GaiaVision

NASA SPACE APPS CHALLENGE 2025

ELVIS AVDULI
MARIA TEREZA VAKONDIOU

Περιεχόμενα

0.The Challenge

Climate change brings about new complexities to consider for maintaining the wellbeing of society and the environment in cities. Natural resources, ecosystems, and existing infrastructure all must be monitored to ensure human quality of life remains high. Your challenge is to demonstrate how an urban planner can use NASA Earth observation data to develop smart strategies for city growth that maintain both the wellbeing of people and the environment.

1. Executive Summary

1.1. Project Name

GaiaVision

1.2. Mission Statement

GaiaVision is an innovative, AI-powered digital twin platform designed to bridge the gap between NASA's vast Earth observation data and the pressing environmental challenges of modern cities. Our mission is to empower engineers and urban planners with predictive insights and interactive simulation tools to design and manage urban environments that significantly enhance the quality of life for all citizens, fostering sustainable, healthy and resilient communities.

1.3. Core Value Proposition

Cities today grapple with complex environmental issues like the Urban Heat Island effect, air pollution and flood risk, which directly impact citizens' well-being. While satellite data exists to understand these issues, it often remains inaccessible for practical, day-to-day design and planning. GaiaVision solves this by integrating multi-source NASA/ESA data with local urban metrics into a single, intuitive web application tailored for engineers and urban planners. The platform doesn't just monitor; it predicts and simulates. Through advanced machine learning and granular scenario simulations, GaiaVision allows professionals to visualize the potential impact of interventions—from altering a single plot of land (pixel-level changes) to large-scale retrofitting of old buildings—before any real-world resources are committed. This transforms urban planning and engineering from a reactive process into a proactive, data-driven design strategy, enabling smarter investments that maximize environmental, social, and quality-of-life benefits.

By translating complex satellite data into actionable intelligence for the built environment professionals, GaiaVision aims to be the essential tool for building the healthy, sustainable and people-centric cities of the future.

2. Introduction & Problem Statement

2.1. The Challenge of Modern Urbanization

For the first time in history, more than half of the world's population resides in urban areas, a trend that continues to accelerate. While cities are engines of innovation and economic growth, this rapid urbanization places unprecedented strain on infrastructure, natural resources and the well-being of inhabitants. The design and management of urban fabric directly influence the quality of life, affecting everything from public health to social equity.

2.2. Specific Problems Addressed

GaiaVision is designed to tackle the most critical and interconnected environmental problems that degrade urban quality of life, including:

- **Urban Heat Island (UHI) Effect & Air Pollution Trapping:** The proliferation of impervious surfaces and specific urban geometries can trap heat and pollutants. GaiaVision maps how air circulates (or stagnates), showing where heat is trapped and how pollutants accumulate, leading to health risks and discomfort.
- **Air Quality Degradation:** Urban centers are hotspots for emissions. Understanding the spatial distribution and concentration of pollutants like particulate matter ($PM_{2.5}$) and nitrogen dioxide (NO_2) is crucial for effective mitigation in urban design.
- **Flood Risk:** Inadequate planning and impervious surfaces increase vulnerability to flash floods. Identifying high-risk areas is essential for resilient infrastructure.
- **Unsustainable Spatial Planning:** Urban expansion often occurs without a strategic assessment of its environmental footprint, locking cities into unsustainable patterns that harm long-term quality of life.

2.3. The Data Gap

NASA and other space agencies provide a wealth of free, open-access Earth observation data that holds the key to understanding and mitigating these urban challenges. However, a significant gap exists between the availability of this complex, large-scale data and its practical application by engineers and urban planners. The data often requires specialized expertise to process and interpret, making it an underutilized resource.

GaiaVision is conceived to bridge this very gap. It addresses the critical need to translate raw satellite data into clear, actionable, and location-specific insights for engineering and planning professionals, empowering them to move from simply understanding problems to actively simulating and implementing effective design solutions that improve living conditions.

3. The GaiaVision Solution

3.1. Concept: The Urban "Digital Twin"

GaiaVision's core innovation is the creation of a dynamic **Digital Twin** for cities. This twin is a virtual, data-driven replica of a physical urban environment. It serves as a virtual sandbox for engineers and planners, allowing them to see the current state of their city's environmental health and, most importantly, to test future design scenarios in a risk-free digital environment.

3.2. High-Level Overview

The GaiaVision platform operates on an integrated data pipeline. It ingests multi-spectral data from NASA's fleet of Earth-observing satellites and combines it with local urban data. This fusion is processed through a powerful analytics engine powered by Machine Learning. The results are then visualized in an intuitive, web-based application that presents complex geospatial data as interactive layers on a map, alongside dashboards and simulation tools. The process transforms terabytes of satellite imagery into clear answers to critical design questions: *Where does air stagnate and pollution accumulate? What is the flood risk for this new development? What is the environmental benefit of retrofitting that old building?*

3.3. Key Differentiators

GaiaVision is designed to be more than just a data visualization tool. Its key differentiators are:

- **Predictive, Not Just Descriptive:** Uses ML models to forecast future urban environmental trends and risks based on development patterns.

- **Granular Interactive "What-If" Scenarios:** This is the platform's cornerstone feature. Engineers and planners can actively propose interventions at a granular level (e.g., changing a single pixel on the map to represent a new building material, a green roof, or a small park) and the model will simulate the resulting environmental impacts, such as changes in local airflow, temperature, or pollution dispersion.
- **Actionable Intelligence for Built Environment Professionals:** The platform is specifically tailored for engineers and urban planners, providing them with the high-fidelity, data-driven insights needed for sustainable design and construction.

4. Technical Architecture & Data Pipeline

The GaiaVision platform is built on a robust, three-stage technical architecture designed to transform raw, multi-source data into an actionable urban digital twin. This end-to-end pipeline ingests diverse datasets, processes them through a powerful analytics engine and delivers clear, visual insights through an intuitive user interface.

4.1. Data Acquisition & Ingestion

This first layer is responsible for the automated collection of our four core data sources, which together provide a comprehensive view of the urban environment.

- **Copernicus Earth Observation Data:** Serves as the primary data backbone. We utilize the **Copernicus Data Space Ecosystem** to access the full range of **Sentinel missions**.
    - **Sentinel-1:** Provides C-band Synthetic Aperture Radar (SAR) data. This offers all-weather, day-and-night capability, which is crucial for consistent flood mapping, monitoring ground subsidence and analyzing urban structure, regardless of cloud cover.
    - **Sentinel-2:** Provides high-resolution (10m) multi-spectral optical imagery. This is essential for calculating vegetation indices (NDVI), land cover classification and monitoring urban green spaces.
- **High-Resolution SAR Data:** To enhance detail in critical areas, we integrate commercial SAR data from providers like **ICEYE**. This data provides finer spatial resolution than Sentinel-1, enabling more detailed

elevation modeling and structural analysis for precise identification of buildings and infrastructure.

- **Land Cover Classification Data:** The **CORINE Land Cover (CLC)** dataset provides a standardized, pan-European land cover inventory with 44 thematic classes. This is a key resource for initial, large-scale land use classification and for understanding the macro-scale environmental context of a city, which can be integrated with more local analyses.
- **High-Resolution Topographic Data:** For high-fidelity 3D urban modeling, we integrate Light Detection and Ranging (LiDAR) data where available. For instance, for pilot studies in Greece, we will utilize the **LiDAR Dataset** (accessed via OpenTopography) to generate precise Digital Elevation Models (DEMs) and Digital Surface Models (DSMs). This data is critical for accurate building height estimation, solar potential analysis, and detailed flood risk modeling.

4.2. Data Processing, Analytics & Modeling

This is the computational core of GaiaVision, where the raw data from our four core sources is harmonized and transformed into intelligence.

- **Data Harmonization & Geoprocessing:** All ingested datasets are projected into a common coordinate system and spatial resolution. **Sentinel-2** optical data, **Sentinel-1/ICEYE** radar data, **CLC** land cover vectors, and **LiDAR** point clouds are fused to create a unified, multi-dimensional data cube for each city, ready for analysis.
- **Machine Learning for Pattern Recognition & Prediction:**
    - **Urban Morphology & Local Climate Zone (LCZ) Classification:** We will employ machine learning models to fuse **Sentinel-2** imagery (for surface material), **SAR** data (for texture and structure), and **LiDAR**-derived building heights and terrain information. This fusion allows for the automatic classification of urban typologies, which is fundamental for analyzing urban canyon effects and identifying areas prone to heat and pollution accumulation.
    - **Predictive Modeling for Intervention Planning:** By analyzing time-series data from the **Sentinel missions**, we can train models to forecast the environmental impact of urban development, such as the effect of replacing vegetation with impervious surfaces on the local microclimate.

- **Scenario Simulations ("What-If" Analysis):**
    - **Green Intervention Simulator:** This tool allows users to simulate the impact of adding green infrastructure. By programmatically modifying the land cover classification (informed by **CLC** and **Sentinel-2**) in a target area, the system recalculates environmental metrics like land surface temperature and air quality based on established physical relationships.
    - **Building Retrofitting Impact Analysis:** This module models the benefits of energy-efficient building retrofits. It leverages **LiDAR** data for accurate building geometry and solar exposure analysis, and **SAR** data for structural assessment, quantifying outcomes like reduced energy demand and lower urban heat contribution.
    - **High-Fidelity Flood Impact Modeling:** This model combines the precise topography from **LiDAR DEMs** with land cover data from **CLC** and near-real-time rainfall data to create detailed surface runoff models. This identifies properties and infrastructure at the highest risk of flash flooding, providing a more accurate assessment than models using standard elevation data.

4.3. Platform & Visualization Layer

This final layer translates the complex analytical results into clear, actionable insights for a non-technical audience through an accessible web platform.

- **Interactive Web Application:** A user-friendly portal where all insights are delivered.
- **Dynamic Map Interface:** The central feature is an interactive map that visualizes the processed data as thematic layers, including:
    - **Environmental Risk Layers:** Heat vulnerability maps (derived from **Sentinel-2 & LiDAR**), flood risk zones (from **LiDAR & SAR**), and pollution dispersion models.
    - **Urban Context Layers:** Land use (**CLC**), building footprints and heights (**LiDAR & SAR**), and vegetation health (**Sentinel-2**).

    - **Scenario Results:** Visual side-by-side comparisons showing the projected outcomes of "What-If" simulations, such as the cooling effect of a new park or the flood mitigation of a restored natural area.
- **Personalized Dashboards:** Users can access tailored reports that quantify the potential benefits of specific actions, such as the energy savings and carbon reduction achievable from retrofitting their own building, with calculations grounded in the platform's analysis of **LiDAR** and **Sentinel** data.

5. Functional Capabilities & Use Cases

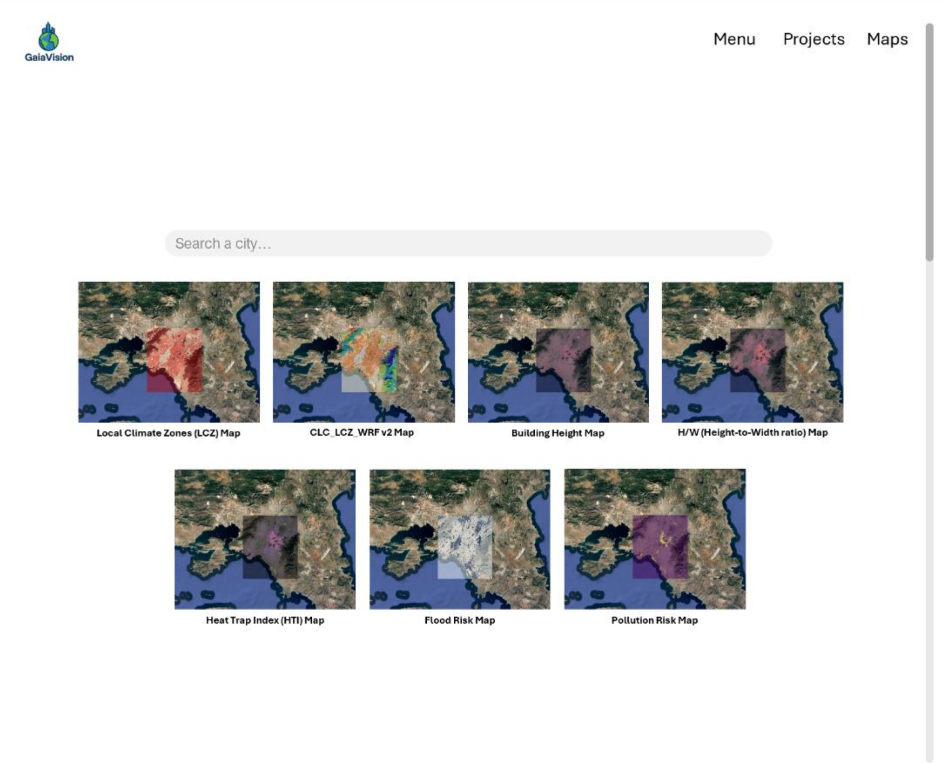
GaiaVision transforms complex Earth observation data into practical tools for engineers and urban planners. The platform's core functionalities are designed to address specific urban challenges through actionable insights and predictive simulations.

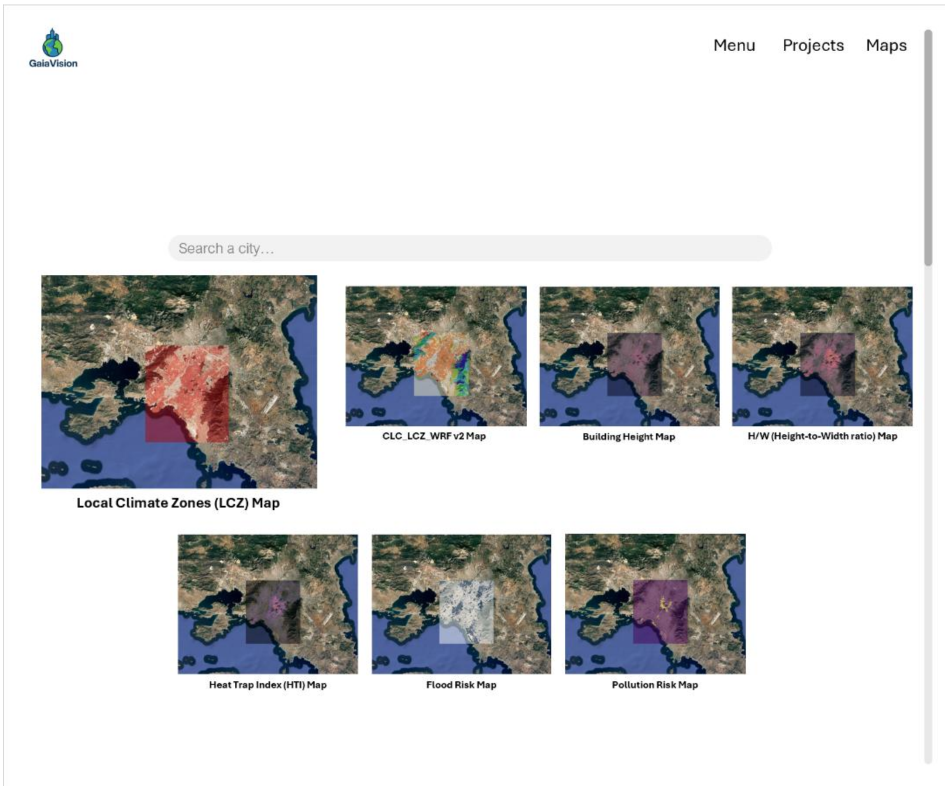
5.1. Core Features

- **Environmental Monitoring Dashboard**
    - **Urban Airflow and Pollution Trapping Maps:** Generate maps that show how the urban geometry influences airflow, identifying hotspots where heat and pollutants (like PM2.5 and NO_2) are likely to accumulate, using data from NASA Earthdata and Copernicus.
    - **Flood Risk Zonation:** Create dynamic flood risk maps by integrating precipitation data, land cover imperviousness, and elevation models.
- **"What-If" Scenario Simulator**
  This is the cornerstone analytical tool of GaiaVision. It allows engineers and planners to test the potential impact of urban interventions at a granular level before any real-world investment**.**
    - **Pixel-Level Urban Design:** Users can digitally modify specific areas on the map (e.g., change a parking lot to a park, add a green roof to a building, alter building density). The platform then recalculates key environmental metrics for the area, predicting outcomes such as:
        - Changes in local wind patterns and pollution dispersion.

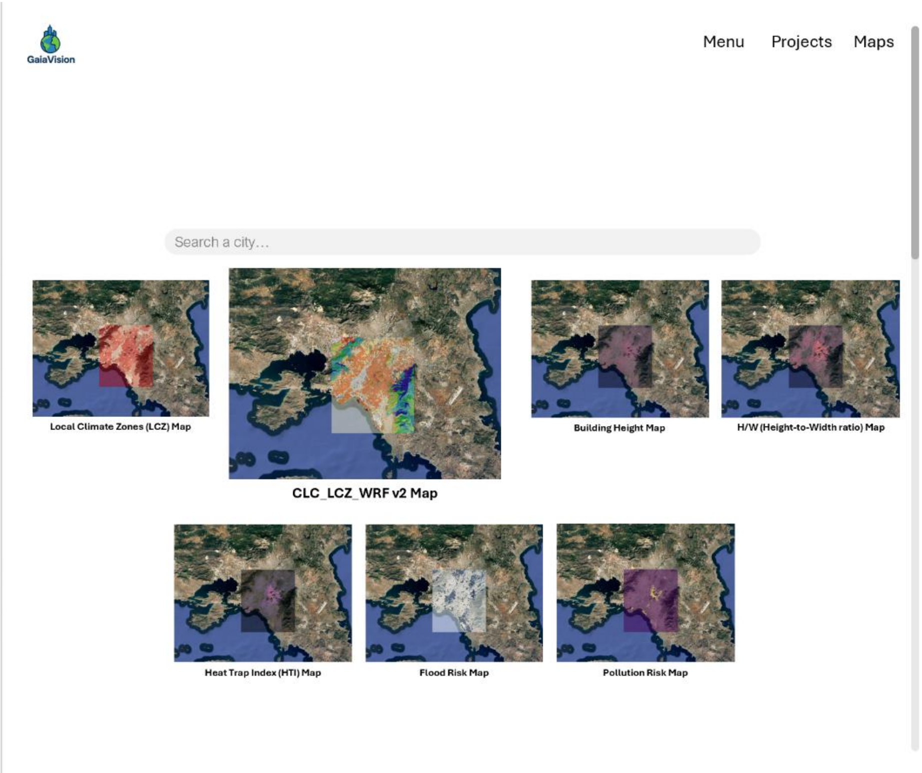
        - Reduction in local land surface temperature.
        - Change in surface runoff potential.
    - **Building Retrofitting Simulation:** Model the environmental benefit of renovating old buildings. Planners and developers can assess the positive impact of implementing energy-efficient materials, green roofs, or improved insulation on the surrounding microclimate and overall urban environmental footprint.
- **Vulnerability and Exposure Analysis**
  By layering environmental hazard data with population data, GaiaVision identifies communities that are most exposed to environmental risks, ensuring equitable planning.

5.2. Practical Application - Case Study: Athens, Greece

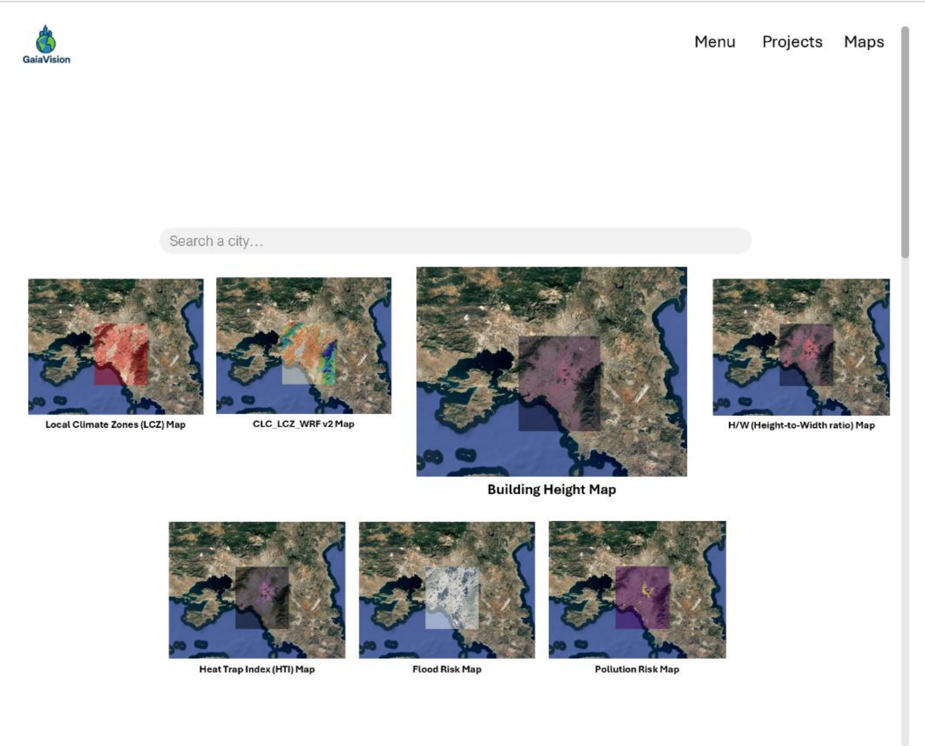




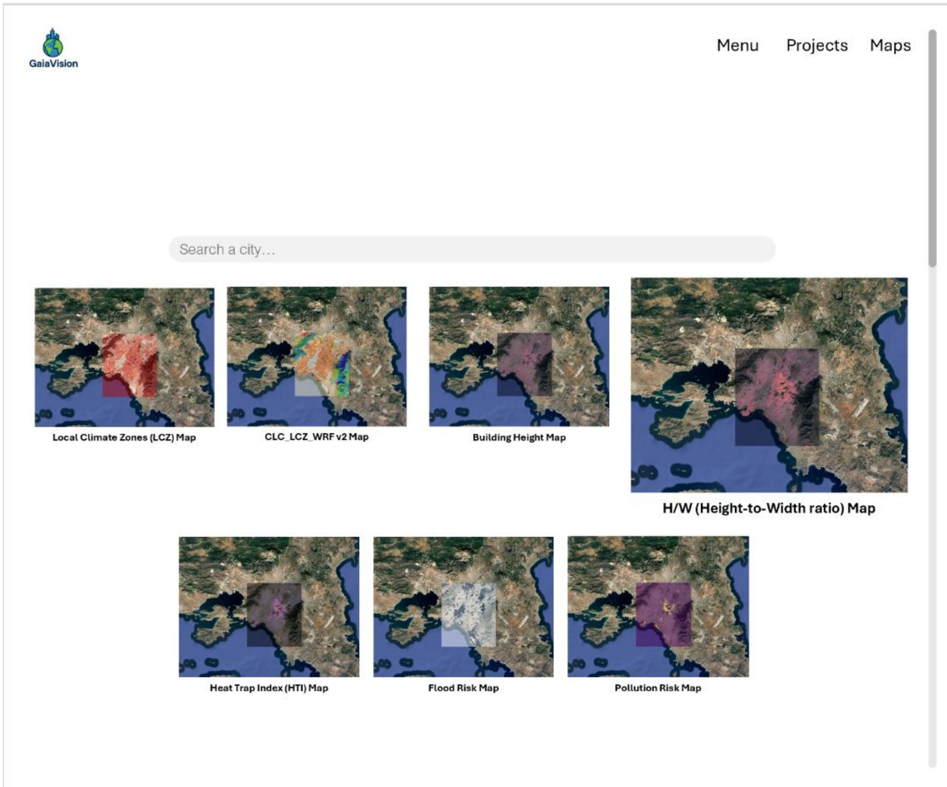
An LCZ map helps urban planners and researchers understand the city's physical structure and its influence on local climate patterns. By categorizing areas based on land cover and built environment characteristics, it guides targeted strategies for climate adaptation and urban design.



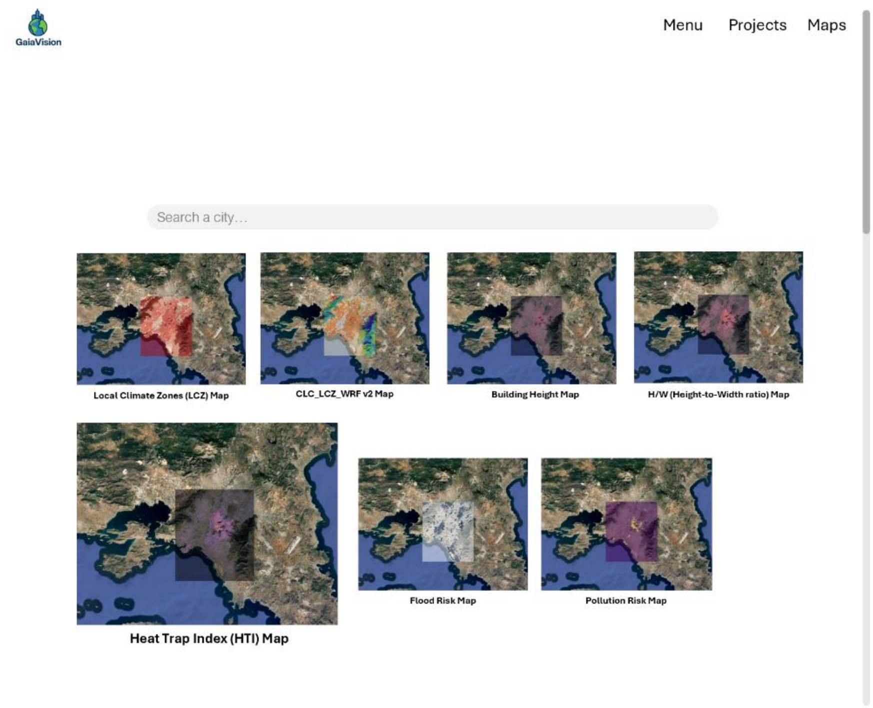
The CLC_LCZ WRF v2 map shows the city's land cover and urban structure, combining CORINE Land Cover for natural areas with Local Climate Zones for urban areas. It distinguishes built-up surfaces, vegetation and water and provides a 100 m resolution WRF-ready dataset for urban climate and meteorological modelling.



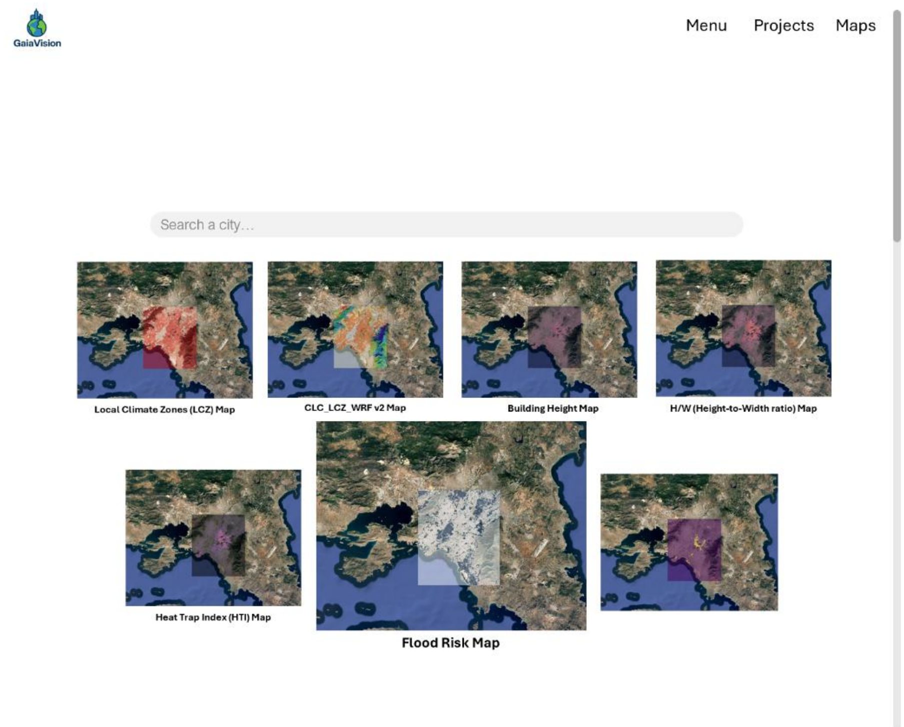
A building height map visually displays the vertical dimensions of structures across a city, showing variations in height and density. Such maps help planners and engineers analyze shading, airflow and urban microclimate effects for better design and climate adaptation strategies.



An H/W (Height-to-Width) map illustrates the ratio of building height to the width of streets or open spaces around them. This visualization helps urban planners understand urban canyon effects, airflow patterns, sunlight penetration and how the built environment influences local microclimates.



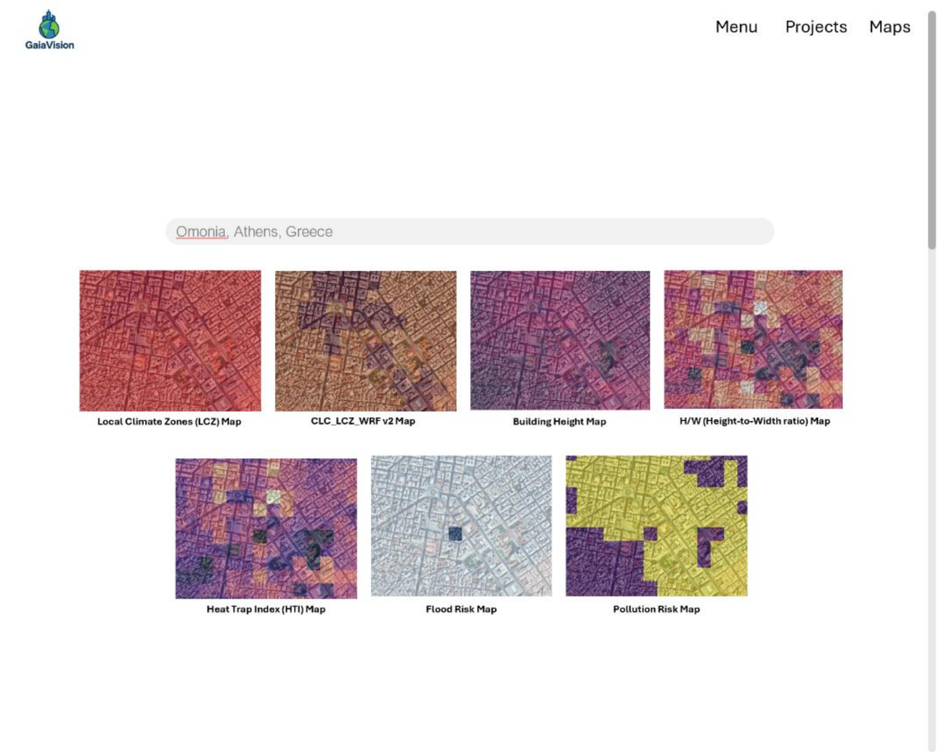
A Heat Trap Index (HTI) map visualizes areas in a city where heat tends to accumulate due to urban materials, building density and limited ventilation. It helps planners identify hotspots, assess the Urban Heat Island effect and target interventions like greening, reflective surfaces or improved airflow to reduce local temperatures.

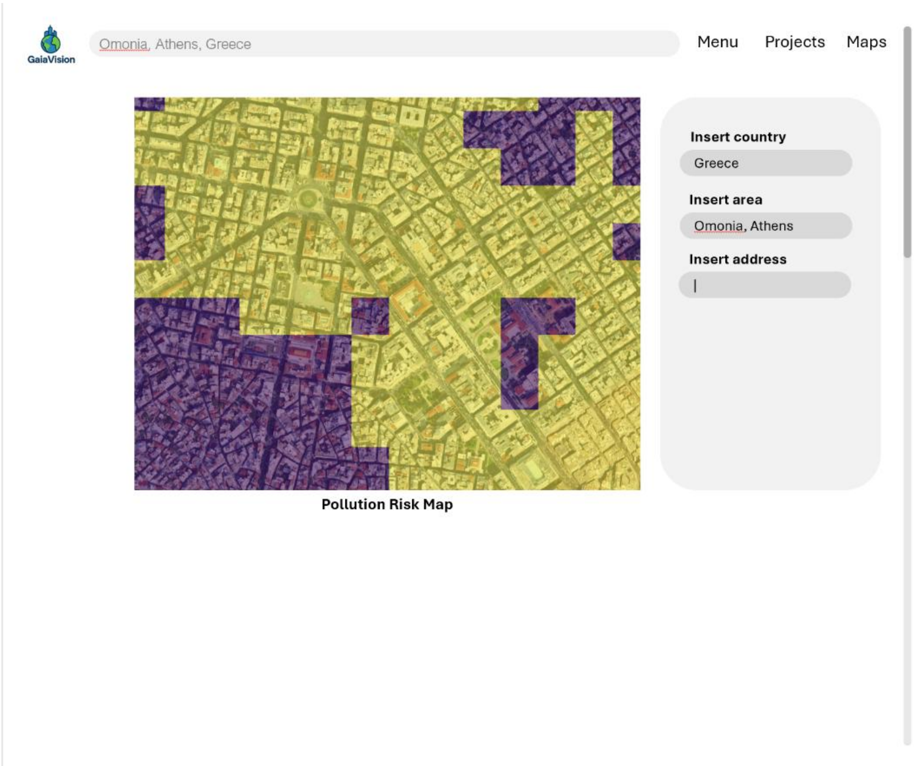


A Flood Risk Map highlights areas within a city that are susceptible to flooding due to rainfall, river overflow, drainage limitations or sea-level rise. It guides urban planners and engineers in designing resilient infrastructure, emergency response strategies and land-use planning to minimize flood damage and protect communities.

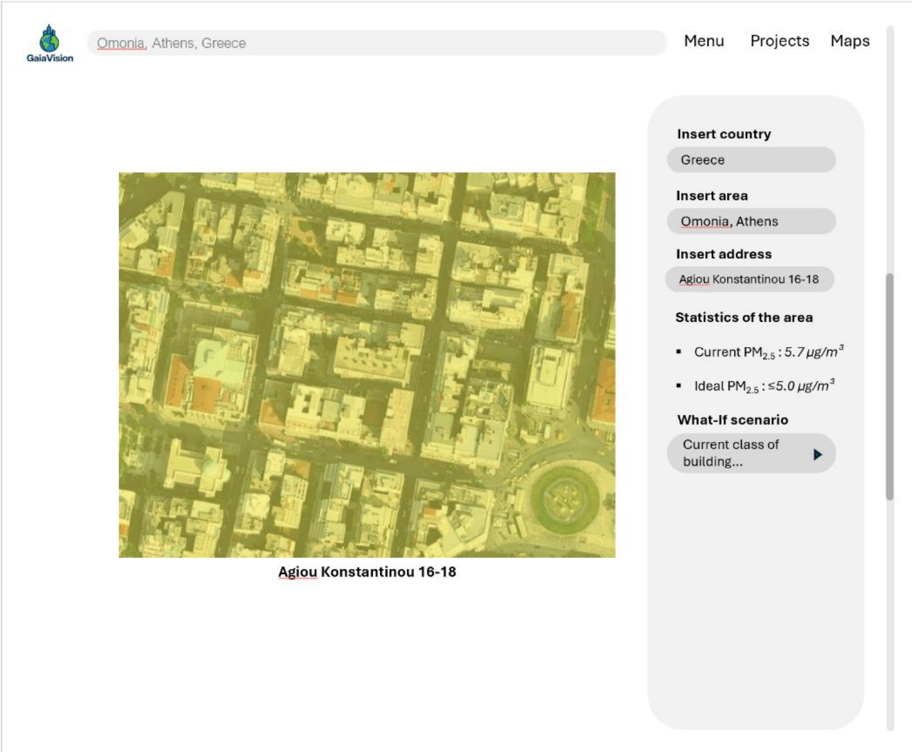
A Pollution Risk Map shows areas of a city exposed to high levels of air, water or soil pollutants. It helps urban planners and public health officials identify hotspots, prioritize mitigation measures and design strategies to reduce environmental and health risks.

Example: GaiaVision interface showing seven urban analysis maps for Omonia, Athens, including:



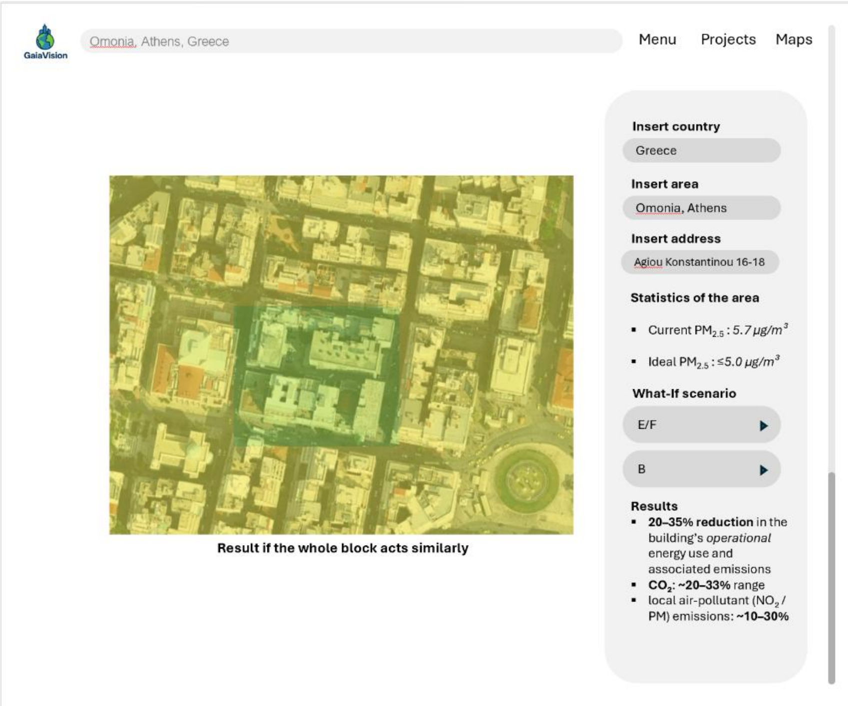


Here we see a close-up of Omonia, Athens, where the map highlights areas with elevated pollution risk.



The urban planner enters a specific address (e.g., Agiou Konstantinou 16-18). The interactive maps then zoom in to this location, allowing a detailed view of relevant metrics such as pollution risk, building height, heat traps and flood zones.

After entering the address, GaiaVision provides detailed statistics for the area, such as current $PM_{2.5}$ levels (5.7μg/m^3) compared to the ideal (≤5.0μg/m^3). Users can also explore ‘What-If’ scenarios, including the current building class and potential improvements.



GaiaVision simulates the impact of upgrading a building from class E/F to B. The map dynamically shows how pollution risk decreases and operational energy use, CO_2 and local air pollutants are reduced.

6. Beneficiaries & Impact

GaiaVision is designed as a multi-stakeholder platform, delivering targeted value and generating significant impact for a diverse range of users, from city hall decision-makers to community residents.

6.1. Primary Users & Benefits

- **Engineers & Urban Planners (Primary Target Group):**
    - **Informed, Data-Driven Design:** Obtain scientific, quantifiable data on the environmental consequences of design choices, from master plans to individual building retrofits.
    - **Granular Scenario Testing:** Use the pixel-level "What-If" simulator to optimize designs for sustainability and resident well-being before construction begins, minimizing negative externalities.
    - **Risk Mitigation:** Proactively identify and design solutions for flood risk and pollution hotspots, creating more resilient infrastructure.

- **Demonstrating Project Value:** Quantify the environmental and social benefits of sustainable designs and retrofitting projects for clients and regulatory approvals.

6.2. Environmental & Social Impact

GaiaVision's impact extends beyond its direct users, contributing to broader global goals:

- **Direct Environmental Impact:** By enabling targeted urban greening and sustainable planning, the platform directly contributes to:
  - **Mitigation of the Urban Heat Island Effect,** reducing energy consumption and associated greenhouse gas emissions from air conditioning.
  - **Improved Air Quality** through strategic vegetation planning that captures particulate matter.
  - **Enhanced Water Security** and reduced flood damage through better watershed management and the promotion of permeable surfaces.
- **Public Health Advancement:** The platform helps tackle critical health threats by identifying areas where environmental hazards most significantly impact populations. This enables proactive public health measures, reducing morbidity and mortality related to heat stress, respiratory illnesses, and flood events.
- **Alignment with Global Frameworks:** GaiaVision is intrinsically aligned with key international sustainability agendas, most notably the **United Nations Sustainable Development Goals (SDGs)**. It provides a direct pathway for cities to measure and advance their progress towards:
  - **SDG 11 (Sustainable Cities and Communities):** Making cities inclusive, safe, resilient, and sustainable.
  - **SDG 13 (Climate Action):** Taking urgent action to combat climate change and its impacts.
  - **SDG 3 (Good Health and Well-being):** Ensuring healthy lives and promoting well-being for all ages.

By democratizing access to NASA and other satellite data, GaiaVision empowers all levels of society to participate in building healthier, more equitable, and more resilient urban environments.

7. Future Roadmap & Enhancements

The initial version of GaiaVision establishes a powerful foundation for data-driven urban planning. To ensure its long-term impact and evolution into an indispensable tool for cities worldwide, we have outlined a strategic roadmap for future development. These enhancements are designed to deepen the platform's analytical capabilities, broaden its user engagement, and increase its practical utility.

7.1. Advanced AI Integration for Proactive Forecasting

- **Objective:** Shift to proactive, forward-looking insights for long-term planning.
- **Implementation:** Develop more sophisticated ML models for predictive urban analytics.
- **Capabilities:**
    - **Predictive Urban Analytics Model:** Forecast the future environmental evolution of districts based on how they are being built, predicting long-term UHI intensity, pollution levels, and flood risk under different development scenarios.

7.2. IoT & Citizen Science Integration

- **Objective:** Create a high-resolution, ground-truthed data network.
- **Capabilities:**
    - **IoT Sensor Network Integration:** Allow streaming data from urban sensors (e.g., air quality monitors, weather stations) directly into the platform for real-time model validation and calibration.

7.3. Economic Analysis & Policy Module

- **Objective:** Empower decision-makers with a clear understanding of the financial implications.
- **Capabilities:**

- **Cost-Benefit Analysis for Retrofitting:** Provide estimates for building renovation projects and quantify their long-term environmental and economic benefits (e.g., energy savings, increased property values).

7.4. Immersive Visualization with VR/AR

- **Objective:** Make urban planning and client presentations more intuitive.
- **Capabilities:**
    - **Virtual Reality (VR) Planning Studio:** Enable engineers and planners to "walk through" a 3D model of a neighborhood and visually experience the environmental impact of different design scenarios.

This roadmap ensures GaiaVision will continuously evolve to remain at the forefront of sustainable urban design and engineering.

8. Conclusion

The challenges facing modern cities are complex and directly impact the quality of life of their inhabitants. Addressing them requires a paradigm shift towards proactive, evidence-based urban design and engineering. GaiaVision is conceived to be the catalyst for this shift.

By harnessing the unparalleled power of NASA Earth observation data, GaiaVision translates vast, complex geospatial information into a clear, actionable digital twin for engineers and urban planners. It moves beyond simply visualizing problems to actively simulating design solutions at a granular level, empowering professionals to answer the critical question: "How can we build better for the well-being of our community?"

The platform's core value lies in its unique ability to make space-based data directly relevant and usable for the professionals who shape our urban fabric. Through its interactive "What-If" scenarios and focus on micro-level impacts, it provides a powerful tool for creating sustainable, healthy and people-centric cities.

As an entry for the NASA Space Apps Challenge, GaiaVision perfectly embodies the spirit of the hackathon: to use open data to solve global challenges and improve life on Earth. This project demonstrates a tangible, scalable and impactful application of NASA's satellite assets to empower those who build our world, ultimately enhancing the quality of life for all city dwellers.

Our vision for GaiaVision is a future where every city is designed with intelligence and foresight, ensuring the well-being of its inhabitants for generations to come. This platform is a decisive step toward turning that vision into a reality.