Taxpayers' Services Division
Central Directorate for Cadastral, Cartographic and Land Registration Services

Joint PCC EuroGeographics CLRKEN Conference and Plenary Meeting

Modern Cadastre for a Competitive, Sustainable and Secure Europe

TERRITORIAL SURVEYS SUPPORTED BY ARTIFICIAL INTELLIGENCE ALGORITHMS BASED ON SEMANTIC SEGMENTATION OF ORTHOPHOTOS



Taxpayers' Services Division
Central Directorate for Cadastral, Cartographic and Land Registration Services

Geomatics for Cadastral Applications Office

Lucio Tropia

Dublin, November 3-5 2026

Framing the scope



CONTROL OF THE TERRITORY

…to improve the effectiveness and sustainability of cadastral updates while enhancing data quality to curb real estate tax evasion and avoidance



A NEW PROCESS…

….for analyzing mapping data quality and conducting comprehensive territorial surveys, using innovative tools to detect cadastral discrepancies



…POWERED BY COMPUTER VISION

…to analyze digital images, recognize patterns, detect objects, and extract useful insights using ***deep learning models***.

Framing the scope



HOW DOES IT WORK?

Photointerpretation of cadastral maps overlaid on orthophotos highlights discrepancies or unregistered features.

AI generates an initial proposal to automatically identify unmapped properties, while the system automatically accounts for inaccuracies in building placement and map geometries.



AI ACT COMPLIANCE

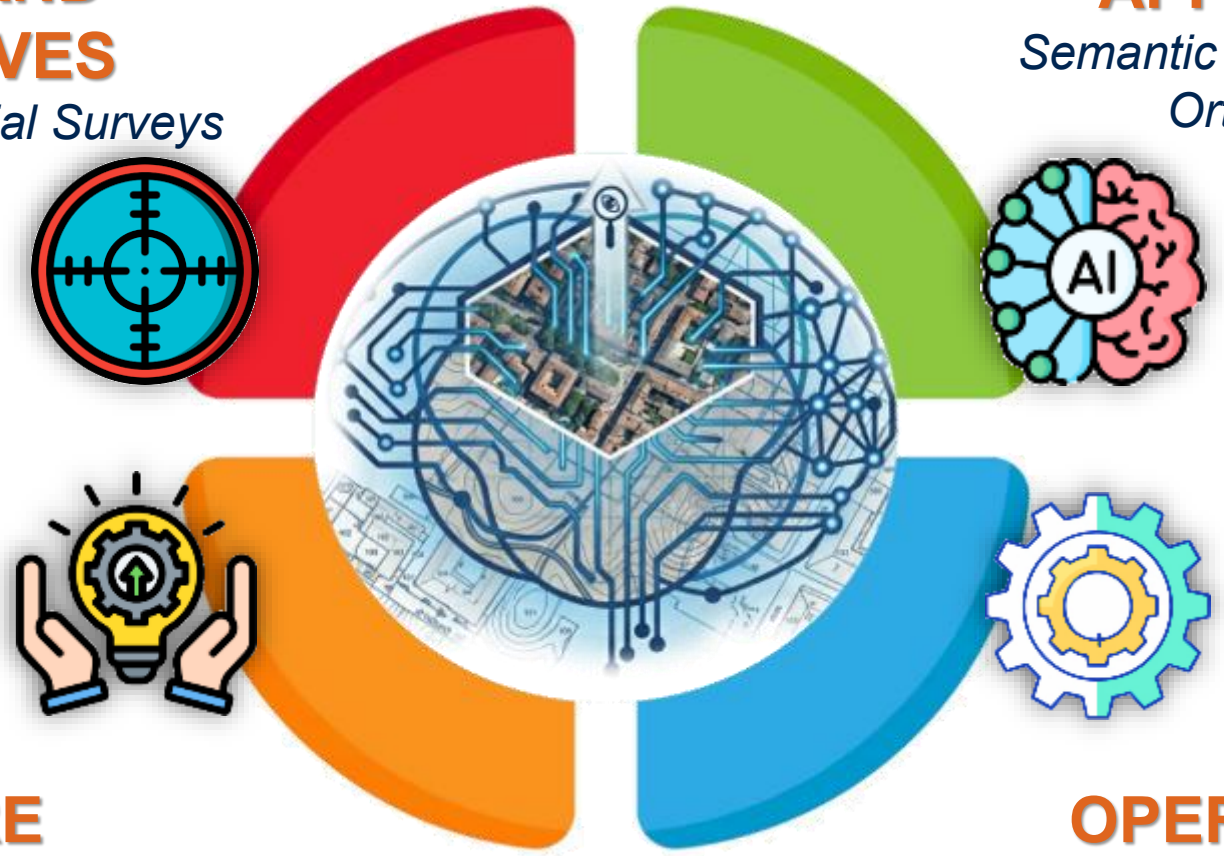
AI OUTPUT AS A MERE PROPOSAL

Technicians review and classify AI-detected missing geometries on a dedicated platform, manually integrating any features the AI might have missed.

All cadastral assessments undergo **human review** and compliance clearance before approval.

SCOPE AND OBJECTIVES
Innovating Territorial Surveys

APPLYING AI
Semantic Segmentation of Orthophotos



FUTURE OUTLOOK
Exploring Further Applications

OPERATIONAL WORKFLOW
Photointerpretation Platform

SCOPE AND OBJECTIVES

Innovating Territorial Surveys



APPLYING AI

Semantic Segmentation of Orthophotos

FUTURE OUTLOOK

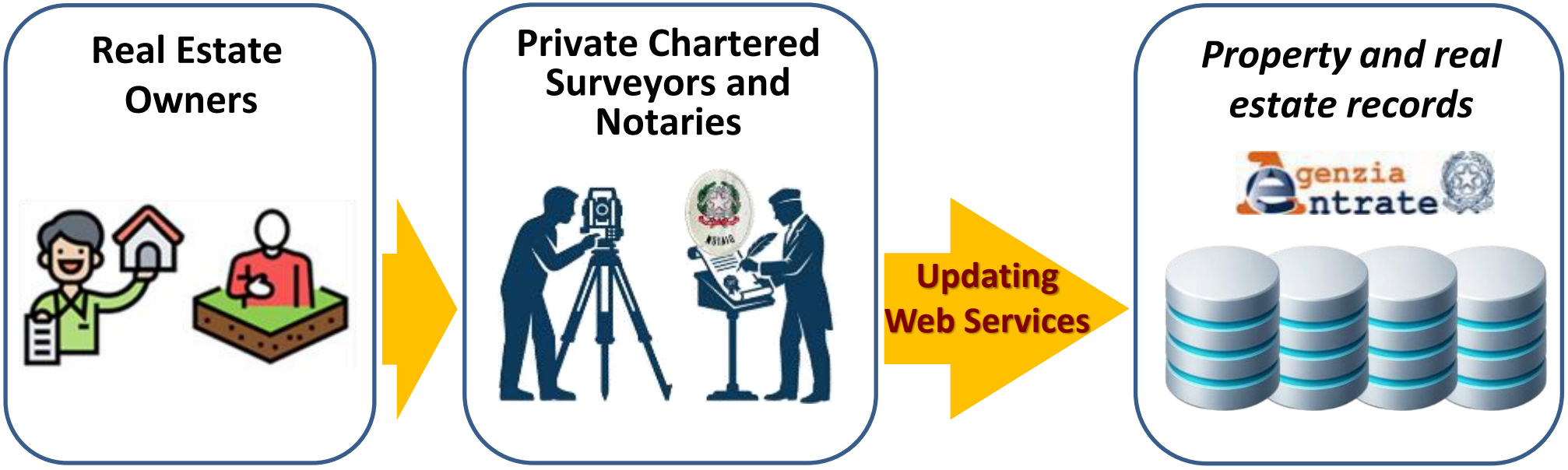
Exploring Further Applications

OPERATIONAL WORKFLOW

Photointerpretation Platform

UPDATE OF THE ITALIAN CADASTRAL SYSTEM

The updating of property and real estate records lies with the respective property owners, who act through licensed surveyors and notaries, under the supervision of the *Agenzia delle Entrate*.



What if the updating process is improper or incomplete?



Institutional mandate to intervene to ensure alignment between database records and the actual state of properties and ownership.

Regulations reaffirm the Agency's responsibility to intervene when declarations are missing, thereby keeping the registries up to date

Regarding the Land Cadastre, these provisions include the practice of '***Lustrazione***', a five-yearly territorial inspection (the term evokes the sacred purifying ceremonies performed periodically by the ancient Romans).

THE "*LUSTRAZIONE*"

Highlighting the term ***Lustrazione*** used for the mandatory, **periodic inspections** of the national territory…

…etymologically, this word carries a **sacred** connotation.

First appearing in the 1886 Land Cadastre founding law and reaffirmed by subsequent legislation, it derives from the Latin *luere* ("to purify"), referring to the purification ceremonies performed periodically by the ancient Romans







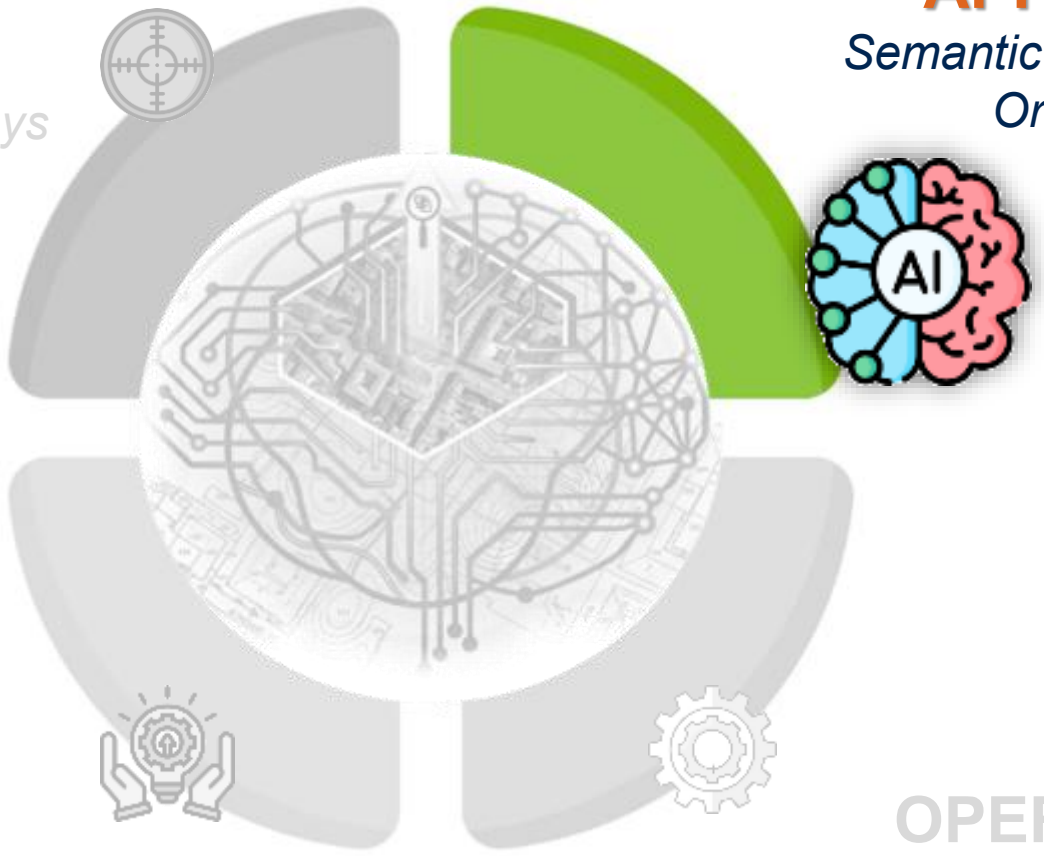
…we could therefore say that the legislator provided for a periodic 'purification' of the cadastre.

SCOPE AND OBJECTIVES

Innovating Territorial Surveys

APPLYING AI

Semantic Segmentation of Orthophotos



FUTURE OUTLOOK

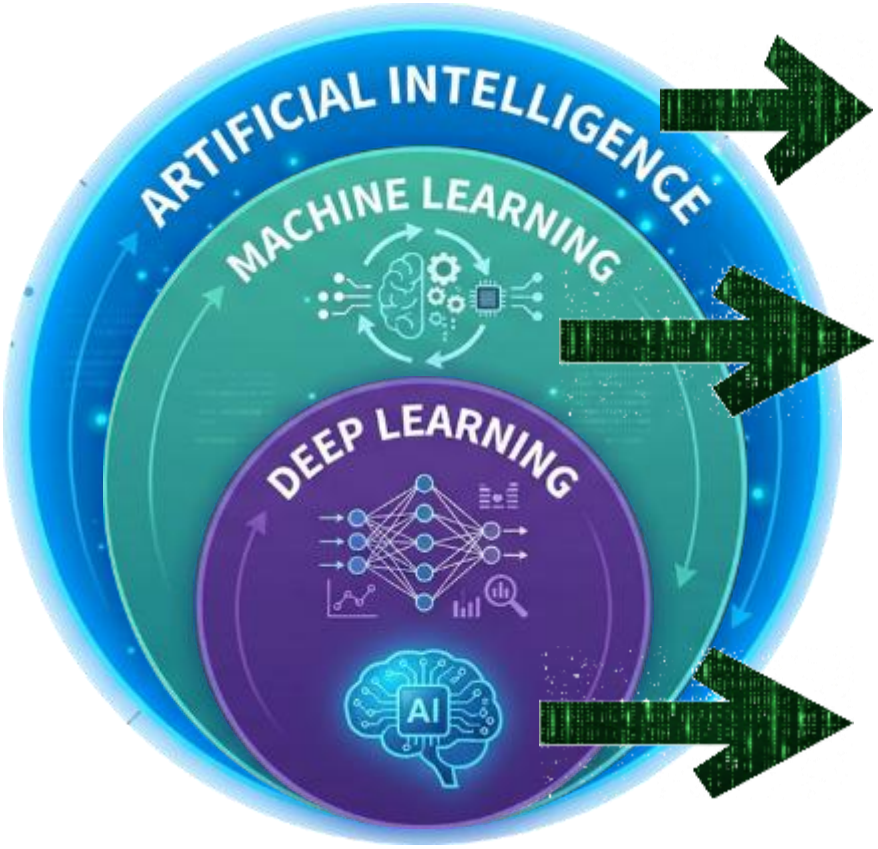
Exploring Further Applications

OPERATIONAL WORKFLOW

Photointerpretation Platform

Fundamental concepts of AI and machine learning paradigms

Different terms for different meanings



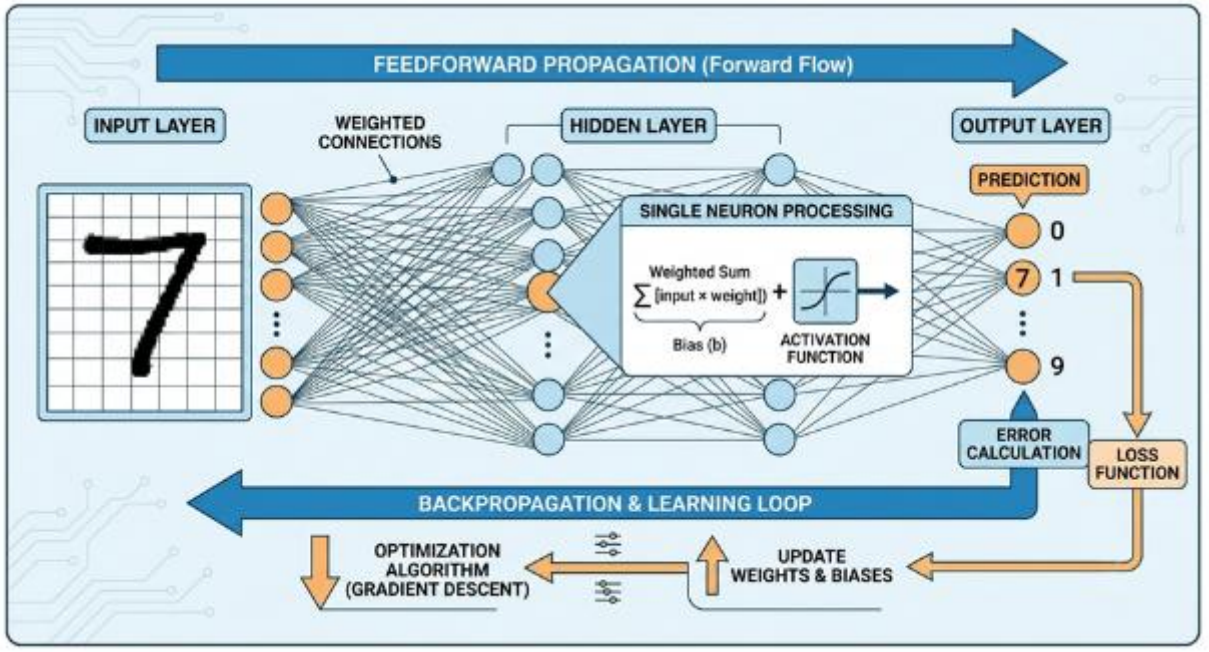
AI A broad and generic term for technologies and systems designed to replicate human cognitive abilities for specific tasks.

ML A subset of AI where **systems improve through experience**. By processing **large datasets** during a **training phase**, the system identifies patterns and relationships to perform specific tasks.

DL A more powerful specialization of ML based on **artificial neural networks (ANN)**, **inspired by the structure and function of the human brain.**

Deep Learning Models based on Artificial Neural Networks

Distinct layers of interconnected nodes, called neurons (mathematical functions)



Input Layer: receives the initial data (e.g., in **Computer Vision** pixel values of an image).

Hidden Layer(s): intermediate layers performing the primary processing, extracting complex features from the input.

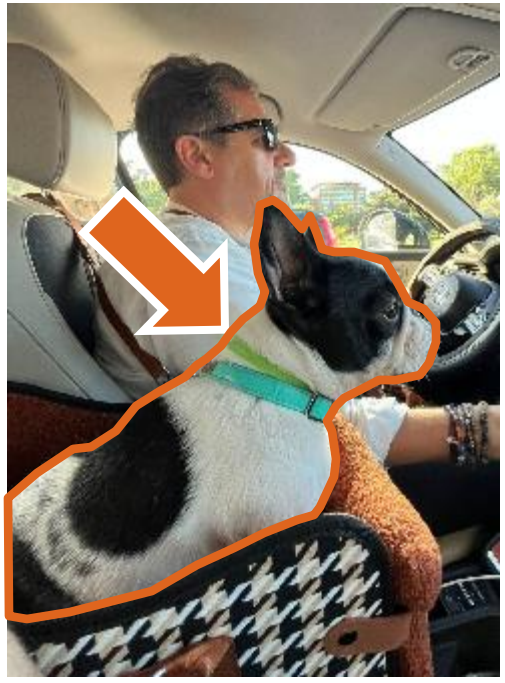
Output Layer: produces the final result (e.g. in Computer Vision recognizing objects, shapes, or structures).

Crucial to this is the **training process**, which progressively optimizes algorithms to maximize task performance.

OUR EXPERIENCE WITH AI

2021: **Development began on tools to automatically detect buildings**, and later **swimming pools** - on nationwide orthophotos **for cadastral map comparison.**

We used **CNN*- based *deep learning models*** for **semantic segmentation**.



Unlike standard classification that merely identifies an object's presence (e.g., "this is a dog" if we are looking for dogs), a **semantic segmentation CNN** performs **pixel-level classification**, determining exactly **which object each pixel belongs to**.

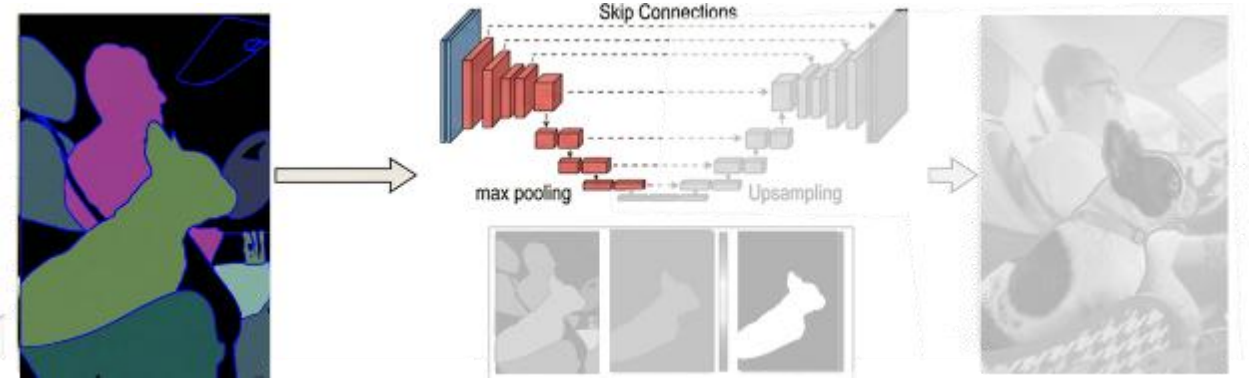
To achieve this, standard CNN architectures are adapted into an **encoder-decoder structure**, often known as a *Fully Convolutional Network* (FCN)

**Convolutional Neural Networks*

OUR EXPERIENCE WITH AI

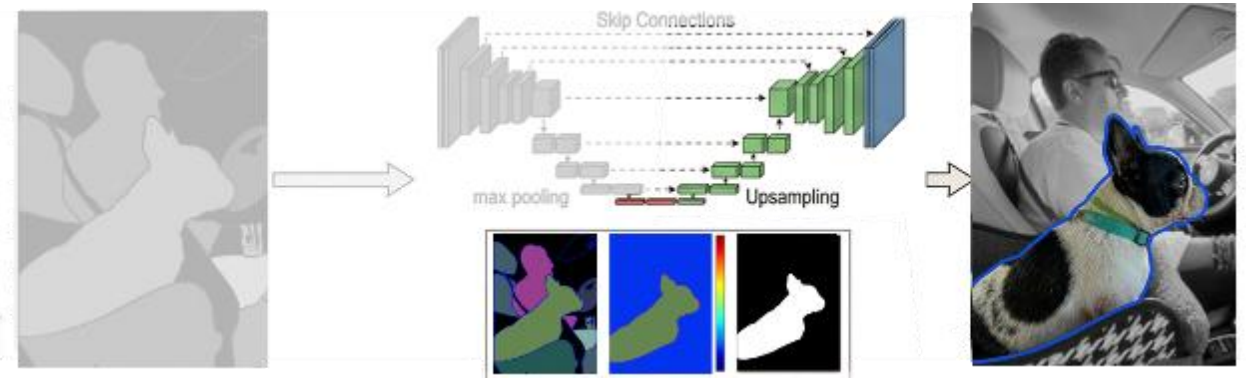
THE ENCODER

The network gains a deep, high-level understanding of **WHAT is in the image**, but it **loses the exact spatial resolution (WHERE things are)**.



THE DECODER

The network shrinks the image to **understand WHAT it is looking at**, blows it back up using architectural shortcuts to **remember WHERE everything was**, and then **labels every single pixel**.



OUR EXPERIENCE WITH AI

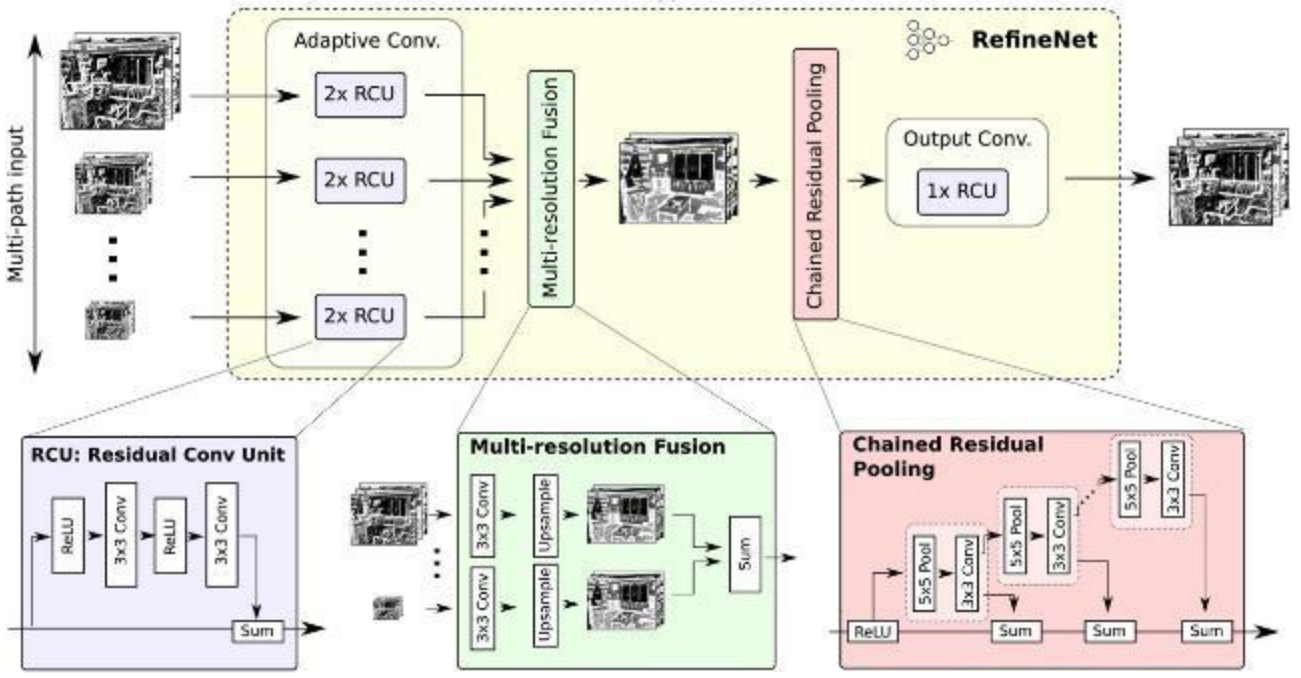
OUR PROCESS: Key Phases of Software Development

Comparative evaluation

We evaluated six semantic segmentation models, comparing four open-source architectures with two proprietary solutions.

Model selection

RefineNet (open-source) was selected based on initial comparative test results



Individual components of the RefineNet architecture (Guosheng Lin et al.)

OUR EXPERIENCE WITH AI

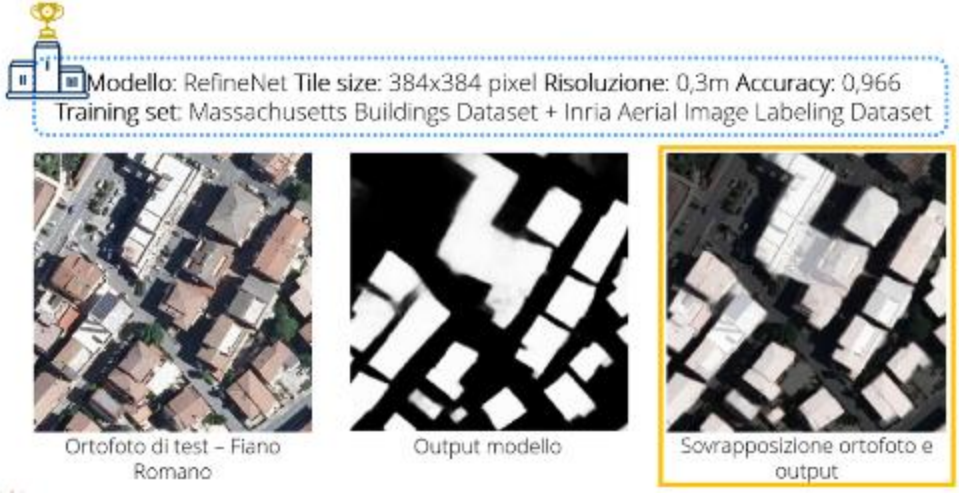
OUR PROCESS: Key Phases of Software Development

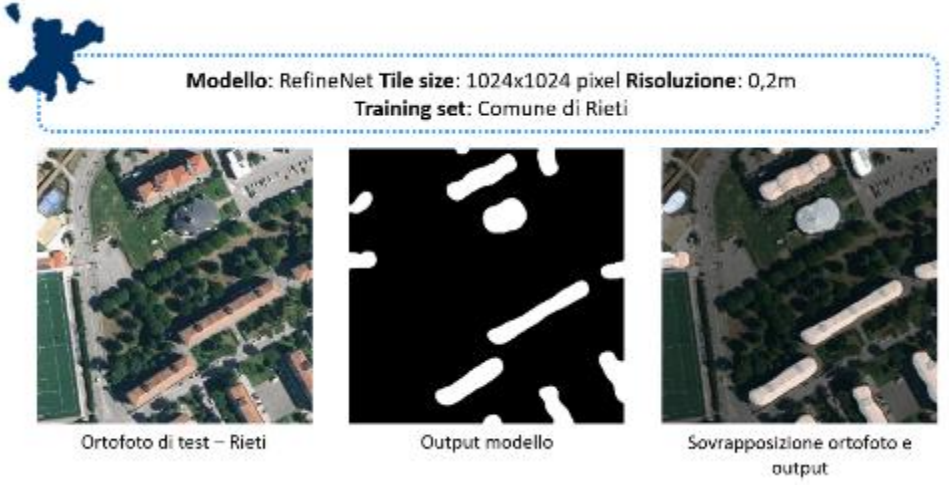
Methodology

Adopted a **transfer learning approach using models pre-trained on large aerial imagery datasets**.

Training and Testing

The model was trained and tested on established datasets: Massachusetts Buildings, Inria Aerial Image Labeling, and a pre-labeled dataset covering Italy





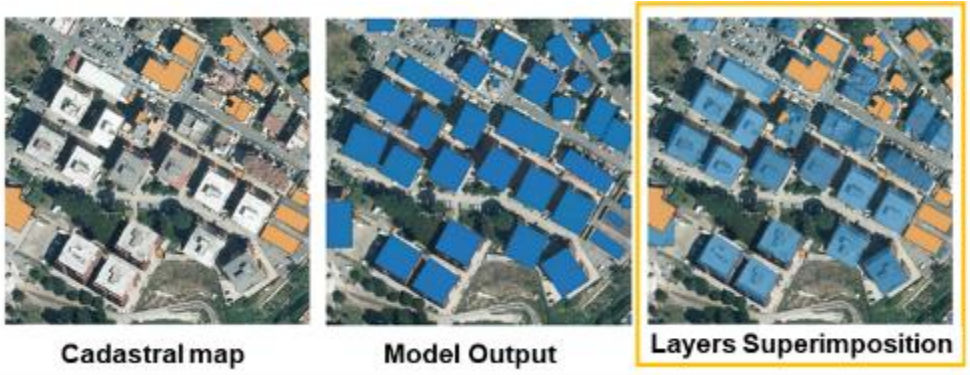
OUR EXPERIENCE WITH AI

OUR PROCESS: Key Phases of Software Development

Output

- **Pixel-level classification** masks to extract **vector geometries** of detected **buildings** and **swimming pools**.
- **Cadastral map overlay** to automatically identify missing structures.

BUILDINGS



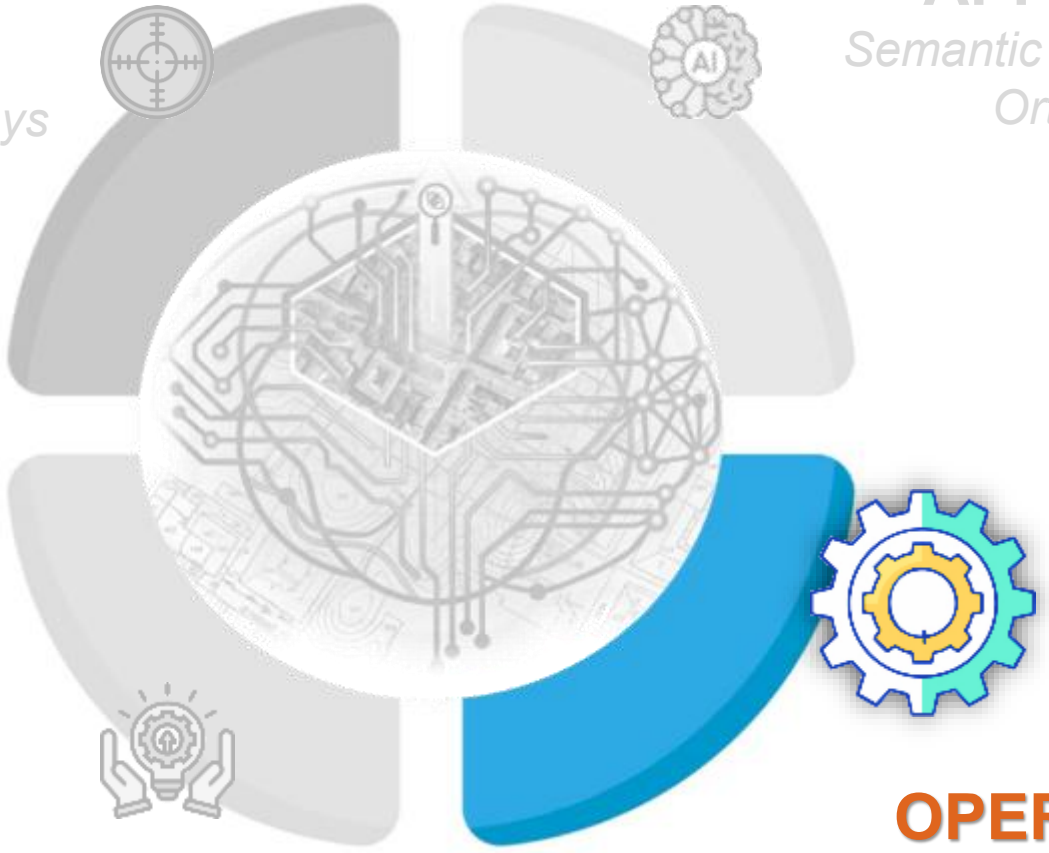
SWIMMING POOLS



Before flagging AI-detected features as missing, an algorithm evaluates overlap percentages to account for cadastral map misalignments and geometric inaccuracies.

SCOPE AND OBJECTIVES
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FUTURE OUTLOOK
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VISION towards LUSTRAZIONE 2.0



Innovation driven by a clear vision



to enable **more effective, efficient, and cost-effective periodic territorial inspections** by leveraging new technologies to minimize expensive fieldwork.



Ultimate goal





'Vertical resolution' of the detected inconsistencies across all cadastral databases (both census and cartographic).

VISION towards LUSTRAZIONE 2.0

PHOTOINTERPRETATION

The rationale: a map-based survey through a photointerpretation process where maps are overlaid with high-resolution orthophotos.

How does it work? Operators trace structures - currently limited to buildings and swimming pools - which are missing from the cadastral maps.

The latest innovation: AI uses semantic segmentation to detect missing properties on orthophotos, which operators then review and verify.

First campaign: Launched in late 2021, AI-enhanced since late 2024, and nearing completion.



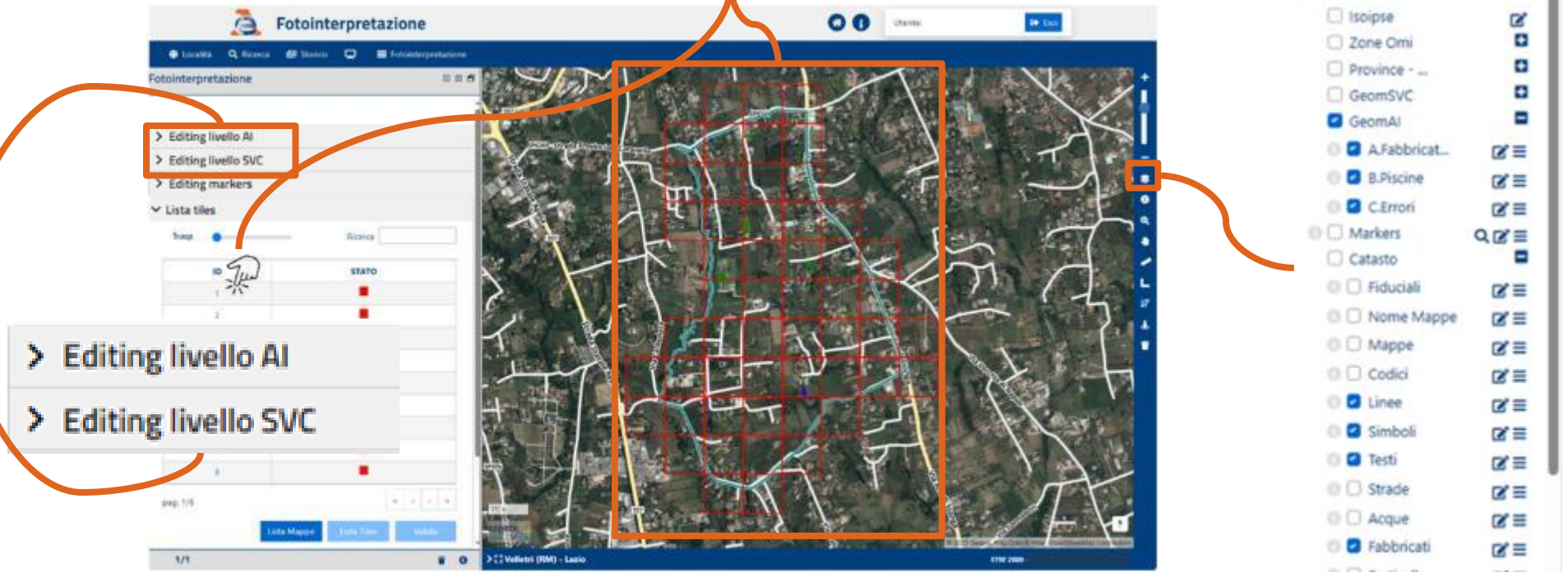
"IOSVC" Project and Photointerpretation Platform

Photointerpretation activities launched as part of the **«IOSVC*» project**, focusing on Orthophoto-based building and swimming pool identification **without prior census Database verification**.

Tools for classifying and drawing identified objects (via AI predictions or direct user input)

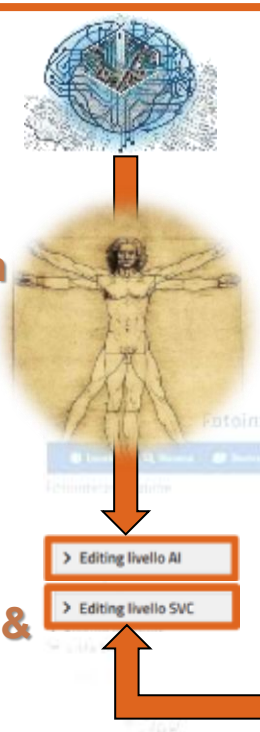
Guided Sequential Exploration of a cadastral map

Layers Panel



*Inserimento da Ortofoto Senza Verifica Censuaria – *Insertion from Orthophotos Without Census Database Verification*

"IOSVC" Project and Photointerpretation Platform



AI Population & Review

AI-detected buildings and swimming pools enter the **GeomAI** layer (AI-Proposed Geometries) for operator verification and classification.

Transition & Manual Editing

Approved features move to the **GeomSVC** layer (Geometries Without Census Verification), where staff can also use CAD tools to manually digitize unmapped features.

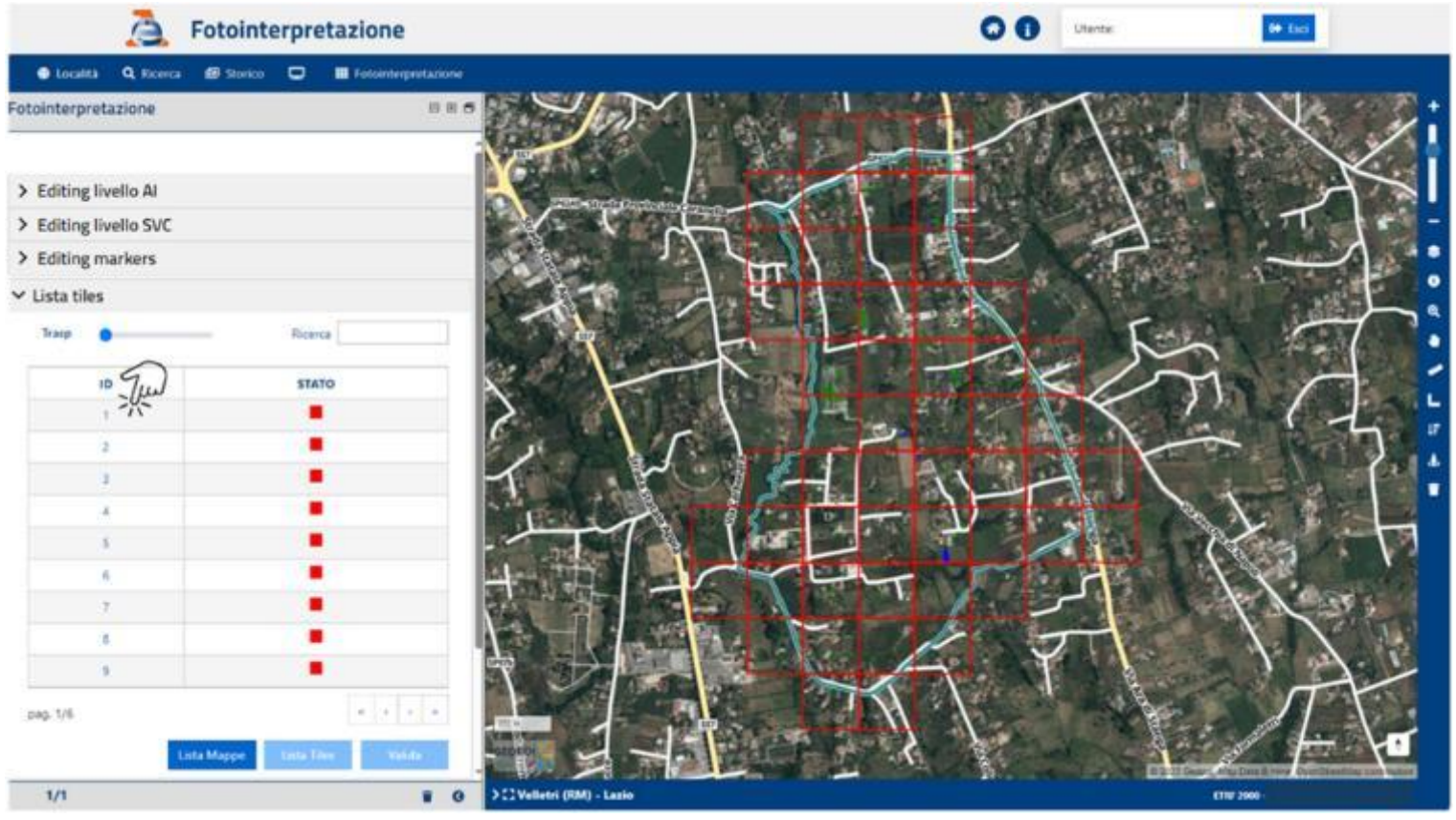
Database Isolation

These features remain isolated from official databases to log flagged locations for future field checks without altering official cadastral records.

VISION towards LUSTRAZIONE 2.0

PHOTOINTERPRETATION

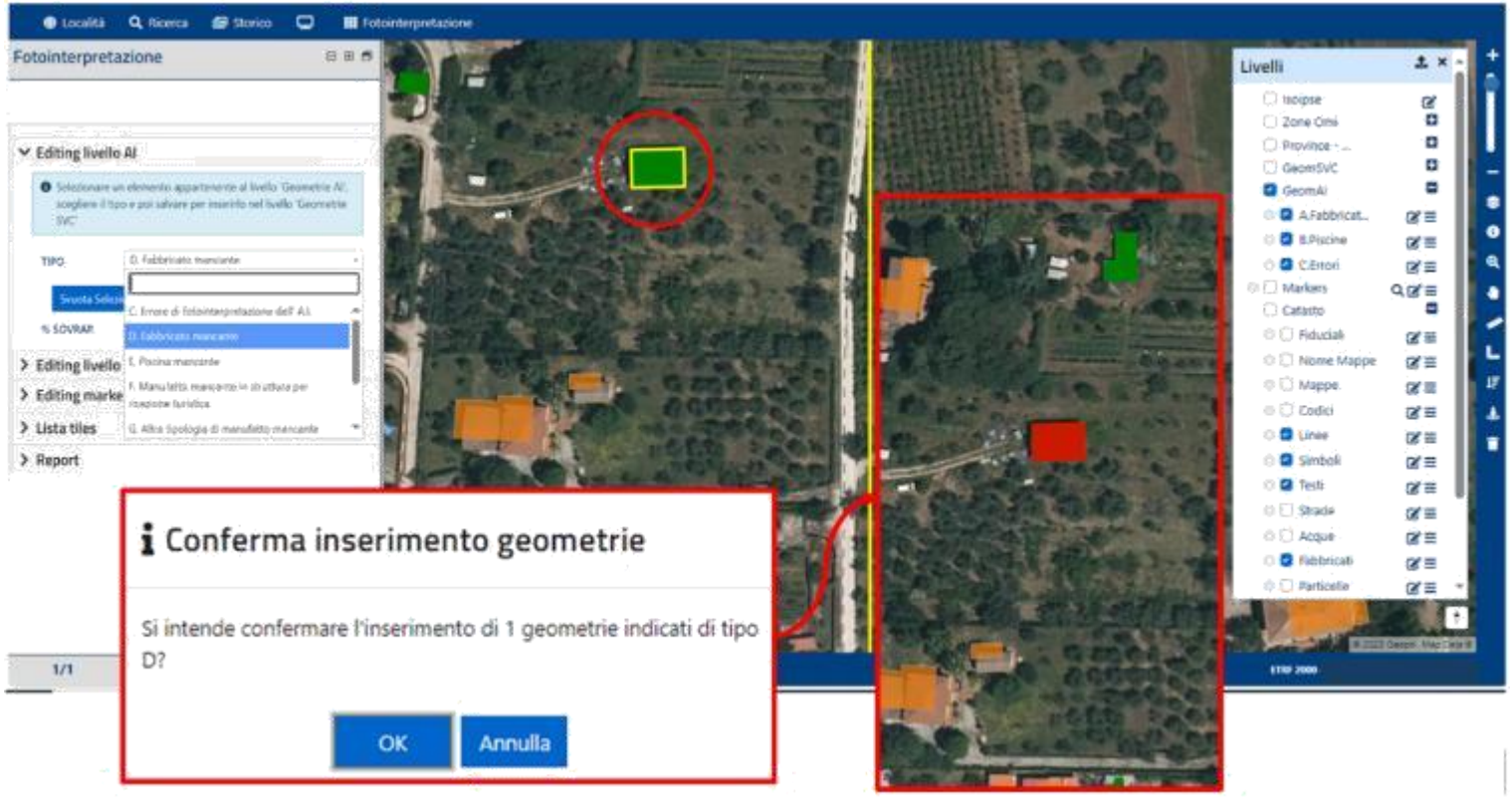
The Process in Brief: Sequential exploration of a map sheet



VISION towards LUSTRAZIONE 2.0

PHOTOINTERPRETATION

The Process in Brief: Verification, Confirmation and classification of AI proposals for unmapped buildings



VISION towards LUSTRAZIONE 2.0

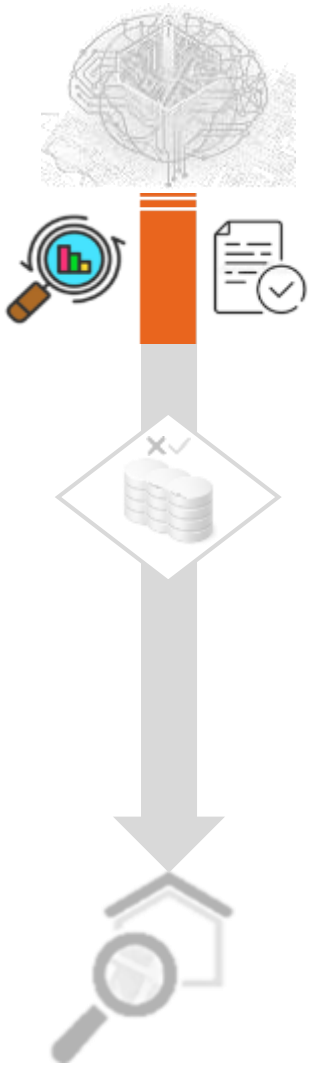
PHOTOINTERPRETATION

The Process in Brief: **Verification, Confirmation and classification** of **AI proposals for unmapped pools**



VISION towards LUSTRAZIONE 2.0

ANALYSIS AND CLASSIFICATION - COMPLIANCE



Second step of the process: Analysis and classification of identified discrepancies, with subsequent engagement of the registered owners of the relevant parcels to encourage compliance.

2026 **Mailing of 20,000 compliance letters planned**

2027 **Mailing of 40,000 compliance letters planned**

VISION towards LUSTRAZIONE 2.0

POST COMPLIANCE CHECKS AND ACTIONS

Third step of the process



No declaration required or compliance achieved.

Inconsistency Closure

STOP



Declaration needed and lack of compliance

Inconsistencies due to cross-database misalignment

Data Misalignment Rectification

STOP

towards LUSTRAZIONE 2.0

OFFICIAL CADASTRAL ASSESSMENT

Final step of the process





No declaration required or compliance achieved.

inconsistency closure





Declaration needed and lack of compliance

Inconsistencies due to cross-database misalignment

Data misalignment rectification

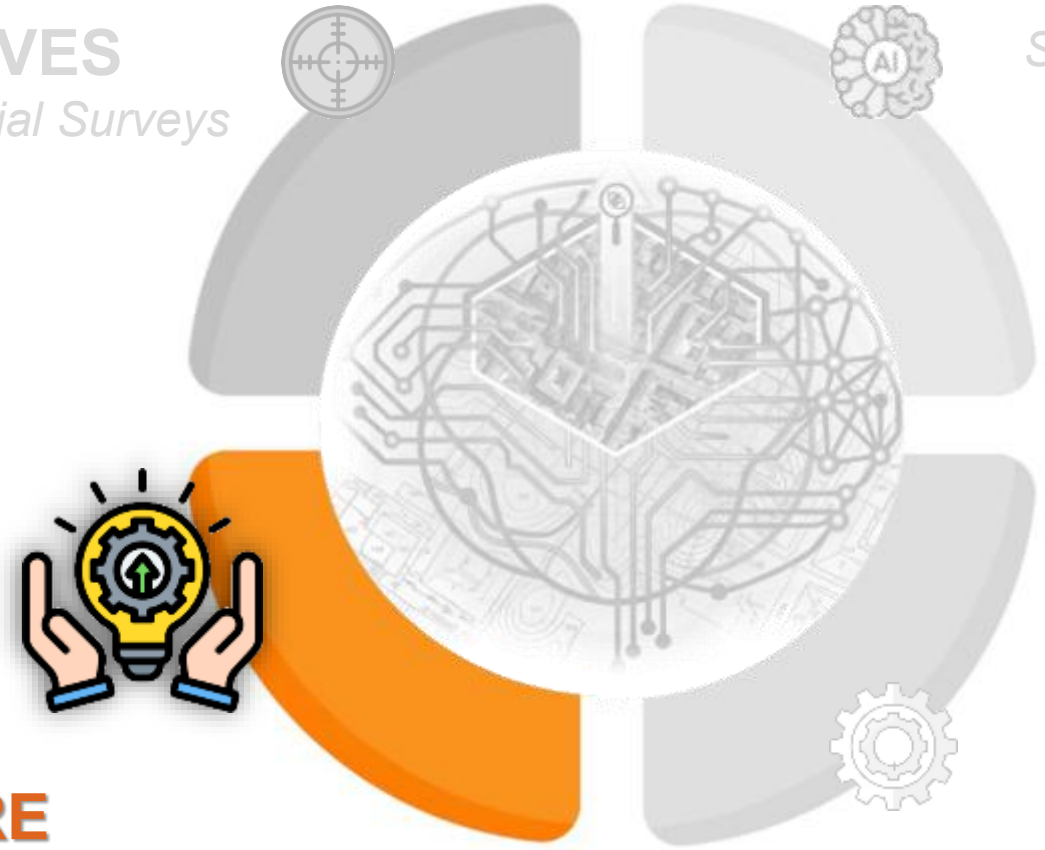




Official Cadastral Assessment launch

SCOPE AND OBJECTIVES
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CHANGE DETECTION

Comparing orthophotos from different years to identify land-use changes

To implement the aforementioned "*Lustrazione* 2.0" vision, we can use **change detection** as a crucial evolution by **comparing multi-temporal orthophotos** to identify **variations over time.**



Achieving this requires logging and **historically tracking initial photointerpretation outcomes.**

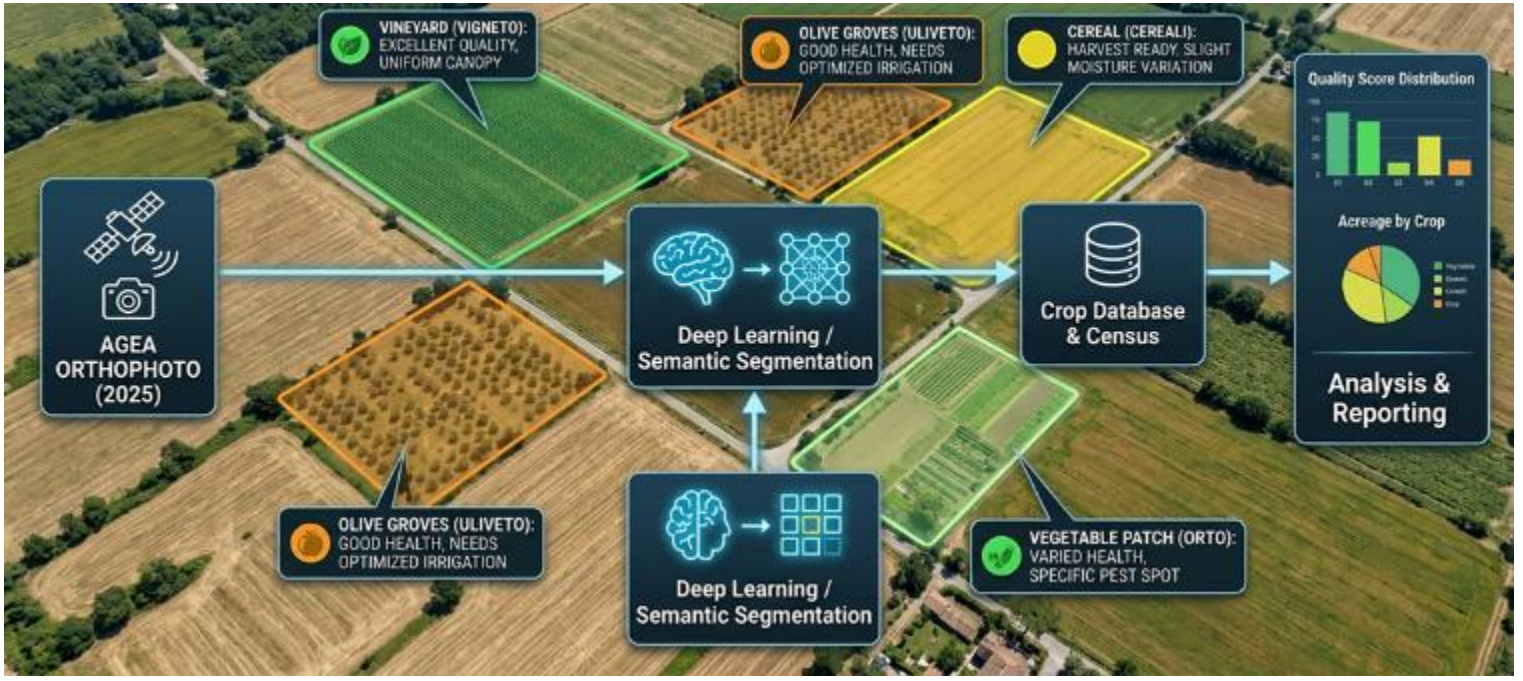
This baseline ensures that future AI iterations will **exclusively flag newly detected, unmapped structures on newer orthophotos**



The **following slides** present preliminary development concepts that **require rigorous legal, property rights, and topographical validation**

AUTOMATED RECOGNITION OF CROP TYPES

Another promising area of application for deep learning semantic segmentation models within the cadastral framework is the **automated identification of crop types**.



This could be leveraged to verify the accuracy of cadastral records regarding declared crop categories.

AUTOMATIC DETECTION OF UNMAPPED ROADS

A review of several academic papers highlights the promising **use of deep learning models for the automatic identification of road networks**.



Once identified via semantic segmentation, these **road networks** can be **vectorized and overlaid** onto existing cadastral layers to isolate unmapped sections.

In practice, this approach can support **large-scale cartographic updates** for **missing public roads**.

AUTOMATED DETECTION OF PARCEL BOUNDARIES

Semantic segmentation can **extract cadastral boundaries from imagery** to **automate cross-checking with official cadastral maps and databases.**

The **primary challenge** is **training models to recognize diverse physical boundaries** (fences, crop edges), especially when obstructed or visually interrupted.



While international projects show promising accuracy, **human-in-the-loop validation remains indispensable**.

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Thank you for your time and kind attention

PCC
Permanent Committee on Cadastre in the European Union

eurogeographics

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