationships between objects are governed by strict rules of cardinality and structural logic.

C. **Validation and topological cleaning:** to ensure compliance with the rigorous standards imposed by Order no. 904/2023 and the technical specifications of the INSPIRE Directive:
   - **a.** Surface integrity check:
     - Removal of sliver polygons
     - No overlaps
     - Validation of continuity (No gaps)
   - **b.** Network Connectivity Validation (transport graphs and utilities):
   - **c.** Audit of logical consistency and referential integrity: between spatial object and attributes:
     - Uniqueness check
     - Validation of hierarchical inclusion

5.2 Analytical Substantiation Studies on Economic and Urban Dynamics

This analytical level aims to interpret territorial dynamics by combining socio-economic indicators with cadastral geometry, providing the empirical basis required to validate urban and regional development strategies.

5.2.1 Integrating Financial Indicators into Geospatial Structures: Modelling Economic Vitality and Territorial Polarization Through Spatial Data Mining Techniques

The purpose of this subchapter is to demonstrate the use of spatial data mining techniques to correlate financial data flows with cadastral entities, using the Romanian tourism sector as a case study.

Analysis of the spatial distribution of accommodation units at county level (Figure No. 14) reveals uneven development of tourism infrastructure. Reducing the granularity to the level of administrative-territorial units highlights a phenomenon of extreme polarisation. Tourism companies tend to cluster in specific nuclei: eight growth poles and four specialised clusters. This uneven distribution indicates that economic activities are influenced by location to a much greater extent than in other sectors, generating areas of intense vitality and marginalised areas.

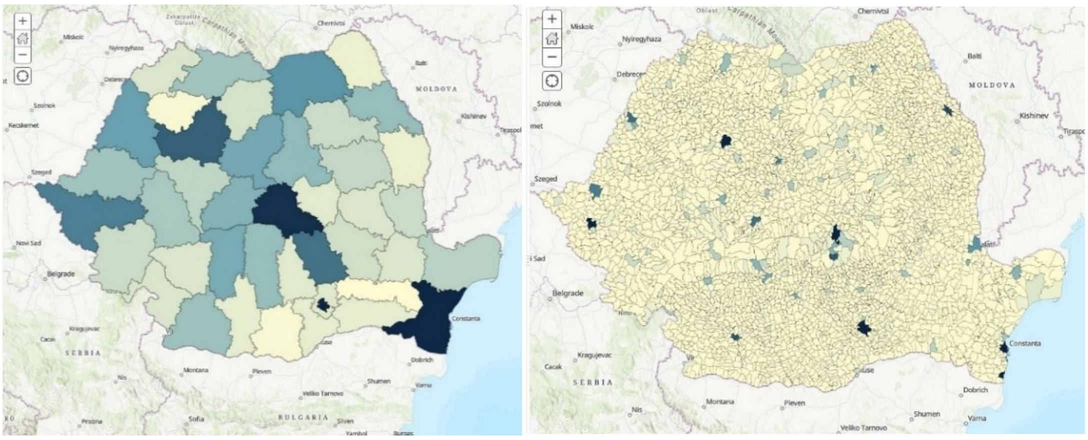


Figure No 5 Distribution of tourism companies by counties and TAUs (Droj, et al., 2020)

To quantify the real economic impact, beyond simply counting companies, we applied the Multi-Distance Spatial Cluster Analysis (Ripley's K) algorithm.

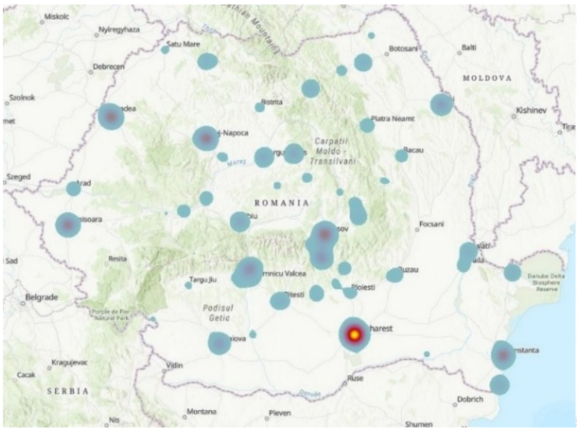


Figure No 6 Distribution of tourism employees

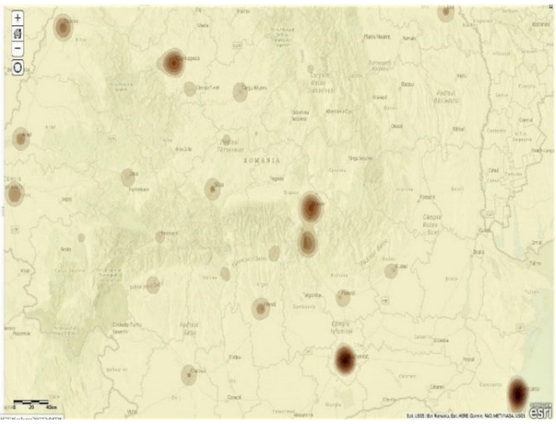


Figure No 7 Clustered distribution of tourism assets

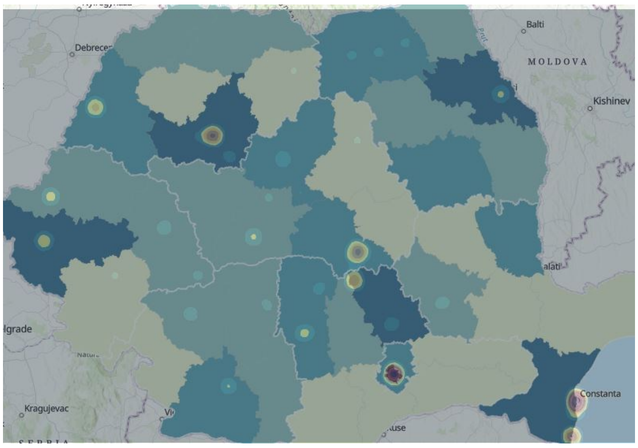


Figure No 8 Purchasing power of leisure services vs assets of tourism companies (Droj, et al., 2020)

The macroeconomic geospatial analysis shows that the use of GIS as a decision-support tool allows:

- Identification of areas of economic vitality by directly correlating tax data with cadastral registers.
- Validation of investment policies by detecting natural development clusters and avoiding inefficient resource allocation.
- Prospective substantiation of infrastructure needs based on the dynamics of purchasing power and regional accessibility.

This methodology, validated at the national level, forms the basis for detailed analyses of economic vitality at the UTR level, which will be applied in the specific context of the Oradea Metropolitan Area.

5.2.2 Analysis of Peri-Urban Relations and the Degree of Urbanization Through Spatial Aggregation Techniques.

Peri-urban relations represent the spatial manifestation of economic, social, and functional interdependencies between a polarising urban nucleus (Oradea Municipality) and its functional area. In the context of updating the PUG, analysis of these relationships using GIS techniques aims to quantify peri-urbanisation, as rural localities lose their traditional agricultural function in favour of residential and industrial functions integrated into metropolitan flows. Aggregate analysis of demographic data reveals centrifugal residential expansion.

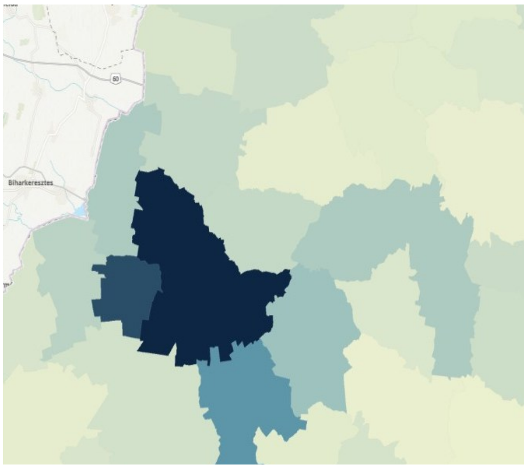


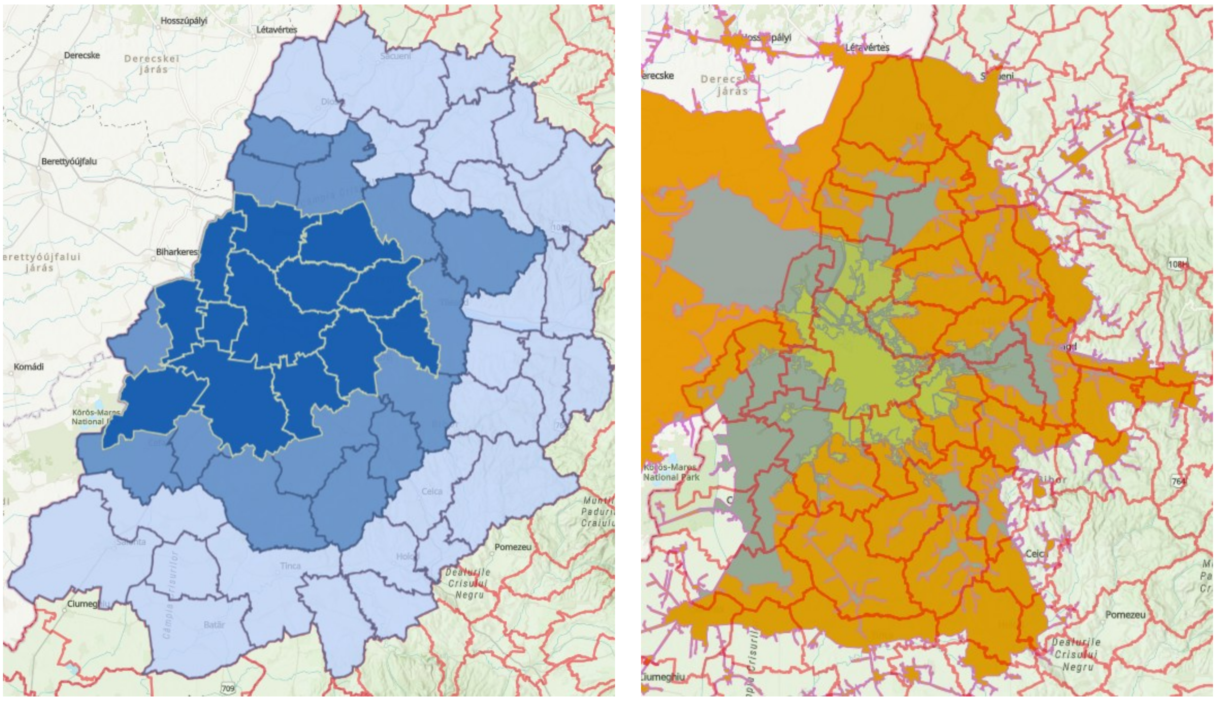
Figure No9 Population density in the peri-urban area of Oradea

The population density indicator, calculated by relating the built-up area to the number of inhabitants, ranks Sântandrei first in the peri-urban zone, with 305 inhabitants per km². This value indicates a high degree of urbanisation, where horizontal expansion has resulted in a dense built environment. The application of spatial data mining techniques to financial reporting data for 2024 confirms the role of ZMO as a driver of the county economy, accounting for 75.4% of Bihor County's turnover.

The structure of peri-urban relations is shaped by the level of spatio-temporal accessibility, which is the main driver of territorial dynamism. The dense, branched road infrastructure network has enabled efficient commuting, increasing the residential attractiveness of neighbouring localities.

The use of standardised thresholds of 15, 30, and 45 minutes is an essential analytical tool for defining the structure of the Urban Functional Area, enabling quantification of commuting mobility intensity and identification of the orientation of dominant commuting flows. As shown in Figure 20(a), mapping these areas for the municipality of Oradea reveals a clear spatial hierarchy:

- 15-minute isochron: Encloses the core of the Oradea Metropolitan Area, defining the perimeter of intense daily interaction.
- 30-minute isochron: Includes the localities of the second peri-urban ring, marking the efficiency limit of daily commuting.
- 45-minute isochron: Extends the sphere of influence over the entire functional region, including secondary urban centres such as Salonta and Aleșd.



(a) (b)

Figure No10 Accessibility of the municipality of Oradea in the peri-urban area

Although geometric modelling suggests extensive accessibility, incorporating dynamic variables such as average traffic values and the topological configuration of roads into network analysis algorithms causes a significant spatial contraction of these areas (Figure 20(b)). This discrepancy between theoretical and actual accessibility highlights the impact of network resilience on the efficiency of regional transport and underscores the need to optimise infrastructure to maintain metropolitan cohesion.

5.2.3 Monitoring Development Trends and Urban Sprawl Using Satellite Time Series Change Detection

Change detection using remote sensing data streams is a fundamental method in diachronic territorial analysis.

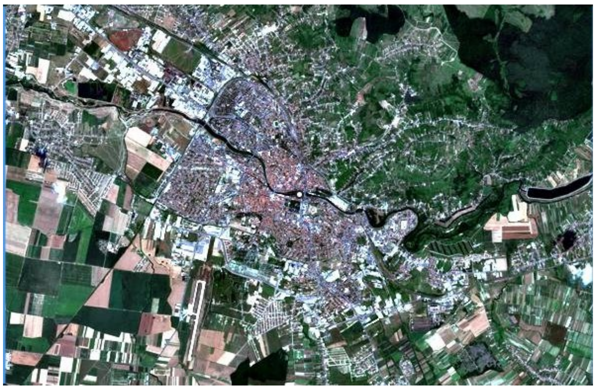


Figure No 11 Oradea - Sentinel 2 image from July 11, 2017. Figure No12 Oradea - Sentinel 2 image from July 25, 2022.

In studies supporting smart urban planning, monitoring the expansion of built-up areas at the expense of green spaces is a key indicator of sustainability. For the analysis of changes in the Municipality of Oradea, time series from the Sentinel-2 mission (ESA Copernicus) were used, characterised by a spatial resolution of 10 m and a high revisit frequency.

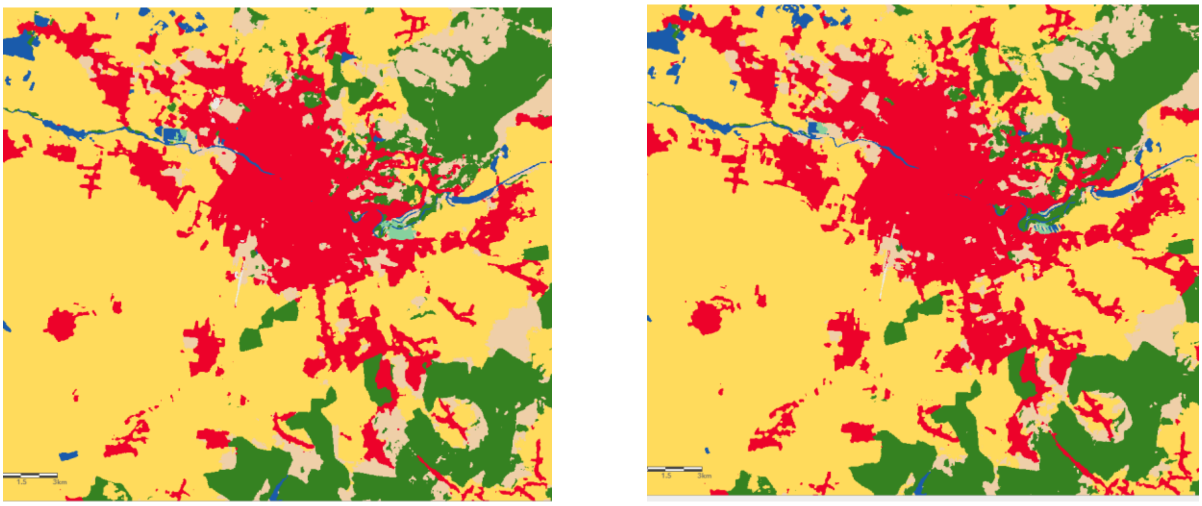


Figure No 23 13 - Sentinel2 data-based usage category with 10 m resolution, comparison between 2017 and 2023 (ArcGIS online)

Direct visual interpretation is characterised by subjectivity and difficulties in accurately quantifying transformations, necessitating advanced computational algorithms to isolate change vectors. Benchmarking the category of use between 2017 and 2023 (Figure 23) highlights a trend of centrifugal urban sprawl. The results indicate the conversion of agricultural land, densification of residential fabric, and fragmentation of green corridors.

5.3 Support Studies on the Organization of Traffic and Transport (GIS-T)

For the preparation of urban planning documentation, it is essential to conduct a substantiation study on the organisation of circulation and transport using advanced spatial data. As road infrastructure and public transport are the most critical components, we present below in detail the methods and technologies for using geographic information systems in the in-depth analysis of road infrastructure in Oradea, followed by an assessment of public transport in the same city and an analysis of the impact of investments in road infrastructure on urban traffic during and after the investment period.

5.3.1 Analysis of Road Infrastructure Using GIS

To analyse traffic in the municipality of Oradea, we used the following methodology:

- We collected traffic data from the municipality of Oradea as shown by waze.com and Google Maps;
- We estimated the capacities of each street segment using the methodology proposed by Transport of London presented in Chapter 3.

As a result of the analysis carried out, we identified the following major dysfunctions:

- Reduced traffic capacity, especially on secondary streets in the historic centre and in collective housing districts.
- Decreased capacity of some streets due to the conversion of parts of the roadway into longitudinal parking spaces.
- Reduced traffic capacity on streets serving the new housing districts.
- Multiple intersections where the flow constraints, are not respected.

5.3.2 Analysis of Mobility and Efficiency of Public Transport

The identification and detailed parameterisation of the street network were conducted as follows:

- The street network was defined as a graph and database for mathematical traffic modelling, serving as the basemap and presentation support for simulated traffic;
- The public transport network and stations were defined as a graph and represented on the basemap;

- The main traffic-generating objectives were identified (administrative, educational and health institutions, commercial and service centres/areas, industrial areas, leisure and recreation areas, etc.);
- The collected traffic data and the traffic data from the PUG of the municipality of Oradea were integrated into the database;
- The collected traffic data were integrated into ArcGIS with real-time traffic data from World Traffic Services, provided by Esri through Living Atlas.

We also adapted the mathematical model defined by Verbavatz and Barthelemy and applied it to traffic data from the municipality of Oradea to model and simulate the travel choices of the population of the city and surrounding villages. Based on network analysis, traffic analysis, and trip simulation, the elements that generate traffic congestion within the city can be easily determined (Droj , et al., 2022).

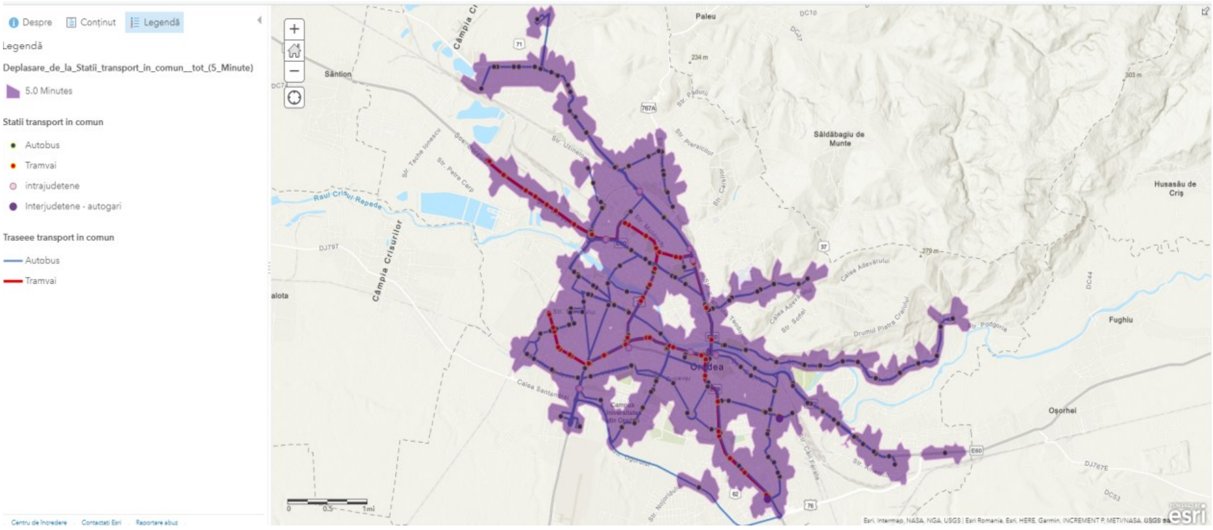


Figure No 14 Accessible areas within 10 minutes from public transport stations((Droj , et al., 2022)

To assess public transport coverage, we conduct a service analysis to determine the area accessible from a public transport station. This network analysis uses the following parameter: a walking and travel time of 10 minutes. The result is a polygon representing the area that can be reached within ten minutes of a public transport station. The generated areas are merged to unify the results.

By overlaying the map created for public transport accessibility with real-time traffic data provided by Esri through Living Atlas World Traffic Services, we observe extensive traffic congestion in the central area of the city, which lacks public transport.

The following figures present a traffic analysis using real-time data, highlighting traffic jams in the city centre due to the lack of public transport during periods when children are travelling to and from school.

Figure No 15 Traffic jams in the central area due to the inaccessibility of means of transport 4.06.2 p.m., (Droj , et al., 2022)

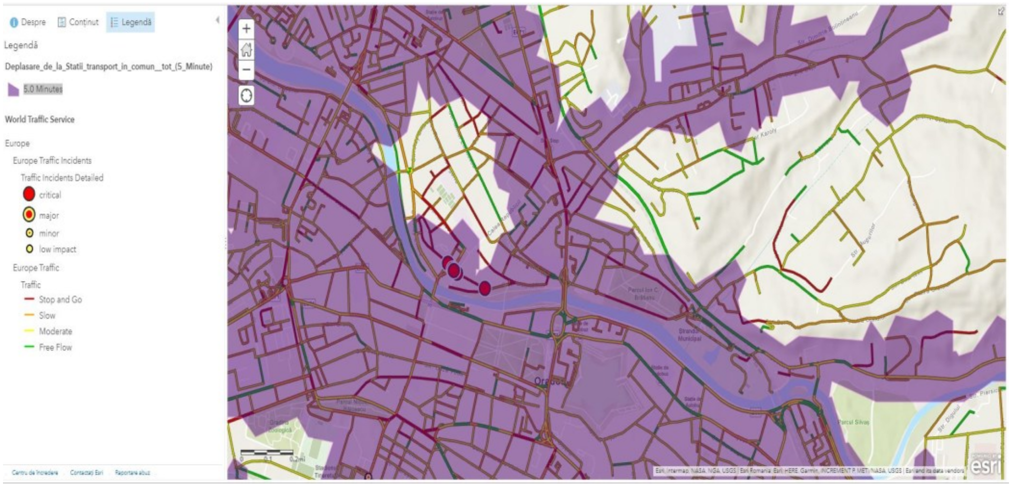


Figure No 16 Traffic jams in the central area due to the inaccessibility of means of transport 17.05.17.17, (Droj , et al., 2022)

In the figures above, we have highlighted areas with limited access to public transport and traffic congestion issues in these areas and on adjacent streets. The choice of travel mode depends not only on the accessibility of public transport, but also on the cost of travel, particularly for parents who must take their children to school before going to work.

For the estimation of travel time, it was assumed that both departure and arrival points are located in neighbourhoods with acceptable public transport access, with an average walking time of 10 minutes from each point to the nearest stop. The waiting time during peak hours was estimated at 10 minutes for Oradea and 25 minutes for the Oradea Metropolitan Area.

As shown in the table below, the time required to travel by car during peak periods is half that needed to travel by public transport, both in the ZMO and in the municipality of Oradea, even when both departure and arrival points are at an acceptable distance from transport stations.

Table no. 4 Simulation of travel times

	Population	Surface area (km²)	Average distance(km)	Traffic index	Time (minutes)t_{PT}	Time (minutes)t_m
ZMO	350000	773	15,69	45,00%	92,07	54,60
Oradea	250000	125	6,30	55,00%	48,92	23,47

5.3.3 Analysis of the Applicability of GIS Technology in Traffic and Congestion Tracking During Road Infrastructure Construction Works

Cities worldwide are expanding, leading to increased population mobility and a corresponding rise in traffic issues such as congestion, traffic jams, accidents, and indirect effects like pollution.

In this study, we analysed the impact of investment in the construction of the Gh. Magheru underpass on traffic and the surrounding area through repeated traffic analyses, using real-time traffic data provided by Esri via Living Atlas World Traffic Services and Google Maps. The following figure shows the result of the traffic analysis conducted in Oradea on 7 November 2019 at 2 p.m., one day before the introduction of traffic restrictions on Magheru Street due to the commencement of underpass construction works, which began on 15 November 2019.

Figure No 17 Traffic in Oradea, November 7, 2019 at 2 p.m. (Droj, et al., 2023)

To monitor traffic during the construction works, we conducted repeated traffic analyses by superimposing real-time traffic data provided by Esri through Living Atlas World Traffic Services and Google Maps onto orthophoto images of the municipality of Oradea.

Figure No 18 Typical traffic in Oradea, February 2020 at 2 p.m. (Droj, et al., 2023)

Figure No 19 Traffic in Oradea on April 29, 2020 at 2 p.m. () (Droj, et al., 2023)

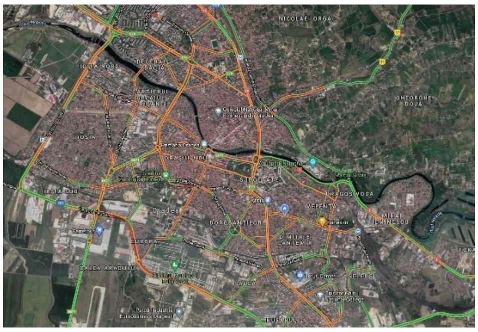


Figure No 20 Traffic in Oradea on September 17, 2020 at 8.00 a.m. (Droj, et al., 2023)

Figure No 21 Traffic in Oradea on October 26, 2020 at 2 p.m. (Droj, et al., 2023)

Figure No 22 Traffic in Oradea on May 17, 2021 at 2 pm (Droj, et al., 2023)

As shown in the figure above, the traffic situation on 17 May 2021 at 2 p.m. indicates congestion along the entire length of Gh. Magheru Street.

5.3.4 Predictive Modelling of Traffic Flows and Dynamic Microsimulation of the Road Network: Case Study of Sântandrei Commune

This section focuses exclusively on the Commune of Sântandrei, an integral part of the ZMO and the administrative-territorial unit with the most severe mobility dysfunctions in the entire metropolitan area. These issues arise from rapid urbanisation and the densification of the built environment. Analysis of the physical infrastructure reveals a highly self-centred and unbalanced system. The commune's street network, which extends for 114 km along the DJ 797 axis, faces major geometric constraints (open gutters) and critical congestion points (Mega Image, Palota) that have reached saturation. This road pressure is exacerbated by systemic vulnerability in mobility alternatives: pedestrian and cycling infrastructure is fragmented, and metropolitan public transport remains uncompetitive due to low frequency and lack of prioritisation in traffic.

Digital Transport Graph Modelling and Microsimulation in SUMO

To move from static data analysis to a dynamic understanding of the transport network in Sântandrei commune, a traffic microsimulation model was developed using the open-source SUMO (Simulation of Urban Mobility) platform. SUMO is a software package for microscopic, continuous simulation of multi-modal road traffic. It enables the modelling of traffic management systems, vehicle behaviour, and their interactions on a detailed road network.(Lopez, et al., 2018)

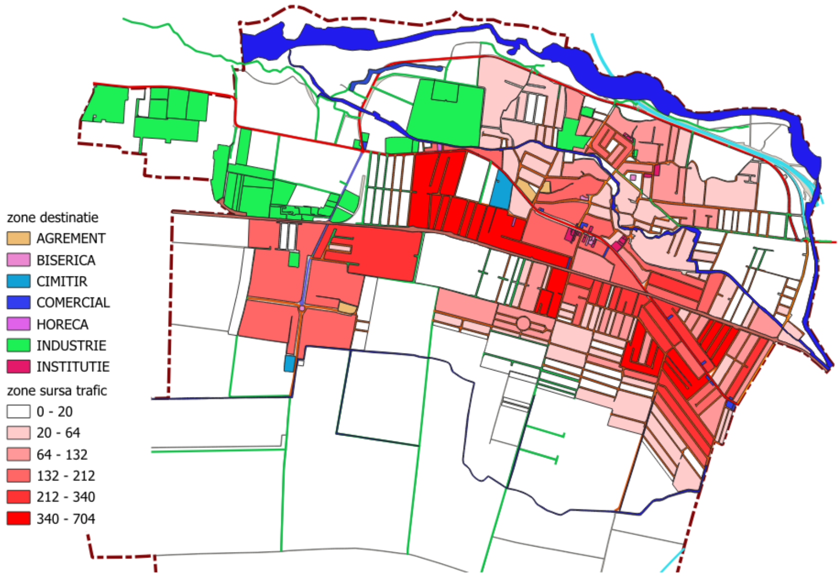


Figure No23 Source and destination of traffic - Sântandrei commune

The transport model uses 2025 as its base year and digitally reproduces the municipality's transport network. Its development involved defining two main components: the physical network and transport demand.

Graph structure: The transport network was topologically modelled as arcs (595 segments) and nodes (1,254 intersections), with each element assigned specific technical characteristics: capacity, design speeds, manoeuvring restrictions, and type of road surface.

Transport request: An Origin-Destination (O-D) matrix was generated and distributed across 485 analysis areas, identifying 257 residential sources and 228 economic or social destinations. Figure No. 43 illustrates the transport demand. The estimation of road emission potential for each block was carried out by correlating the number of housing units with local indicators of car fleet density, enabling a spatial hierarchy of traffic sources.

Model calibration: A traffic census was conducted in 2025, using strategic census points at critical intersections on the DJ 797 artery. Data collected included traffic volumes aggregated at 15-minute intervals, with a detailed classification of vehicles (passenger cars, light commercial vehicles, and heavy vehicles). The census data were entered into the modelling platform as checkpoints. Calibration involved an iterative procedure of adjusting the weights in the Origin-Destination matrix and refining the network parameters**.**

Once calibrated, the model was used to simulate morning rush hour traffic conditions. The transport model, adjusted for the situation, was then used for traffic forecasting to simulate scenarios of demographic development and levels of motorisation, generating demand maps for the future time horizons of 2030 and 2040. Predictive analysis for the 2030 horizon (Figure 45) and 2040 (Figure 46) visually demonstrates the phenomenon of network paralysis in the "business as usual" scenario, without structural interventions.

Figure No24 Average network speed rush hour morning simulation 2030 - map made with SUMO

Figure No 25 Average network speed rush hour morning simulation 2040 - map made with SUMO

The model highlights the propagation of bottlenecks from the radial arteries to the entire local service network, validating the urgent need for the corrective measures proposed in the PUG: the construction of the South bypass, the optimization of the connection with the Arad-Oradea Express Road (DEx) and the implementation of the tram-train system for the modal transfer of commuters.

5.4 Supporting Studies on Environmental Protection and Anthropogenic Risks

5.4.1 Multicriteria Analysis of Green Space Accessibility: Comparative Study of Isotropic Modelling and Network Analysis

Population accessibility to green infrastructure is a key indicator of public health and urban resilience. In this context, a central element supporting studies on environmental protection is the Local Register of Green Spaces, an instrument regulated by Order no. 1466/2010 of the MDRT (Ministerul Dezvoltarii Regionale si Turismului, 2010)

Analysis of data provided by Oradea City Hall (2019) shows a total area of 534 ha, equivalent to 24.19 m² per inhabitant. Although this value appears close to the national standard of 26 m² per inhabitant, we have identified a phenomenon of "statistical inflation" through the inclusion of areas that do not serve active recreational functions, such as extra-urban agricultural land, technical protection areas, or private land with restricted access.

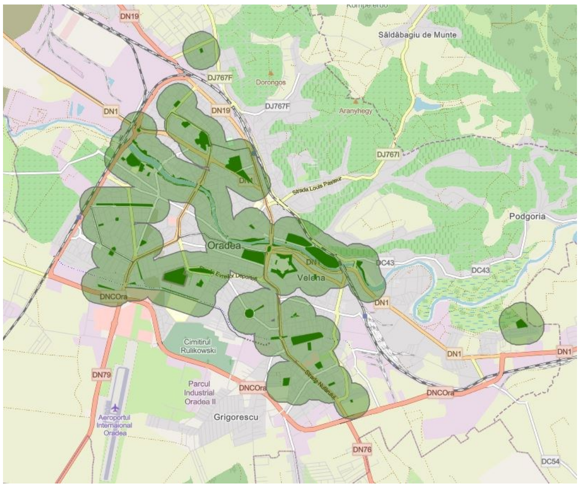


Figure No 26 - Proximity analysis for public green spaces in Oradea (Droj, et al., 2021)

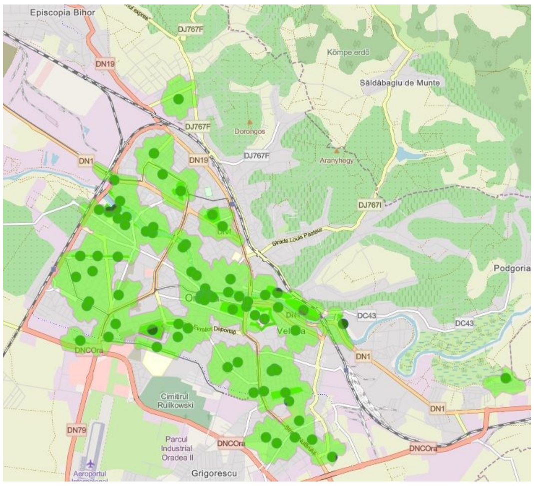


Figure No 27 The areas from which the green spaces intended for recreation can be accessed in 5 minutes (Droj, et al., 2021)

Modern urban policy, such as the "15-minute city" concept, aims to limit pedestrian travel time to a maximum of 5 minutes (approximately 300 m) to a public green space. To assess the efficiency of the current distribution in Oradea, we used two geospatial methodologies for comparison:

1. **Buffer modelling:** This isotropic approach is based on Euclidean (aerial) distance. It generates a circular spatial field around green space polygon (Figure 48). Although it provides a quick overview, it is highly abstract, as it

ignores physical barriers such as rivers, railways, and fences, as well as the configuration of the road network.

2. **Service Area Analysis:** This anisotropic approach is based on graph theory and Dijkstra's algorithm. Implemented using the Network Analyst tool, it calculates accessibility on the actual street network, taking into account the topology of communication routes and traffic barriers (Figure 49).

The results from comparing the two methods (Figure 50) highlight a significant spatial difference. The area defined by buffer zones is considerably larger, creating a misleading perception of "good service". In contrast, the analysis of the service area (5-minute walk) reveals "shade" or "green deserts" – neighbourhoods where, although a park is nearby, a lack of road connectivity or infrastructural barriers makes easy access for residents impossible.

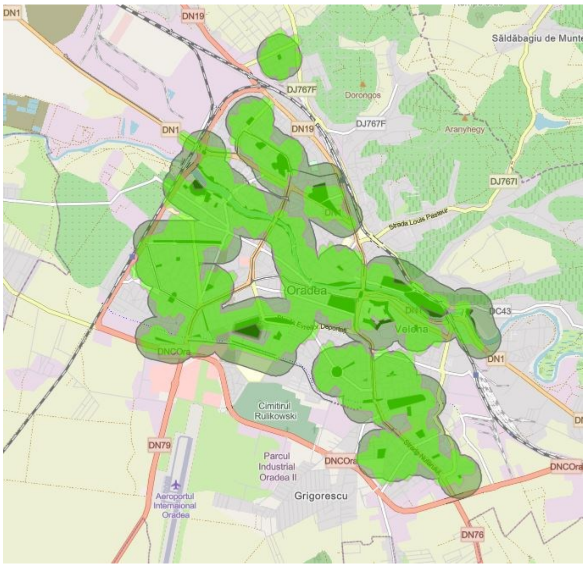


Figure No 28 Comparative superimposed representation of the 2 methods (Droj, et al., 2021)

5.4.2 The Use of Satellite Remote Sensing in Monitoring Anthropogenic Risks and Air Quality: Case Study – The Impact of The COVID-19 Pandemic on Air Quality in the Municipality of Oradea

In this case study, we examined the use and integration of satellite images in GIS to assess air quality during the COVID pandemic, monitor vegetation, and track urban expansion and land use changes to identify the increase in built-up areas in the municipality of Oradea and its impact on the environment.

The analysis of air quality and the presence of aerosols (suspended solid and liquid particles from natural or anthropogenic sources, including road traffic) was conducted by merging two complementary data sources:

1. Sentinel-2 multispectral data (ESA Copernicus): Used for qualitative analysis of atmospheric transmittance through specific band combinations. (European Space Agency, 2023)

2. MERRA-2 (NASA EOS) reanalysis data: used for AOT indicator extraction and estimation of surface mass concentration of fine particulate matter (PM2.5). Although satellite observations involve a degree of uncertainty due to cloud contamination or radiometric variations, they are the only source of continuous monitoring in the absence of access to ground sensor data. (Buchard, et al., 2016)

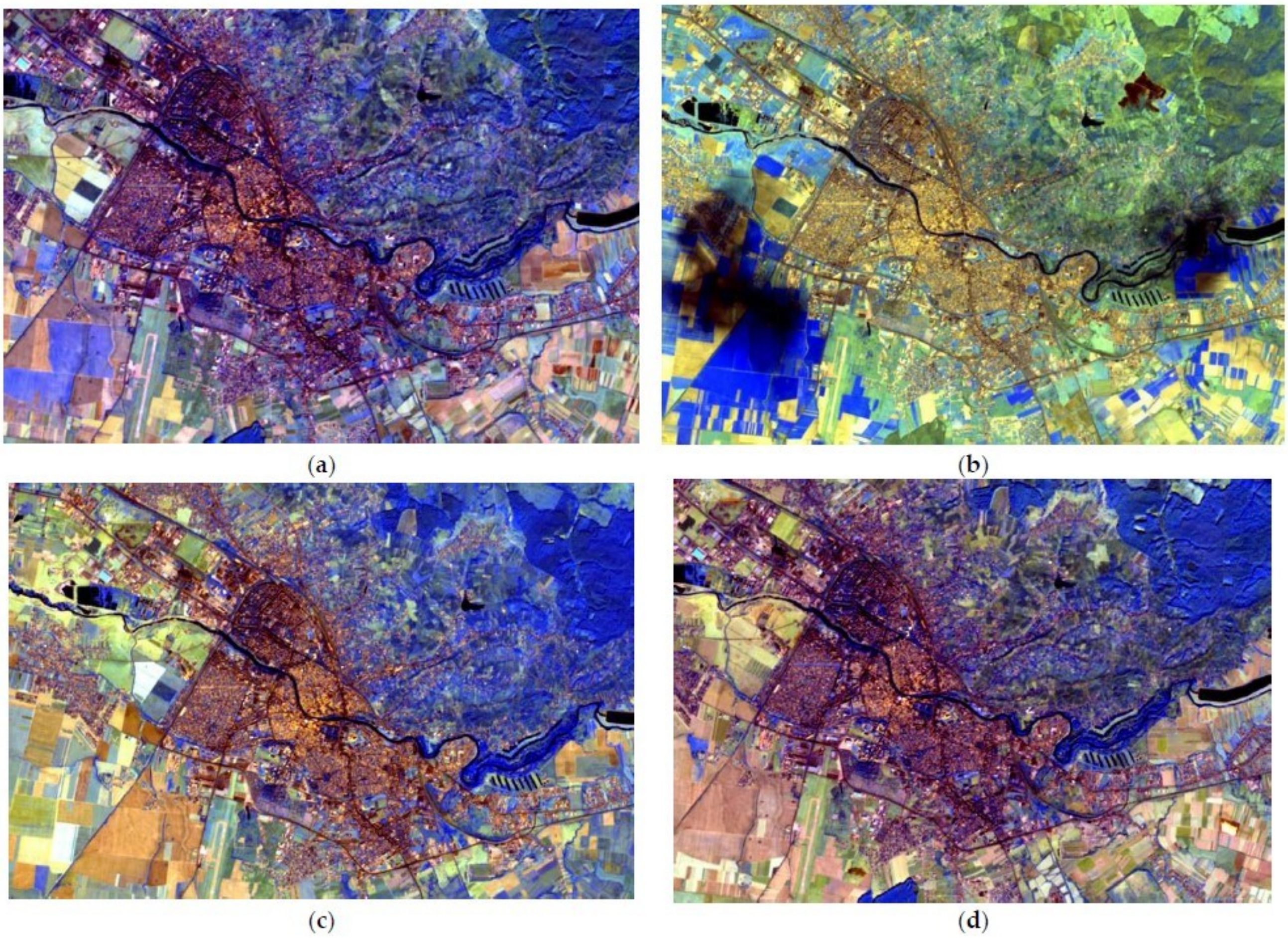


Figure No 51 29 Atmospheric penetration (a) February 2020, (b) April 2020, (c) September 2020, and (d) October 2020

To assess the impact of mobility restrictions during the COVID-19 pandemic on the urban atmosphere, we examined four key periods in 2020: pre-quarantine (February), total quarantine (April), post-quarantine (September), and the resumption of activities (October).

- Atmospheric penetration (SWIR2-SWIR1-NIR composition): This combination (Figure 51) uses wavelengths that penetrate fine particles of smoke and fog. Comparative analysis shows greater image clarity in April 2020, indicating a significant reduction in dispersion caused by anthropogenic aerosols during the restrictions.

- Elimination of the atmospheric effect (SWIR2-NIR-Green composition): The results presented in Figure 52 confirm the previous hypothesis. The high atmospheric transmittance recorded in April 2020 is directly correlated with decreased emissions from road transport and industrial activities, providing a visual reference for a 'clean atmosphere' scenario.

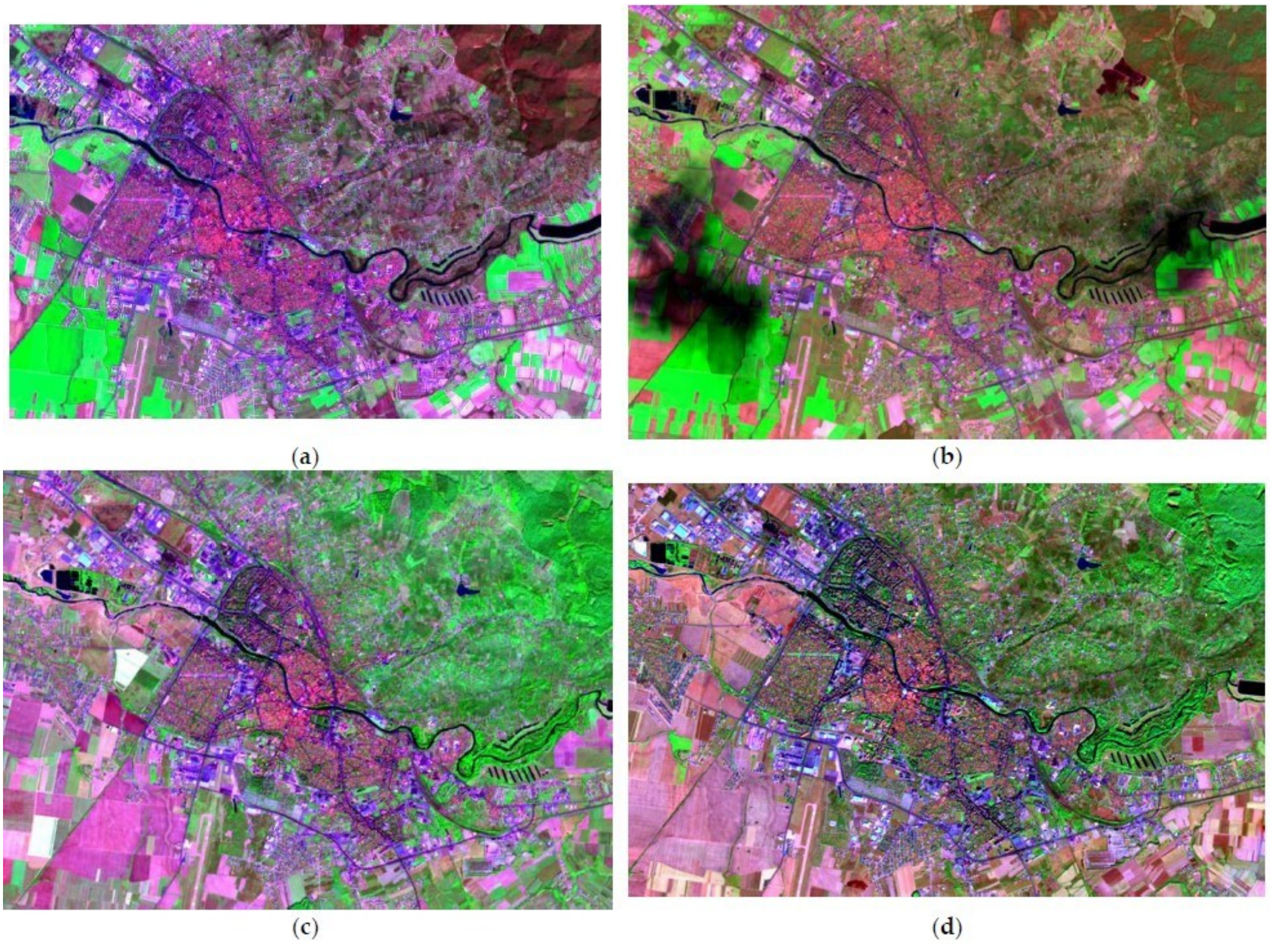

(a) (b) (c) (d)

Figure No 52 30 Atmospheric Effect Elimination (a) February 2020, (b) April 2020, (c) September 2020, and (d) October 2020

For a rigorous evaluation, we used the particle surface mass (PM) calculation model, with a diameter of 2.5 μm (1.0 μm) or less, referred to as PM2.5, provided by the MERRA-2 platform. Time series analysis (January 2019 – January 2022), calculated with Giovanni and shown in Figure 53, highlights a drastic decrease in PM2.5 values in spring 2020. This negative anomaly coincides with the quarantine period, demonstrating the direct impact of reduced urban traffic on air quality in the municipality of Oradea (NASA).

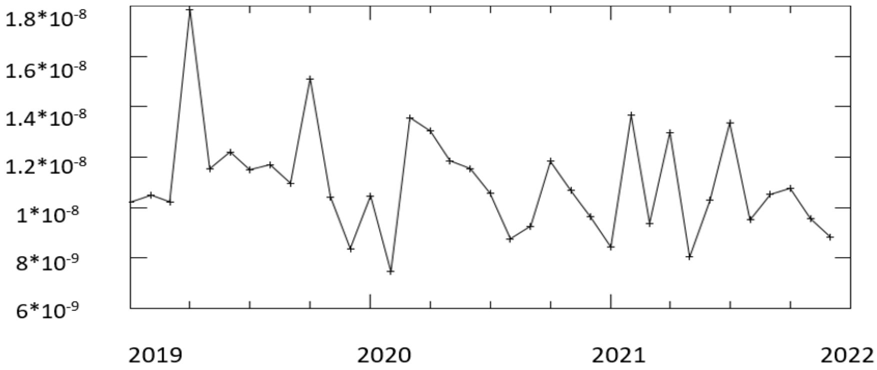


Figure No 31 PM 2.5 surface mass concentration for Oradea, analysed monthly from January 2019 to January 2022 (Droj, et al., 2023)

In interpreting air quality trends, it was observed that the dispersion of pollutants depends not only on emission volumes but also on meteorological variables such as wind speed, relative humidity, and boundary layer height. However, the sharp decrease in PM2.5 levels recorded in April 2020 (Figure 53) exceeds the usual seasonal climatic variations for the region.

Studying the impact of the COVID-19 pandemic through remote sensing techniques has reconfirmed the need for spatial data infrastructures as crisis management tools. The results demonstrate that:

- Satellite data overcomes the limitations of fixed sensors, providing continuous spatial coverage over the entire built area;
- The correlation between mobility and pollution is quantifiable through AOT indices and reanalysis models, providing decision-makers with a scientific basis for low-emission zone planning;
- The GIS becomes an integrative platform, capable of processing data from NASA and ESA to generate essential environmental indicators in the development of prospective substantiation studies of the PUG.

5.4.3 Identification of Areas of Ecological Vulnerability Through Spectral Indices (NDVI, NDWI).

In this study, we applied an analysis protocol based on the correlation between vegetative vigour (NDVI) and moisture content (NDWI) using Sentinel-2 time series data, with a resolution of 10 metres, for the period 2017–2025, processed in QGIS (Quantum GIS). To highlight changes in green areas and facilitate analysis, we determined the normalised NDVI vegetation differentiation index for the Sentinel-2 satellite images. The NDVI index uses the contrast between strong absorption of red-band radiation (RED) by chlorophyll and high near-infrared (NIR) reflection by the leaf cell structure. For the Municipality of Oradea, we calculated the NDVI using bands 4 and 8 of the Sentinel-2 sensor according to formula (1).

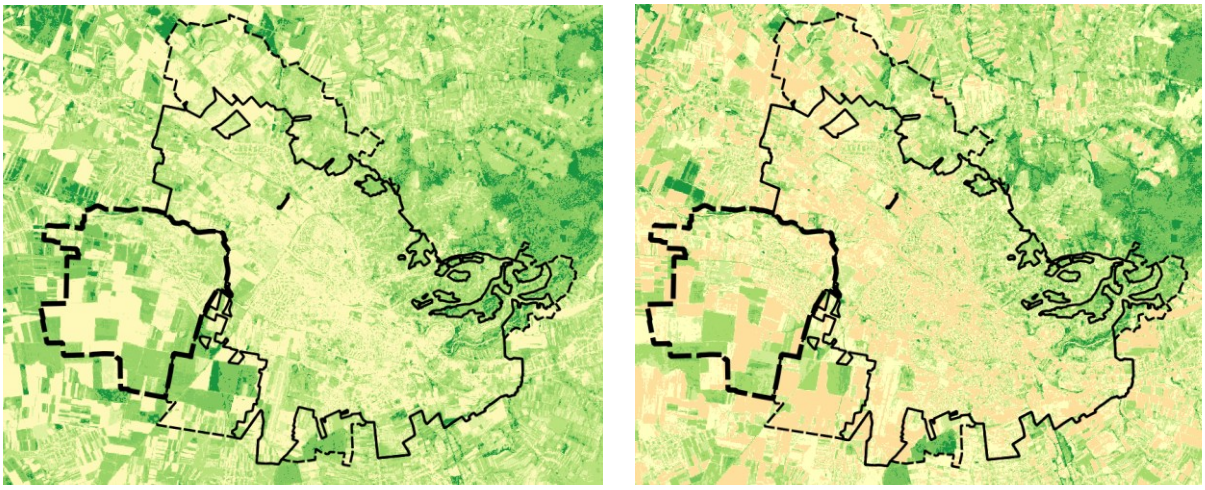


Figure No 32 NDVI July 11, 2017 Sentinel 2 compared to NDVI July 21, 2025 Sentinel 2

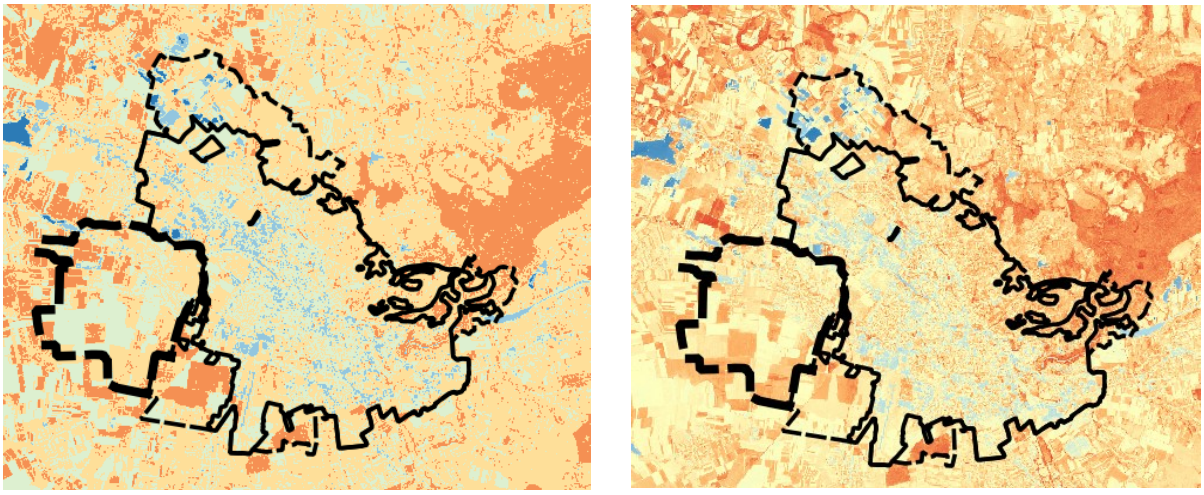


Figure No 55 33 NDWI 11 July 2017 Sentinel 2 compared to NDWI 21 July 2025 Sentinel 2

To separate the effect of drought from that of actual urbanisation, we introduced the normalised water difference index (NDWI) into the analysis model. To isolate this phenomenon, the NDWI was calculated according to formula 2. The use of the short-wave infrared (SWIR) band enabled mapping of water stress at the canopy level.

To highlight the real expansion of built-up areas at the expense of green spaces, we generated the difference image, ΔNDVI, by performing pixel-by-pixel subtraction between reference dates. Areas affected by drought show a uniform and moderate decrease in values, while recently urbanised areas (the western periphery of the municipality, new industrial zones) appear as extreme negative anomalies, represented in red (Figure 56).

The combined use of NDVI, NDWI, and ΔNDVI indices transforms GIS from a visualisation tool into a high-precision diagnostic system. The results show that:

- Reporting green areas without water stress analysis (NDWI) may result in erroneous public policies.

- The difference map enables the prioritisation of urban reforestation programmes in areas identified as "negative anomalies", ensuring ecological compensation for new infrastructure projects.
- Integrating these indices into the digital twin of the municipality of Oradea enables the authorities to monitor compliance with the "Oradea Green City" strategies in an automated and objective manner.

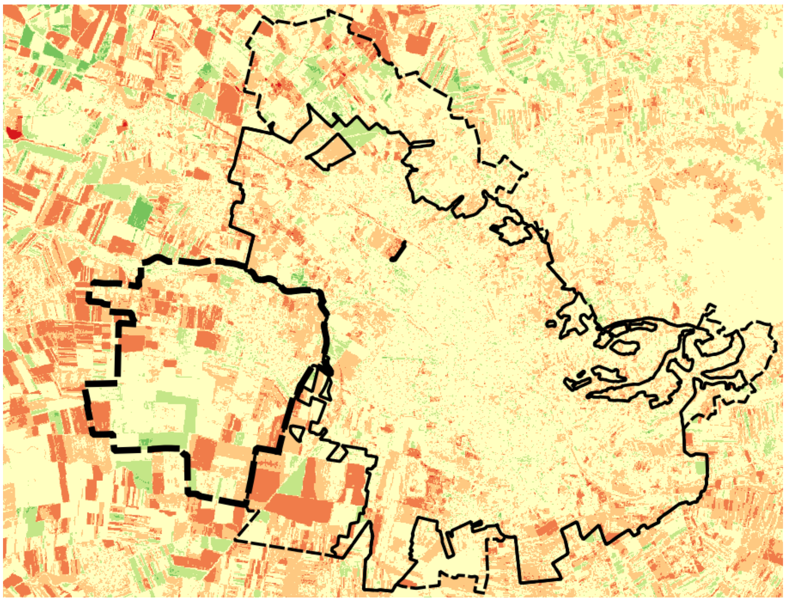


Figure No 56 34 Picture difference between NDVI 2017 and 2025

5.4.4 Urban Heat Island Analysis at Neighbourhood Level

For the analysis of the urban heat island, we have incorporated the Construction Index (NDBI) into the model to identify impervious surfaces and built floor density accurately. NDBI uses the reflectance contrast between the shortwave infrared (SWIR) and near-infrared (NIR) bands: $NDBI = \frac{SWIR - NIR}{SWIR + NIR}$

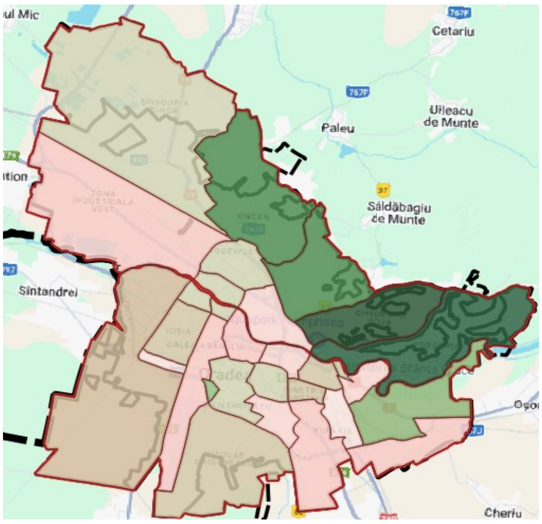


Figure No 57 35 Analysis of urban heat islands

High NDBI values indicate a significant concentration of building materials (concrete, asphalt, ceramics), which have high heat retention capacity and low albedo. Using the administrative boundaries of Oradea's neighbourhoods as an aggregation layer, we calculated the average values of both indices (NDVI and NDBI) for each sector.

To highlight the spatial interdependence between the built and natural environments, we implemented a hybrid visualization technique, by superimposing the anthropogenic pressure gradient (NDBI on the red scale) with the green resilience gradient (NDVI on the green scale), using an opacity coefficient of 50%, classifying the territory according to vulnerability to the urban heat island phenomenon (Figure No 57 35):

- Deep Green (High NDVI / Low NDBI): Identifies areas of maximum ecological resilience
- Deep Red (Minimum NDVI / Maximum NDBI): Delineates the thermal critical points or "Hot Spots".
- Transition Shades (Yellow/Brown): Reflects areas of fragile equilibrium, where built density begins to suffocate residual green spaces, indicating areas where the urgent implementation of "Nature-Based Solutions" policies is needed.

This methodology demonstrates that merging NDVI and NDBI through zonal statistics provides a robust proxy indicator for analysing urban heat islands. This enables local government to prioritise urban regeneration interventions not only on aesthetic criteria, but also on actual climate risk. Thus, GIS becomes a tool to ensure the transition from reactive to proactive urban management, oriented towards climate neutrality and increased urban resilience.

5.5 Predictive Studies and Decision Support

5.5.1 Application of Multi-Criteria Spatial Analysis (SMCDA) to Identify Optimal Investment Areas

The decision-making process in contemporary urban and regional management is characterised by structural complexity, arising from the interdependence of heterogeneous factors: economic, ecological, legal and technical. To objectively substantiate future directions for residential expansion, this research applies the methodological framework of spatial multicriteria analysis, transforming the geographic information system from a visualisation method into an active spatial engineering tool capable of mediating between development needs and territorial constraints.

The analytical process followed the flowchart (Figure 58), progressing through the stages of acquisition, standardisation, weighting and synthesis via geoprocessing operations. The model operates on a logic of successive filtering, where the territory of the municipality of Oradea is subjected to sets of constraints and opportunity factors. To implement the methodological flows and conduct complex geoprocessing analyses, we used the QGIS (Quantum GIS) software environment, version 3.40 LTR.

This platform was chosen for its ability to manage heterogeneous data streams and integrate advanced algorithmic libraries, which are essential for raster processing and spatial analysis.

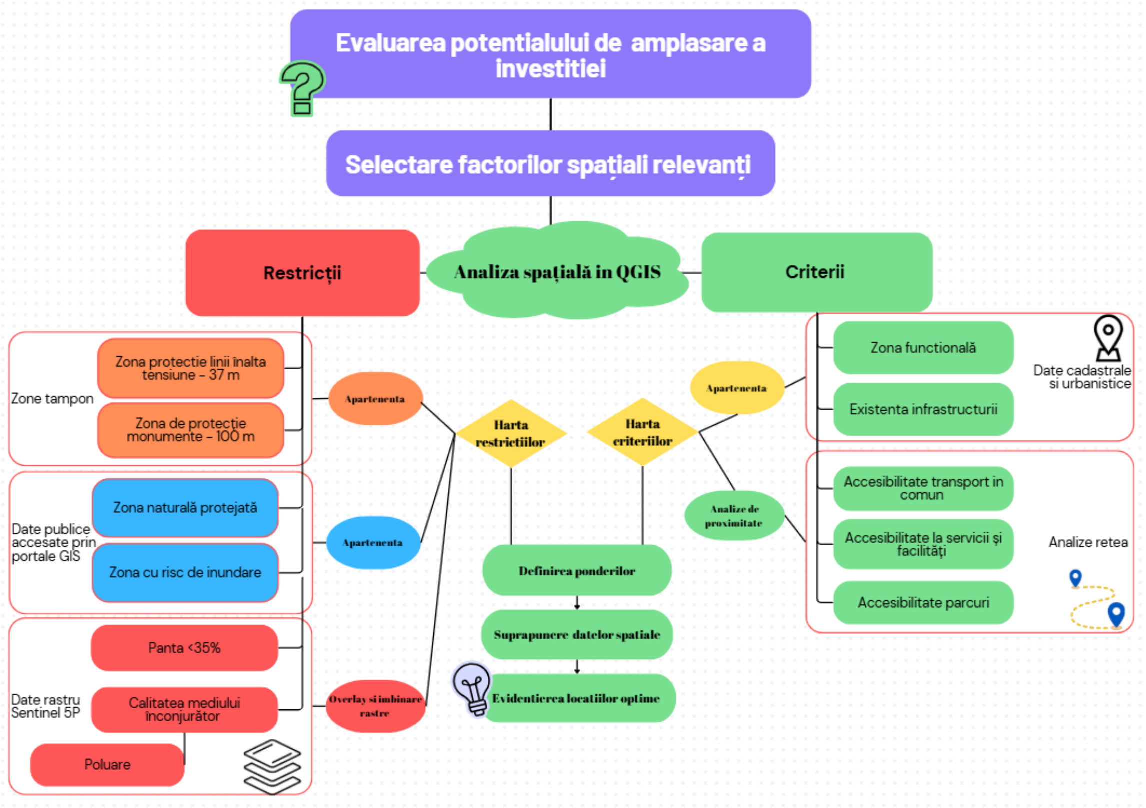


Figure No 58 36 Spatial Analysis Flow Diagram

The first stage involved identifying non-buildable areas where residential investments are prohibited by law, require additional regulations, or present significant risks:

- Protected areas and natural sites: Protection of biodiversity and ecosystem integrity (Figure No37).
- Flood risk areas: Use of hazard maps to eliminate vulnerable areas in the Crișul Repede meadow (Figure No 60 38).
- Geomorphological constraints: Exclusion of land with slopes above the 35° threshold, where construction costs and risks of slope instability become critical.
- Technical corridors (high-voltage lines): Electromagnetic safety buffers to protect public health at a distance of 37 m from the line.
- Areas for the protection of historical monuments: Preservation of cultural identity by restricting and regulating construction methods within the protection perimeters of the architectural heritage.

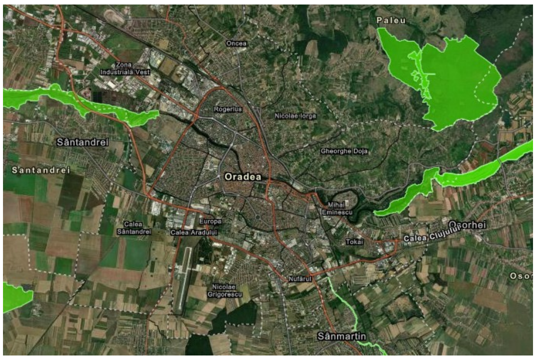


Figure No37 Protected areas

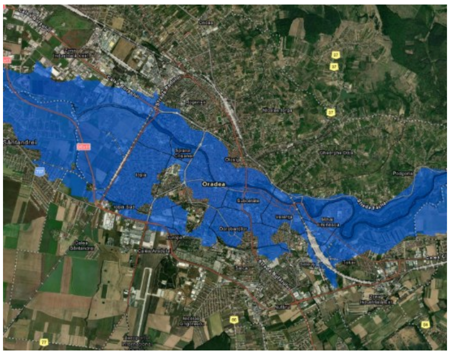


Figure No 60 38 Flood risk

To obtain a unified view of these limitations, as shown in the figure below, we used a methodology of successive topological aggregation, structured as follows:

- Buffer operations defined the protection zones
- The raster layers (flood zones and slopes>35◦) were automatically vectorised.
- These heterogeneous layers have undergone a topological union operation. This process merged all constraint geometries into a single data layer, preserving the complexity of the constraints specific to each.
- After unification, the internal barrier dissolve algorithm based on the constraint attribute was applied. This step simplified the database by eliminating geometric redundancies between overlapping areas (e.g. a monument protection area partially located in a flood zone), resulting in a unique and continuous geometry of constraints.

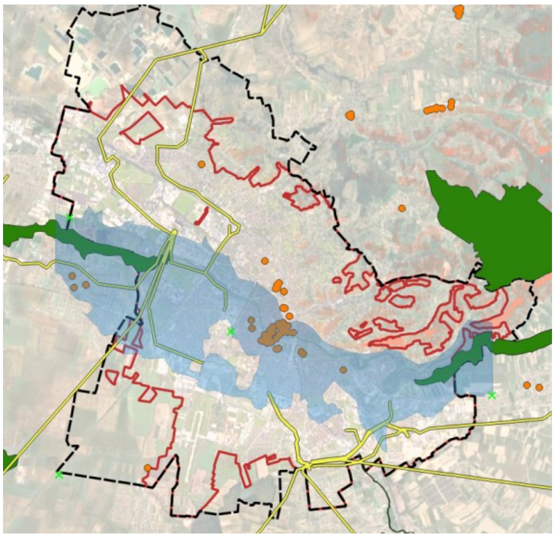


Figure No 61 39 Areas with restrictions or constraints on the construction regime

The final stage of constraint modelling involved applying a spatial differentiation algorithm (Difference operation) between the boundary of the built-up area of the Municipality of Oradea and the previously developed binary mask of cumulative constraints. This process removed all areas with restrictions and constraints from the space designated for urbanisation, resulting in a fragmented geometry representing the "space of real opportunity", as shown in Figure 62.

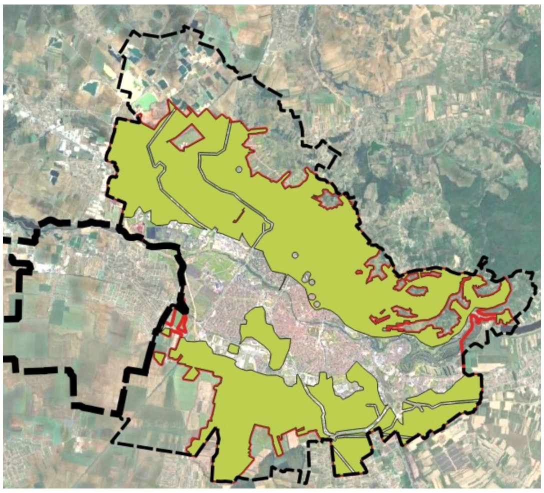


Figure 40 Built-up areas without restrictions

After removing the restrictive areas, the remaining area was evaluated using opportunity factors, which serve as value multipliers for future residents:

- Accessibility to green infrastructure: Modelled using a 5-minute walk (approximately 300 m) service area analysis to identify areas benefiting from proximity to parks (Figure 49).
- Accessibility to the public transport network: Modelled using a service area analysis based on a 10-minute walk to transport stations, which is essential for reducing dependence on private cars and promoting sustainable mobility (Figure 30).
- Proximity to facilities: Access to educational, medical, and commercial facilities.

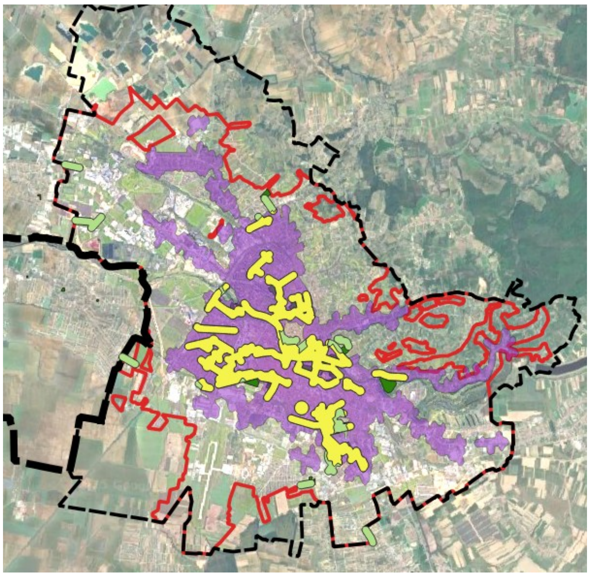


Figure No 63 41 Areas that comply with all accessibility criteria

In Figure 63, we show the areas that meet all three positive requirements simultaneously. The analysis results (Figure 64) highlight the areas that satisfy all the conditions for study:

- Absence of restrictions and constraints – safe land, located outside areas affected by natural hazards and construction restrictions.
- Ideal connectivity – zones that optimise travel time and maximise access to recreational spaces and facilities.

The map displays a spatial hierarchy of suitability, identifying the "nuclei of opportunity" where urban densification can be achieved sustainably, without compromising ecological balance or public safety.

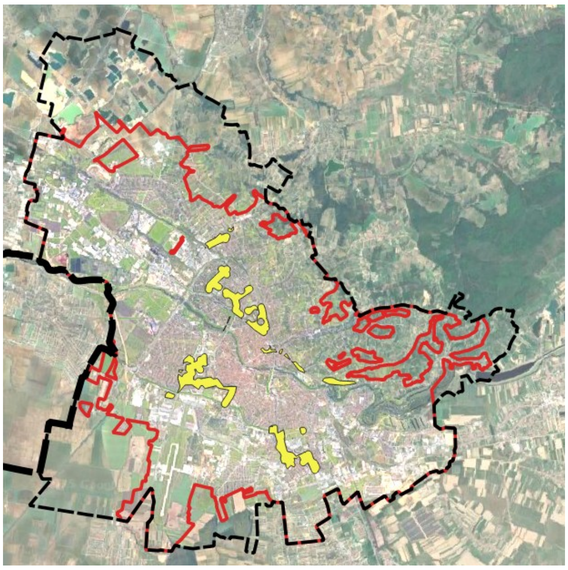


Figure No 64 42 Areas of the city that meet all selected criteria

The multi-criteria analysis in this case study demonstrates the superiority of GIS-based planning over traditional zoning methods, offering the following strategic advantages for the Oradea administration:

- The model eliminates subjectivity in changing the construction rights regime.
- Modular architecture allows integration of additional dynamic layers.
- The analysis results provide a basis for negotiation and substantiation of the new PUG.

5.5.2 Integration of Geographic Information Systems and Automated Valuation Models into Local Tax Policies

Computer-aided valuation systems (CAMAs) are designed to determine the value of multiple properties within a geographical area, such as a municipality or county, simultaneously, using standardised statistical models. Recent studies highlight that, by removing non-spatial limitations, GIS has improved the accuracy of assessments, enabling the visualisation of value distribution and the identification of correlations between the physical characteristics of properties and their geographical context (Demetriou , 2016).

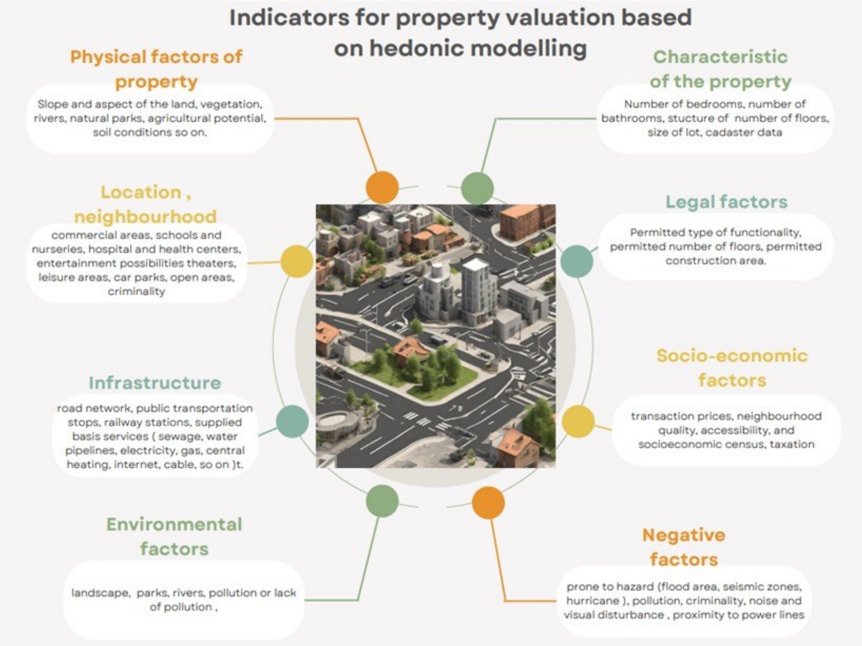


Figure No 43 Schematic representation of relevant indicators for hedonic modelling (adapted after) (Ayalke & Sisman, 2022) (Droj , et al., 2024)

The core of mass evaluation algorithms is hedonic modelling, which decomposes the value of a property into a set of independent attributes. In the system proposed for Oradea, the hedonic models are optimised by integrating externalities identified through spatial analysis:

- Positive externalities: Proximity to green infrastructure, public transport networks and points of interest (POIs) or location in a high-rated neighbourhood or tourist area.
- Negative externalities: Impact of noise pollution factors, proximity to high-voltage lines or natural hazards. GIS plays a vital role in the valuation of properties located in vulnerable areas, allowing the adjustment of the tax value or insurance premium based on risk maps.

From the perspective of the local administration, AVM-GIS is an essential tool for the functionalization of the urban economy by:

1. Ensuring tax fairness: By using spatial regressions (GWRs), inequities are eliminated at the border of current tax zones, where two similar properties may have different taxes just because of an outdated administrative delimitation. The system ensures a fair correlation between the tax burden and the real utility of the site, taking into account access to infrastructure, air quality and proximity to green spaces.
2. Strategic forecasting of budget revenues: The integration of AVM into an SDSS gives the local administration the ability to produce multi-annual financial forecasts.
3. Optimising and increasing the tax base with GIS by detecting anomalies between recorded data and the reality on the ground.

4. Capitalisation of the added tax value: if the administration increases the value of private land through road infrastructure works or utilities, the GIS-AVM system quantifies this added value, providing the legal and technical basis for adaptive taxation.

The efficient implementation of AVM and CAMA systems is structurally conditioned by the existence of a granular data architecture, capable of harmonising and processing heterogeneous information flows: building cadastre, transport graphs, functional zoning and address nomenclatures.

5.6 Synthesis of the Results of the Case Study and Validation of the Information System as a Decision Support Tool

The main conclusions drawn from the operationalisation of the analysis pillars are as follows:

1. Synergy between economic data and cadastral structures: The use of spatial data mining techniques and Ripley's K function has shown that economic performance is not uniform but highly polarised. Integrating fiscal data with the geometry of territorial administrative units enabled precise identification of areas of vitality, allowing the administration to tailor development policies. This method can be extended to the urban level for formulating taxation policies and stimulating investment, thereby ensuring tax fairness based on spatial realities.
2. Efficiency of dynamic modelling in mobility management: Analysis of road infrastructure through microsimulation and predictive traffic modelling for 2040 has highlighted the limitations of static approaches. The case study confirmed that the system's ability to generate what-if scenarios provides a technical basis for prioritising major infrastructure projects, which are essential for maintaining metropolitan cohesion.
3. Environmental monitoring using advanced remote sensing: The use of satellite time series and correlated spectral indices (NDVI, NDWI, NDBI) has overcome the limitations of traditional administrative reporting. Monitoring 'green deserts' and urban sprawl (Change Detection) with artificial intelligence has been shown to provide a neutral and objective picture of ecological degradation.
4. Decision optimisation through multi-criteria spatial analysis: This demonstrates that geographic information systems can automate the process of selecting land for investment, ensuring compliance with restrictions and maximising quality of life, while eliminating arbitrary subjectivity from the approval of urban planning documentation.
5. The study showed that the minimum data set required by Order no. 904/2023 is insufficient for proactive regional management. Only by including smart objects (IoT sensors), complex cardinality relationships, and hybrid spatial fields can the system evolve into a true digital twin of the region.

6 Conclusions

The research presented in this thesis demonstrates that Geographic Information Systems have evolved beyond simple cartographic representation tools to become essential infrastructures for territorial intelligence. The study confirms the hypothesis that combining geodetic precision with advanced spatial analysis provides an objective basis for sustainable local and regional development. It also shows that the Digital Twin vision of the territory can be achieved only through the symbiotic convergence of four methodological pillars:

1. Analytical and geospatial methods.
2. Mathematical and geostatistical models.
3. Artificial Intelligence (GeoAI).
4. Synergy for decision support.

The main results confirm:

- Systemic data integration.
- The efficiency of dynamic modelling.
- Decision-making objectivity.

6.1 Original Contributions by the Author

This paper presents a series of theoretical, methodological, and applied contributions that substantiate the role of the modern geodesist as a manager of geospatial information:

- Establishing, based on national and international literature, the methods, techniques, and algorithms used in advanced spatial analysis as an objective basis for sustainable local and regional development.
- Development of the Extended Conceptual Outline (Figure 13): We proposed and validated a data model that exceeds the minimum requirements of national legislation. The integration of complex cardinality relationships, inheritance/composition ontologies, and IoT sensors transforms the static model into an initial step towards a regional Digital Twin
- Modelling economic vitality at the level of territorial units through spatial data mining: The integration of financial micro-data with territorial reference units is an innovative approach in regional planning, enabling fair taxation and zoning based on real economic potential. (Droj & Droj , 2019) (Droj, et al., 2020)
- Methodology for decoupling climate noise through spectral synergy: An original contribution is the combined use of NDVI and NDWI indices to separate the effect of drought from actual urbanisation, providing a neutral audit method for green space compliance in urban planning documentation. (Droj, et al., 2021) (Kwartnik-Pruc & Droj , 2023)

- Modelling public transport efficiency by analysing service areas, identifying underserved zones, and offering solutions for optimising nodal connectivity between Oradea and peri-urban localities. (Droj , et al., 2022)
- Disruptive impact analysis (COVID-19) on the urban microclimate: Using MERRA-2 reanalysis models and Sentinel-2 atmospheric transmittance to create a baseline of air quality in the municipality of Oradea in the absence of road traffic pressure. (Droj, et al., 2023)
- GIS-T dynamic microsimulation by modelling transport demand based on origin-destination matrices and simulating congestion scenarios for the 2040 horizon in Sântandrei commune.
- Combining geographic information systems with automatic valuation models (AVM/CAMA) for the technical substantiation of fair fiscal policies(Droj , et al., 2024)
- Operationalisation of the spatial support model for residential investment decisions: Development of a complete algorithmic flow that integrates constraints and restrictions with multimodal accessibility factors, providing a method for prioritising land suitability.

6.2 Practical Applicability and Recommendations for the Administration

The results of the case study on the Oradea Metropolitan Area provide practical tools for local authorities:

- Modernization of Spatial Data Infrastructure and compliance with LADM (ISO 19152)
- Urban planning: Use of suitability maps derived through SMCDA as an official tool for approving General and Zonal Urban Plans. This approach removes subjectivity and provides rigorous mathematical justification in the planning process.
- Implementation of AVM/CAMA models to optimise budget revenues and ensure transparency for taxpayers. Integration of change detection routines from satellite imagery to identify new constructions, thereby increasing own revenues without raising tax rates.
- Prioritisation of infrastructure projects in "opportunity hubs" by reducing urbanisation costs and maximising social benefits per unit of capital invested.
- Use of Service Area analyses to address public transport coverage gaps, ensuring compliance with the '15-minute city' principle.
- Adoption of microsimulation platforms as a standard procedure in assessing the impact of infrastructure works.
- Use of the synergy of NDVI/NDWI indices as a neutral method for verifying environmental obligations, real-time monitoring of urban vegetation health, and identifying areas requiring irrigation or reforestation.
- Publication of aerosol dispersion data (AOT/PM2.5) accessible to citizens to raise awareness and justify the implementation of low emission zones.

6.3 Directions for Further Research

The research can be extended in the following directions:

- Evolution towards 3D and 4D representations, and subsequently towards the 3D and 4D cadastre.
- GeoAI Implementation: development of intelligent agents capable of automatically updating the geospatial database based on continuous streams of satellite imagery and social sensors (VGI).
- Expansion of IoT sensor networks and their integration into the spatial data infrastructure, enabling the transition from a static to a dynamic Digital Twin.
- Modelling climate resilience using stochastic simulations.

Bibliography

Afolayan, A. et al., 2022. GIS-Based Spatial Analysis of Accident Hotspots: A Nigerian Case Study. *Infrastructures,* 7(103).

Aggarwal, C. C. & Abdelzaher, T., 2011. INTEGRATING SENSORS AND. In: C. C. Aggarwal, ed. *Social Network Data Analytics.* London: Springer, pp. 379-412.

Alawadi, K., & Benkraouda, O., 2018. What Happened to Abu Dhabi's Urbanism? The Question of Regional Integration. *Journal of Urban Design,* 23(3), pp. 367–394.

Andrews, C., 2018. *GIS and BIM Integration Leads to Smart Communities.* [Interactive] Available at: www.esri.com [Accessed 21 April 2022].

Antoniou, V., Vassilakis, E., & Hatzaki, M., Without an Is Crowdsourcing a Reliable Method for Mass Data Acquisition? The Case of COVID-19 Spread in Greece During Spring 2020. *International Journal of Geo-Information.*

Ayalke, Z. & Sisman, A., 2022. Nominal Land Valuation with Best-Worst Method Using Geographic Information System: A Case of Atakum, Samsun. *ISPRS Int. J. Geo-Inf,* 11(4).

Aydinoglu, A. C., Bovkir, R., Sisman, S., & Kara, A., 2025. Enhancing the National Spatial Data Infrastructure to Support 3D Real Estate Valuation: A Case Study of GIS-Supported Scoring of 3D Residential Units Based on Expert Opinion. *Transactions in GIS,* Volume 29.

Badea, A. C. & Badea, G., 2021. *Aspects about Spatial Information Management to optimize Spatial Planning and Sustainable Development.* Prato, Italy, https://www.fig.net/resources/proceedings/2021/Workshop%20FIG_PRATO_BADEA .pdf, s.n.

Badea, A. C. & Badea, G., 2021. *Traffic Analysis Studies Using GIS Tools.* Virtually in the Netherlands, s.n.

Badea, G. & Badea, A. C., 2013. *Cadastre, data banks and GIS applications in urban areas.* Bucharest: Conspress (U.T.C.B.).

International Bank for Reconstruction and Development and World Bank, 2020. *URBAN POLICY 2020-2035 AND ACTION PLAN,* Bucharest: Ministry of Public Works Development and Administration.

Bezdek, J. C., Robert, E. & William, F., 1984. FCM: The fuzzy c-means clustering algorithm. *Computers & Geosciences,* 10(2-3), pp. 191-203.

Biljecki, F. et al., 2015. Applications of 3D City Models: State of the Art Review.. *ISPRS International Journal of Geo-Information,* Volume 4, pp. 2842–2889.

Borges, A. V. K., Davis, J. A. C. & Laender, , H.-., 2001. OMT-G: An Object –Oriented Data Model for Geographic Applications,. *Geoinformatics,* 5(3).

Borrough, P. A. & Frank, A. U., 2020. *Geographic Objects with Inderterminate Boudaries*. Taylor and Francis.

Boulos, M. et al., 2017. From urban planning and emergency training to Pokémon Go: applications of virtual reality GIS (VRGIS) and augmented reality GIS (ARGIS) in personal, public and environmental health.. *You're J Health Geographics.*

Buchanan, M., 2019. The benefts of public transport. *Nature Physics.*

Buchard, V. et al., 2016. Evaluation of the surface PM2.5 in Version 1 of the NASA MERRA Aerosol Reanalysis over the United States.. *Atmospheric Environment,* Volume 125, pp. 100–111.

Bühlmann, P., Drineas, P., Kane, M., & van der Laan, M., 2019. *Handbook of Big Data*. 1 ed. s.l.: Chapman & Hall.

Bull, A., 2003. *TRAFFIC CONGESTION - THE PROBLEM AND HOW TO DEAL WITH IT,* Santiago de Chile: United Nations Economic Commission for Latin America and the Caribbean.

Cardone, B. & Di Martino, F., 2020. A Fuzzy Rule-Based GIS Framework to Partition an Urban System Based on Characteristics of Urban Greenery in Relation to the Urban Context. *Applied Sciences.*

Carniel, A. C., 2022. Defining and designing spatial queries: the role of spatial relationships. *GEO-SPATIAL INFORMATION SCIENCE,* pp. 1-25.

Câmara, G., Souza, R. C. M., Freitas, U. M. & Garrido, J., 1996. Spring: Integrating remote sensing and gis by object-oriented data modelling. *Computers & Graphics,* 20(3), pp. 395–403.

Chaves, R. et al., 2019. Crowdsourcing as a Tool for Urban Emergency Management: Lessons from the Literature and Typology. *Sensors.*

da Silva, C. N., da Silva, J. M. P. & Castro, C. J. N., 2015. Methodological Guidelines for the Use ofGeoprocessing Tools: Spatial AnalysisOperations—Kernel, Buffer and theRemote Sensing Image Classification. *Agricultural Sciences,* Volume 6, pp. 707-716.

Demetrescu, C. & Italiano, G., 2014. *Speeding Up Dijkstra's Algorithm for All Pairs Shortest Paths,* s.l.: s.n.

Demetriou , D., 2016. GIS-Based Automated Valuation Models (AVMs) for Land Consolidation Schemes.

Dijkstra, E., 1959. A note on two problems in connexion with graphs.. *Numerische Mathematik,* pp. 269-271.

Dimopoulos, T., & Moulas, A., 2016. A Proposal of a Mass Appraisal System in Greece with CAMA System: Evaluating GWR and MRA Techniques in Thessaloniki Municipality. *Open Geosciences,* Issue 8, pp. 675–693,.

Dixon, P. M., 2006. Ripley's K function. In: *Encyclopedia of Environmetrics.* s.l.:s.n.

Droj , G. & Droj , L., 2019. *Spatial Data Mining Using GIS Webservices.* Oradea, s.n.

Droj, G., Droj, L., & Badea, A.-C., 2022. GIS-Based Survey over the Public Transport Strategy: An Instrument for Economic and Sustainable Urban Traffic Planning. *ISPRS International Journal of Geo-Information.*

Droj, G., Kwartnik-Pruc, A. & Droj, L., 2024. A Comprehensive Overview Regarding the Impact of GIS on Property Valuation. *ISPRS Int. J. Geo-Inf.,* 13(6).

Droj, L. & Droj, G., 2010. *Spatial Decision Support System for Property Taxation Modelling.* Istanbul, IBIMA.

Droj, G., 2009. *Introduction to GIS.* s.l.:University of Oradea.

Droj, G. & Droj, L., 2020. *Usage of GIS based application for assessing urban traffic under influence of COVID-19.* Oradea, s.n.

Droj, G., Droj, L., Badea, A.-C., & Dragomir, P. I., 2023. GIS-Based Urban Traffic Assessment in a Historic European City under the Influence of Infrastructure Works and COVID-19,. *Applied Sciences,* p. 1355.

Droj, G., Droj, L. & Kwartnik-Pruc, A., 2021. *GIS Based Analysis For Urban Green Space Accessibility.* Virtualy in Oradea, University of Oradea.

Droj, L. & Droj, G., 2015. Usage of Location Analysis Software in the Evaluation of Commercial Real Properties. *Proceedings of the EMERGING MARKETS QUERIES IN FINANCE AND BUSINESS 2014,* Volume 32, pp. 826–832.

Droj, L., Droj, G., & Ban, O., 2020. Geospatial And Financial Analysis Of The Tourism Sector In Romania,. *Tourism and Hospitality Industry.*

European Space Agency, 2023. *https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-2-msi/document-library.* [Interactive] [Accessed December 2023].

Feizizadeh, B. et al., 2022. A GIS-Based Spatiotemporal Modelling of Urban Traffic Accidents in Tabriz City during the COVID-19 Pandemic. *Sustainability,* 14(7468).

Force, R. T., 2013. *Roads Task Force - Technical Note 10 - What is the capacity of the road network for private motorised traffic and how has this changed over time?,* s.l.: Transport of London .

Franch-Prado, I., Napoletano, B., Rosete-Verges, F. & Billa, L., 2020. Spatial analysis and GIS in the study of COVID-19. A review. *Science of the Total Environment,* Volume 739.

Getis, A. & Ord, J. K., 1992. The Analysis of Spatial Association by Use of Distance Statistics. *Geographical Analysis,* Volume 24, pp. 189-206.

Geymen, A., Yomralioglu, T., & Baz, I., 2008. Developing an urban information system for local governments. *ICE Proceedings Municipal Engineer,* 161(3), pp. 163-173.

Gillian, J. & Gonzales, L., senza an Ripley *'s K Function and pair correlation function.,* s.l.: s.n.

Goh, C., Li, H. & Li, M., 2014. A Comparative Analysis of Domestic and International Tourism Spatial Distribution: Trends and Impacts. *Journal of China Tourism Research, 10(4),,* pp. 388–413.

Goodchild, M. F., 2007. Citizens as sensors: The world of volunteered geography.. *GeoJournal, 69(4), , pp* . 211-221.

Grieves, M. & Vickers, J., 2017. Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems. In: *Transdisciplinary Perspectives on Complex Systems* . Springer, pp. 85-113.

Gudivada, V., Irfan, M., Fathi, E., & Rao, D., 2016. Cognitive Analytics: Going Beyond Big Data Analytics and Machine Learning. In: *Handbook of Statistics.* s.l.:Elsevier, pp. 169-205.

Guo, W., et al., 2017. Urban Analytics: Multiplexed and Dynamic Community Networks. *IEEE COMMUNICATIONS MAGAZINE,.*

Gupta, P., Neelam, J., P. K., S., & Kishor, K., 2009. Geographical Information System in Transportation Planning. *Geospatial World.*

Herrera, J. C. et al., 2010. Evaluation of traffic data obtained via GPS-enabled mobile phones: the Mobile Century field experiment,. *Transportation Research Part C,* pp. 568–583.

Huang, B., Cova, T. J., & Tsou, M.-H., 2018. *Comprehensive Geographic Information Systems.* s.l.:Elsevier.

Huang, B. & Pan, X., 2007. GIS coupled with traffic simulation and optimization for incident response. *Computers, Environment and Urban Systems,* pp. 116-132.

Huang, B. & Wang, J., 2020. Big spatial data for urban and environmental sustainability. *GEO-SPATIAL INFORMATION SCIENCE,* 23(2), pp. 125–140.

Indrajit, A., Van Loenen, B., & Van Oosterom, P., 2019. Assessing Spatial Information Themes in the Spatial Information Infrastructure for Participatory Urban Planning Monitoring: Indonesian Cities. *ISPRS International Journal of Geo-Information,* 8(305).

International Organization for Standardization, 2012. *ISO 19125-1:2012 - Geographic information - Simple feature access - Part 1: Common architecture.* s.l.:ISO.

Jiménez-Espada, M., Marticez García, F. M. & González Escobar, R., 2022. Urban Equity as a Challenge for the Southern Europe Historic Cities: Sustainability-Urban Morphology Interrelation through GIS Tools. *Land,* p. 11.

Karthik, S. & Loui, T. R., 2021. Development of Traffic Congestion Model to Evaluate the Level of Congestion and its Associative Cost for an Urban Arterial Road: a Case Study. *Journal of The Institution of Engineers (India): Series A volume,* Volume 102, pp. 623-632.

Ketzler, B., et al., 2020. Digital Twins for Cities: A State of the Art Review. *Built Environment,* 46(4), pp. 547-573.

Kontgis, K. et al., 2021. *Global land use/land cover with Sentinel-2 and deep learning.* s.l., IGARSS 2021-2021 IEEE International Geoscience and Remote Sensing Symposium.

Kopczewska, K., Churski, P., Ochojski, A. & Polko, A., 2019. SPAG: Index of spatial agglomeration.. *Papers in Regional Science, volume 98, pp* . 2391–2424.

Kutzner, T., Chaturvedi, K. & Kolbe, T. H., 2020. CityGML 3.0: New Functions Open Up New Applications. *Journal of Photogrammetry, Remote Sensing and Geoinformation Science,* Volume 88, pp. 43-61.

Kutzner, T. & Kolbe, T. H., 2018. *CityGML 3.0: Sneak Preview.* Munich, Conference: PFGK18 - Photogrammetry - Fernerkundung - Geoinformatics - Cartography, 37. Jahrestagung in München 2018At:.

Kwartnik-Pruc, A. & Droj, G., 2023. The Role of Allotments and Community Gardens and the Challenges Facing Their Development in Urban Environments—A Literature Review. *Land,* 12(2).

Långström, S. & Fridsäll, E., 2019. *Optimizing traffic flow on congested roads,* STOCKHOLM: KTH ROYAL INSTITUTE OF TECHNOLOGY SCHOOL OF ELECTRICAL ENGINEERING AND COMPUTER SCIENCE.

Leng, L. et al., 2022. A Generalized 9-Intersection Model for Topological Relations. *ISPRS Int. J. Geo-Inf,* 11(118).

Litman, T., 2021. *Well measured - Developing Indicators for Sustainable and Livable Transport Planning, ,* s.l.: Victoria Transport Policy Institute.

Liu, P. et al., 2019. Building footprint extraction from high-resolution images via spatial residual inception convolutional neural network.. *Remote Sensing,* 11(7).

Li, W., 2020. GeoAI: Where machine learning and big data converge in GIScience. *Journal of Spatial Information Science,* Volume 20.

Li, Z., 2021. *Big Social Media Data to Measure Place Connectivity and Human Mobility Dynamics.* s.l., s.n.

Li, Z. et al., 2025. GIScience in the era of Artificial Intelligence: a research agenda towards Autonomous. *Annals of GIS,,* 31(4).

Loidl, M. et al., 2016. GIS and Transport Modeling—Strengthening the Spatial Perspective. *International Journal of Geo-Information.*

Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. R., 2005. *New Developments in Geographical Information Systems: Principles, Techniques, Management and Applications.* Second ed. s.l.:Abridged.

Longley, P., Higgs, G., & Martin, D., 1994. The Predictive Use of Gis to Model Property Valuations. *International Journal 764 of Geographical Information Systems,* Volume 8, pp. 217–235.

Lopez, P. A. et al., 2018. *Microscopic Traffic Simulation using SUMO.* Maui, Hawaii, USA, IEEE, pp. 2575-2582.

Luncan, T. A., Covăcescu, R. & Gavriş (Droj) , G., 2004. *GIS - Urban Management and Control Tool - Case Study Oradea.* Bucharest, Romanian Academy.

Lwin, K. K., & Murayama, Y., 2025. *Handling of Geospatial Data with QGIS.* s.l.:Springer.

Mai, G. et al., 2025. Towards the next generation of Geospatial Artificial Intelligence. *International Journal of Applied Earth Observation and Geoinformation,* Volume 136.

Malczewski, J., & Rinner, C., 2015. *Multicriteria Decision Analysis in Geographic Information Science*. s.l.:Springer nature.

Marsal-Llacuna, M.-L., Tat Leung, Y., & Ren, G.-J., 2011. Smarter Urban Planning: Match Land Use with Citizen Needs and Financial Constraints. *Computational Science and Its Applications - ICCSA 2011* , LNCS Volume 6783, pp. 93-108.

Marsal-Llacuna, M.-L. & Segal, M. E., 2016. The Intelligenter Method (I) for making "smarter" city projects and plans. *Cities,* Volume 55, pp. 127-138.

Marušić, B. G. & Marušić, D., 2012. Behavioural Maps and GIS in Place Evaluation and Design. In: B. M. Alam, ed. *Application of Geographic Information Systems*. London: Intechopen, pp. 113-138.

Masahisa, F. & Hideaki, O., 1982. Multiple equilibria and structural transition of non-monocentric urban configurations.. *Regional science and urban economics,* Volume 12, pp. 161-169.

Mesquitela, J., Elvas, L. B., Ferreira, J. C. & Nunes, L., 2022. Data Analytics Process over Road Accidents Data—A Case Study of Lisbon City. *ISPRS Int. J. Geo-Inf.,* 11(143).

Ming Zhang , et al., 2022. GIS Based Procedural Modeling in 3D Urban Design. *ISPRS Int. J. Geo-Inf.,* 11(10), p. 531.

Ministry of Regional Development and Tourism, 2010. *Order 1466/2010 on the Maintenance and updating of the Local Register of Green Spaces in the Built-Up Area of Localities,* s.l.: MDRT.

Ministry of Public Works Development and Administration, 2023. *Order no. 904/2023 amending and supplementing the Methodological Norms for the application of Law no. 350/2001 on territorial planning and urban planning and on the elaboration and updating of urban planning documentation, approved by the Deputy Prime Minister Order,* s.l.: Official Gazette.

Ministry of Development, Public Works and Administration, 2017. *TECHNICAL NORMS regarding the design, construction and modernization of roads,* Bucharest: Ministry of Development, Public Works and Administration.

Mitchell, A., 2005. *The Esri Guide to GIS Analysis.* s.l.:ESRI Press.

Morar, T., Radoslav, R., Spiridon, L. C. & Păcurar, L., 2014. Assessing Pedestrian Accessibility To Green Space Using GIS. *Transylvanian Review of Administrative Sciences,* 2014, pp. 116-139.

NASA, without year *Giovanni The Bridge Between Data and Science v 4.37.* [Interactive] Available at: https://giovanni.gsfc.nasa.gov/giovanni/ [Accessed March - November 2022].

Nations, U., 2015. *Transforming our world: the 2030 Agenda for Sustainable Development,* s.l.: United Nations.

Nguyen, H. X. et al., 2020. A Hybrid Approach Using GIS-Based Fuzzy AHP–TOPSIS Assessing Flood Hazards along the South-Central Coast of Vietnam. *Applied Sciences,* 10(20).

Olaode, A., Naghdy, G., & Todd, C., 2014. Unsupervised Classification of Images: A Review. *International Journal of Image Processing,* 8(5), pp. 325-342.

Organisation for Economic Co-operation and Development, 2024. *OECD Economic Surveys: Romania,* s.l.: OECD.

Papadopoulou , C.-A. & Giaoutzi, M., 2014. Crowdsourcing as a Tool for Knowledge Acquisition in Spatial Planning. *Future Internet,* pp. 109-125.

Romanian Parliament, 1996. *Law on Cadastre and Real Estate Advertising no. 7,* s.l.: Official Gazette.

European Parliament, Council of the European Union, 2024. *Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an infrastructure for spatial information in the European Community - updated version,* s.l.: European Union.

Oradea City Hall, 2016. *Plan Urbanistic Genera Oradea,* s.l.: s.n.

Oradea City Hall, 2019. *Program for urban regeneration and increase of the quality of green spaces in the municipality of Oradea: Oradea green city 2020-2030,* Oradea: s.n.

Rashid, M. F. A., 2018. Capabilities of a GIS-based multi-criteria decision analysis approach in modelling migration. *Springer Nature, GeoJournal.*

Riedler, B. & Lang, S., 2022. INTEGRATING GEOSPATIAL DATASETS FOR URBAN STRUCTURE ASSESSMENT. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* V(4).

Ripley, B. D., 1981. *Spatial Statistics.* New York: Wiley.

Romanian Government , 2007. *Act nr 24,* s.l.: s.n.

Sani, M. J., & Rahman, A. A., 2018. GIS and BIM integration at Data Level: a Review. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* XLII(4).

Satria, R. & Castro, M., 2016. GIS TOOLS FOR ANALYZING ACCIDENTS AND ROAD DESIGN: A REVIEW. *Transportation Research Proceedings,* Volume 18, pp. 242-247.

Satterthwaite, D., McGranahan, G., & Tacoli, C., 2010. Urbanization and its implications for food and farming. *Philos Trans R Soc Lond B Biol Sci,* pp. 2809-2820.

Sestras, P. et al., 2025. A novel method for landslide deformation monitoring by fusing UAV photogrammetry and LiDAR data based on each sensor's mapping advantage in regards to terrain feature. *Engineering Geology,* Volume 346.

Shahidinejad, J., Kalantari, M., & Rajabifard, A., 2024. 3D Cadastral Database Systems— A Systematic Literature Review. *ISPRS Int. J. Geo-inf.*

Soares Machado, C. A. et al., 2015. Characterization of Black Spot Zones for Vulnerable Road Users in São Paulo (Brazil) and Rome (Italy). *ISPRS Int. J. Geo-Inf.,* 4(2), pp. 858-882.

Songchitruksa, P. & Zeng, X., 2010. Getis–Ord Spatial Statistics to Identify Hot Spots by Using Incident Management Data. *Journal of the Transportation Research,* Volume 2165.

Song, Z., Zhang, H., & Dolan, C., 2020. Promoting disaster resilience: Operation mechanisms and self-organizing processes of crowdsourcing. *Sustainability,* 5(12).

Southworth, F., 1995. *A Technical Review of Urban Land Use – Transportation Models as Tools for Evaluating Vehicle Travel Reduction Strategies, Oak* Ridge: Oak Ridge National Laboratory; Department of Energy, Office of Environmental Analysis and Sustainable Development; Martin Marietta Energy Systems, Inc.

Sperandio, V. G., DIAs, V. E. C., Stempliuc, S. M. & Lisboa-Filho, J., 2018,. Creating Municipal Databases from OpenStreetMap: The Conceptual Database Schema. *Proceedings XIX GEOINFO Campina Grande, PB, Brazil,* Volume XIX, pp. 25-35.

Steffeck, A. W., 2021. Insignificant Impacts of COVID-19 Stay-At-Home Orders on Chicago Air Quality. *DePaul Discoveries,* 10(1).

Sun, C. & Lu, J., 2022. The Relative Roles of Socioeconomic Factors and Governance Policies in Urban Traffic Congestion: A Global Perspective. *Land,* Volume 11.

Sunita & Garg, D., 2018. Dynamizing Dijkstra: A solution to dynamic shortest path problem through retroactive priority queue. *Journal of King Saud University –Computer and Information Sciences.*

Toadere, T., 1992. *Elements of graph theory.* s.l.:Babeș-Bolyai University.

Todd, L., & Donihue, R., 2021. *Crowdsourcing for digital storytelling.* [Interactive] Available at: Esri.com [Accessed 27 September 2022].

UN HABITAT, 2007. *Inclusive and sustainable Urban Planning: A Guide for Municipalities.* Pristina, Kosovo: UNON Publishing Service Section.

van Maarseveen, M., Martinez, J., & Flacke, J., 2019. *GIS in Sustainable Urban Planning and Management: A Global Perspective.* London: Taylor & Francis Group.

Vanegas, C. A., Aliaga, D. G., Benes, B., & Waddell, P., 2009. Interactive Design of Urban Spaces using Geometrical and Behavioral Modeling. *ACM Transaction on Graphics,* 28(10).

Verbavatz, V. & Barthelemy, M., 2019. Critical factors for mitigating car traffic in cities. *PLOS ONE.*

Wang, D., Abdelzaher, T., & Kaplan, L., 2016. *Social Sensing - Building Reliable Systems on Unreliable Data.* S.L.: Morgan Kaufmman.

Wang, Y.-L., Li, L.-B. & Wo, B., 2011. The Mechanism of Urban Land Redevelopment Impact on Traffic Systems. *ICCTP.*

Wang, Y., Peng, H., Xiong, Y., & Song, H., 2023. Spatial relationship recognition via heterogeneous representation: A review. *Neurocomputing,* Volume 533, pp. 116-140.

Wei, C. et al., 2022. The Research Development of Hedonic Price Model-Based Real Estate Appraisal in the Era of Big Data. *Lang (Basel_,* 11(334).

Wilkie, D., Sewall, J., & Ming, C., L., 2010. Transforming GIS Data into Functional Road Models for Large-Scale Traffic Simulation. *IEEE TRANSACTIONS ON VISUALIZATION AND COMPUTER GRAPHICS.*

Worboys, M. & Duckham, M., 2004. *GIS: A Computing Perspective.* s.l.:CRC Press,.

World Bank Group, 2021. *Demographic trends and urbanization, , Washington* : World Bank Group.

Wuest, B. A., & Mioc, D., 2007. *Visualization and modeling of traffic congestion in urban environments,.* Aalborg University, Denmark, s.n.

Xin, L. et al., 2017. A State-of-the-Art Review on the Integration of Building Information Modeling (BIM) and Geographic Information System (GIS). *ISPRS Int. J. Geo-Inf,* 6(53).

Xu, C. et al., 2021. A Modular Remote Sensing Big Data Framework. *IEEE Transactions on Geoscience and Remote Sensing,* Volume 60.

Yamada, H., 2024. Moran's I for Multivariate Spatial Data. *Mathematics,* 12(17).

Yılmaz, O., Sürmenelib, H. G., & Alkan, M., 2023. Spatial-Land use planning system data model proposal for edition II of LADM. *Geocarto International,* 38(1).

Ying, Y., Koeva, M., Kuffer, M., & Zevenbergen, J., 2023. Toward 3D Property Valuation—A Review of Urban 3D Modelling Methods for Digital Twin Creation. *ISPRS Int. J. Geo-Inf,* 12(2).

Yu, D. & Fang, C., 2023. Urban Remote Sensing with Spatial Big Data: A Review and Renewed Perspective of Urban Studies in Recent Decades. *Remote Sensing,* 15(1307).

Yuan, S., Zhao, X., & An, Y., 2014. Identification and optimization of traffic bottleneck with signal timing. *Journal of Traffic and Transportation Engineering,* pp. 353-361.

Zadeh, L. A., 1965. Fuzzy sets. *Information and Control,* 8(3), pp. 338-353.

Zhang, C., Wei, S., Ji, S. & Lu, M., 2019. Detecting large-scale urban land cover changes from very high resolution remote sensing images using cnn-based classification. *SPRS International Journal of Geo-Information,* Volume 8.

Zhang, T., & Huang, X., 2018. Monitoring of urban impervious surfaces using time series of high-resolution remote sensing images in rapidly urbanized areas: A case study of Shenzhen. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing,* 11(8), pp. 2692–2708.

Zhang, W., Tan, G., Ding, N., & Wang, G., 2012. Traffic Congestion Evaluation and Signal Control Optimization Based on Wireless Sensor Networks: Model and Algorithms. *Mathematical Problems in Engineering, Hindawi Publishing Corporation.*

Zhang, X., Zhou, Y., & Luo, J., 2022. Deep learning for processing and analysis of remote sensing big data: a technical review. *Big Earth Data,* 6(4), pp. 527-560.

Oradea Metropolitan Area, 2021. *Integrated Urban Development Strategy for the Municipality of Oradea and the Oradea Metropolitan Area for the period 2021-2027.*

[Interactive] Available at: https://zmo.ro/download/SIDU.pdf [Accessed 2025].