Seeing Urban Densification through the Buildings' Lens: A User-Oriented and Collaborative Approach

B. Bucher, M. Ndim, J. Perret, J. Raimbault, A-M. Raimond, C. Stoian

SUBDENSE 2023-2026

Context: the SUBDENSE project

1. The SUBDENSE European project studies the dynamics of suburban densification by:

   - Exploring how diverse strategies of land policy interact with landowners' and local stakeholders' interest and actions to influence urban densification and their impact on different planning systems: France, Germany, UK

   - Combining quantitative approaches (spatial data analysis and geosimulation) with qualitative approaches (social and policy science, and planning).

→ Need for a consistent quantification of urban change at the building scale, despite various spatial data qualities across compared countries: France, Germany, and UK

Context: the SUBDENSE project

What is urban densification ?

Urban densification can be interpreted as:

- an increase of density and more specifically a “net increase of the number of housing units” within the pre-existing built-up area (Broitmanand Koomen, 2015)
- the actions taken to achieve this increase, more specifically public actions.

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How urban densification can be measured ?

Urban densification can be measured:

- as an evolution over time of density values

→ **Research hypothesis:**

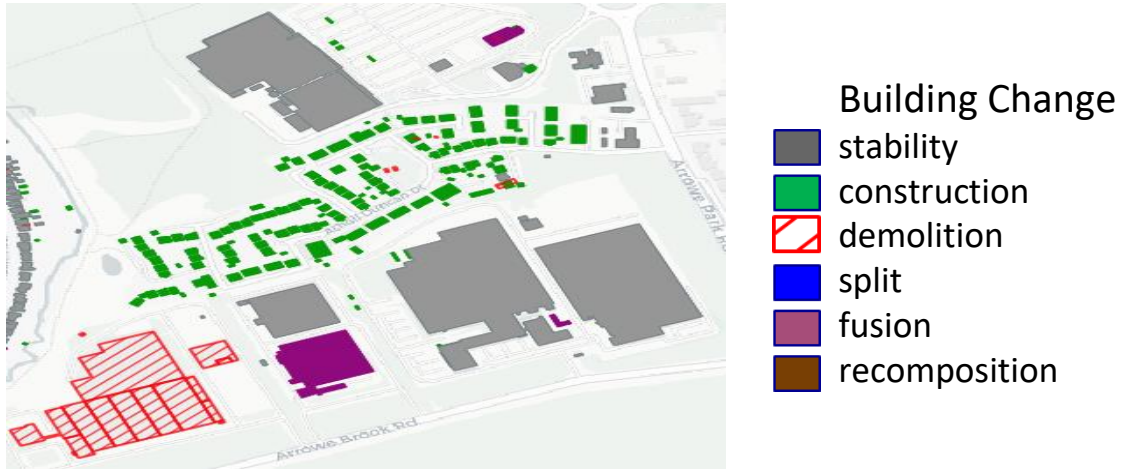
Building changes derived from buildings database can be used to measure the evolution of buildings entities

Goals

1. Propose an experimental environment to produce building evolution data within an Open Science framework, emphasizing reproducibility, transferability, and comparability between countries

2. Produce initial maps, assess their contribution to discussions on densification, and revise the methodology

3. To propose a method to determine residential densification drivers across countries



Challenges

Which input data, i.e., *buildings in city regions in Uk, Fr, De, and past decades*?

OpenStreetMap

+ homogeneous data model and API
+ ‘open’ licence
+ world spatial coverage

- completeness when going back decades ago
- relation between data changes and real world changes

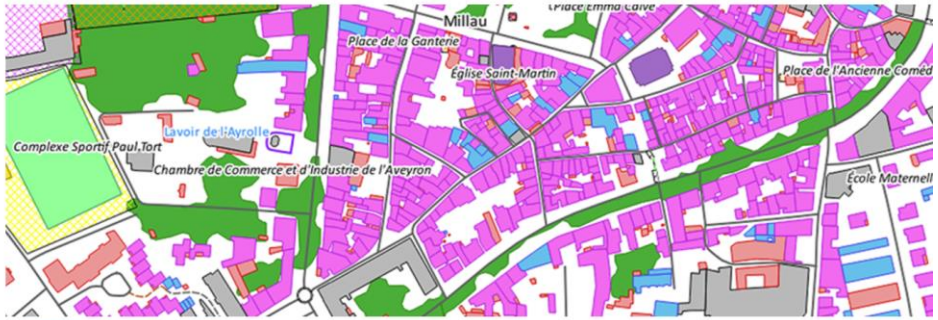
Challenges

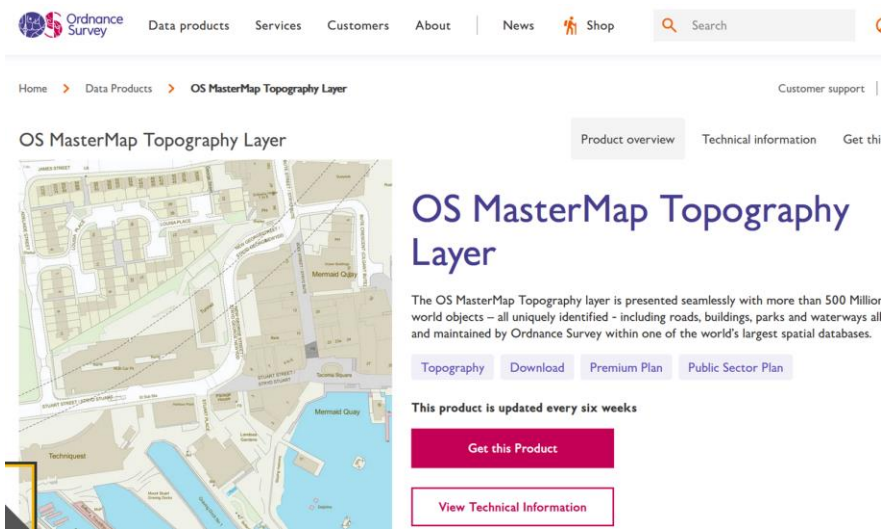
Which input data, i.e., *buildings in city regions in Uk, Fr, De, and past decades*?

- heterogeneous API
- not always ‘open’

+ completeness when going back decades ago
+ relation between changes in data and in real world is somehow documented

Select authoritative building data for each country keeping data in the source format, and harmonise building changes

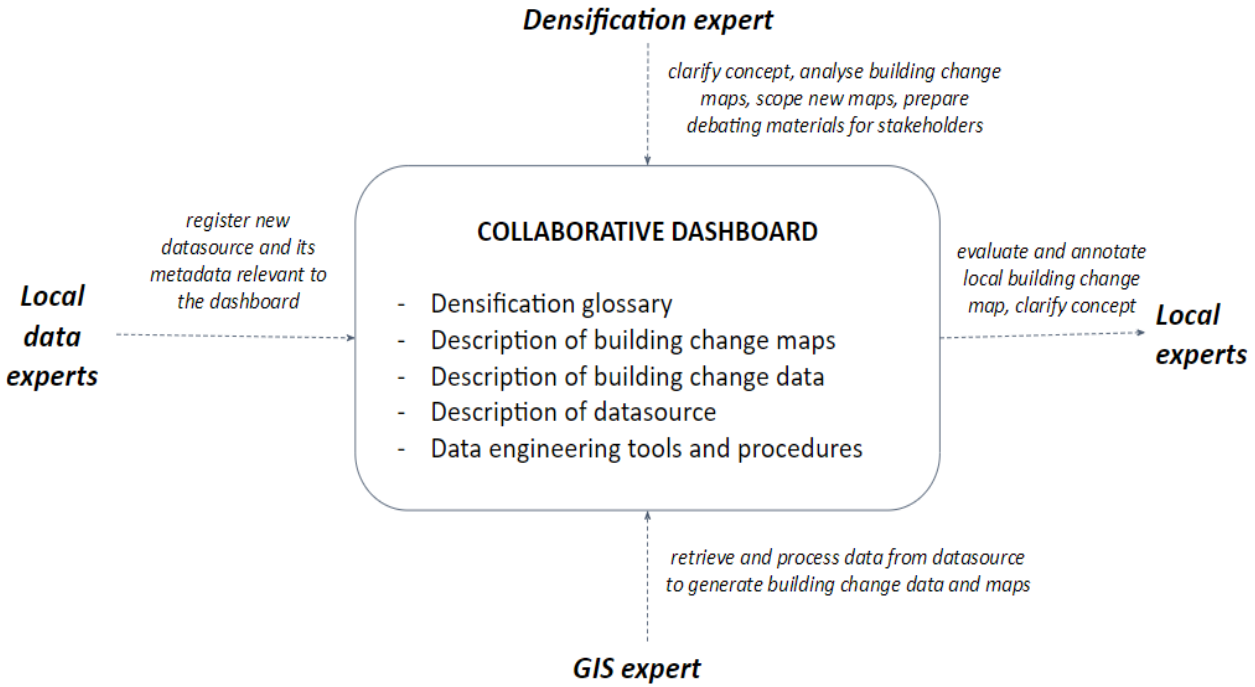




Outline

1. Context and goal
2. Contributions
   - A collaborative dashboard for mediation
   - Annotation Web-Application for data evolution benchmarks
3. Reproducibility
4. Conclusion and futur works

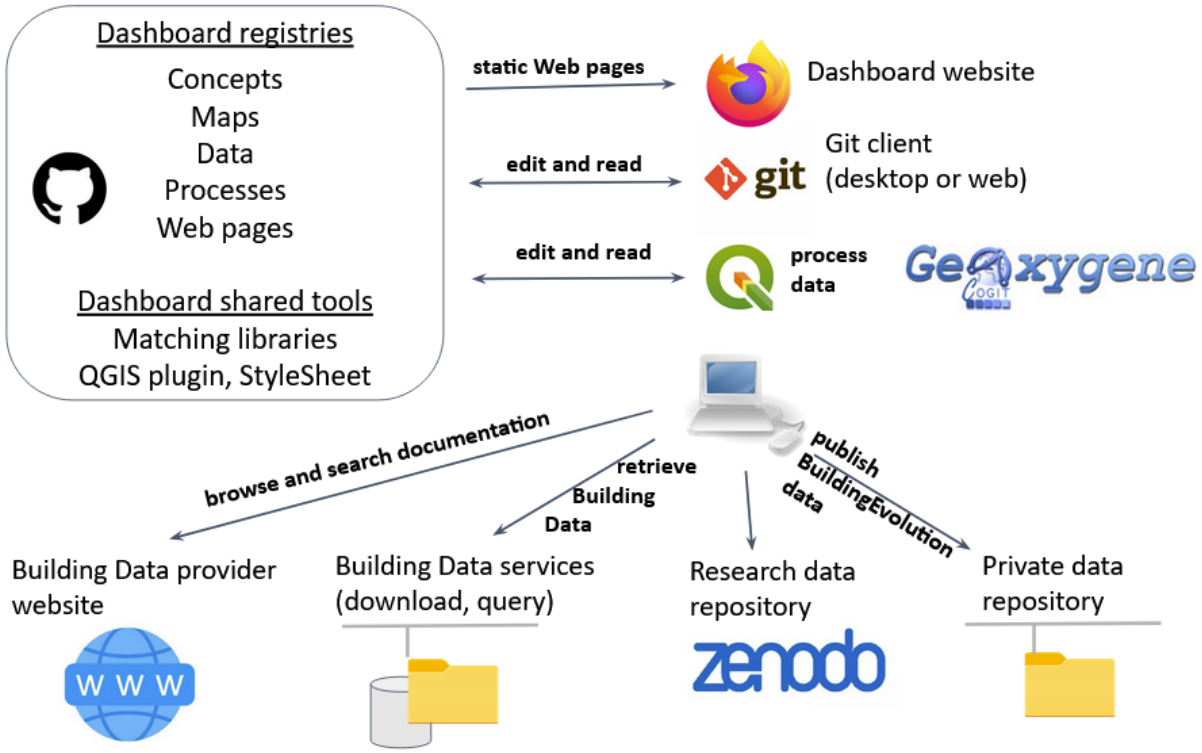
Contribution 1: A collaborative dashboard for mediation



- Harmonising operational concepts and data sources qualification across countries:

→ git-based dashboard to share knowledge and resources between experts (Bucher et al., 2025)

Contribution 1: A collaborative dashboard for mediation



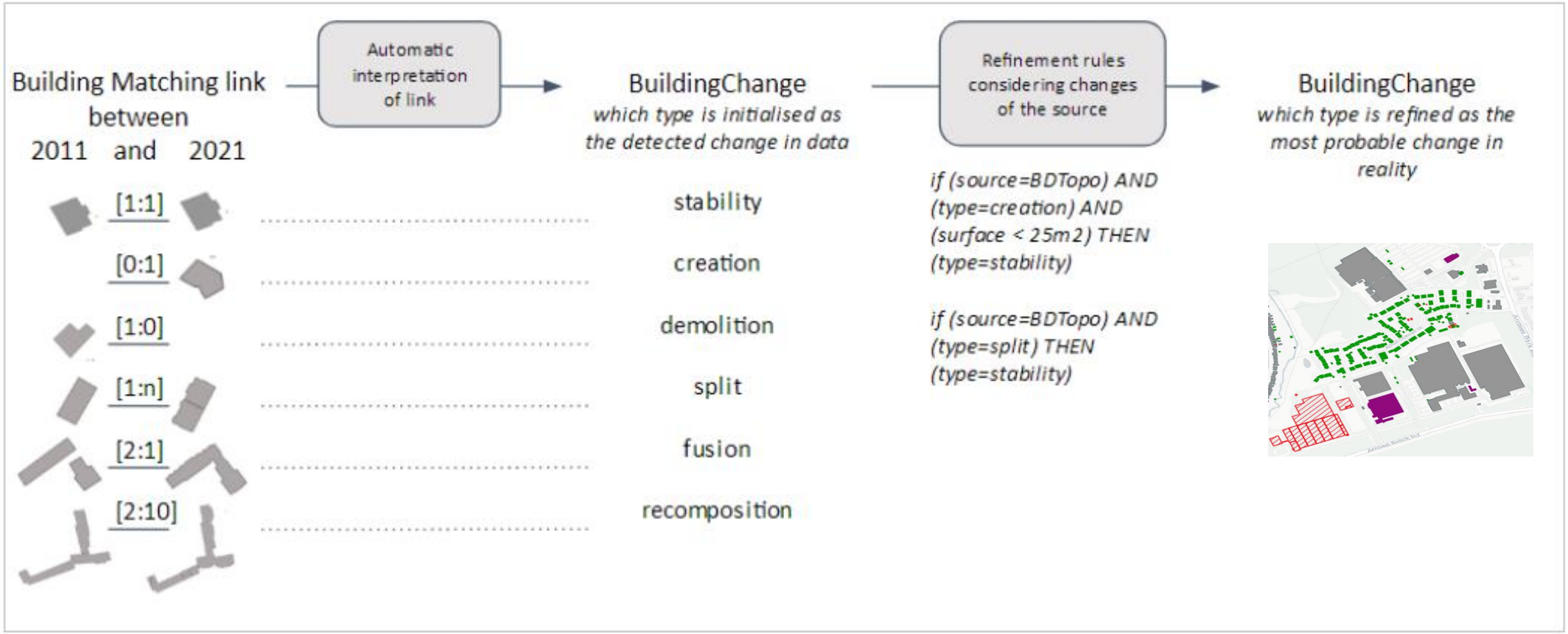
- Harmonising operational concepts and data sources qualification across the countries:

→ git-based dashboard to share knowledge and resources between experts (Bucher et al., 2025)

→ reproducible tools and methods, including building change detection scripts

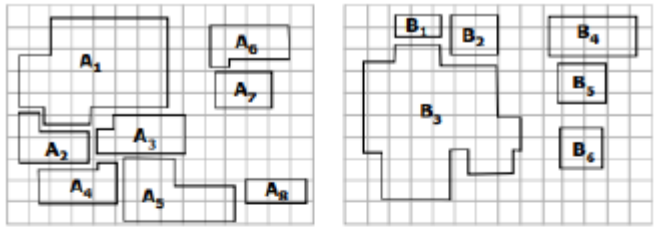
Contribution 1: General workflow to produce evolution buildings

Data matching

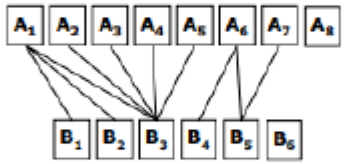


Automatic interpretation of matching links into building change, with specific adjustements for BDTopo (Bucher et al., 2025), by a python script available at https://github.com/subdense/matching

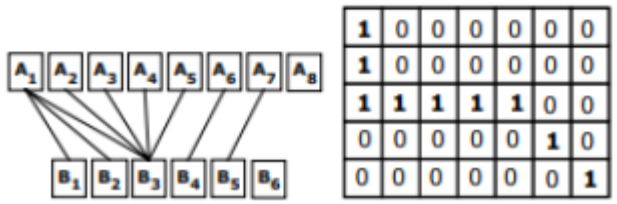
Geometric Matching of Areas algorithm (GMA)



Jeu de données #1 Jeu de données #2



Graphe d 'association



Graphe d 'association

1	0	0	0	0	0	0
1	0	0	0	0	0	0
1	1	1	1	1	0	0
0	0	0	0	0	1	0
0	0	0	0	0	0	1

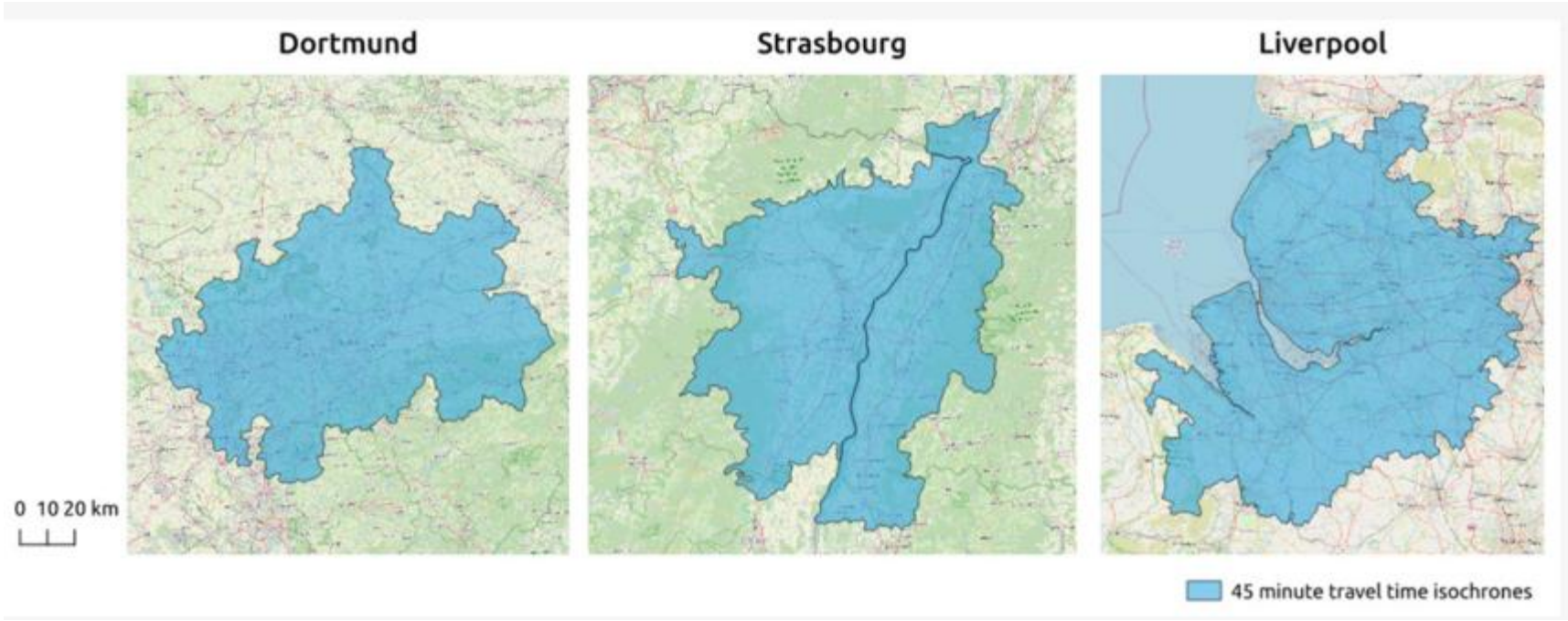
Matrice d 'association

GMA: Algorithm to produce m-n links based only on geometries (Harvey et al., 1998, Bel Hadj Ali, 2001):

1. Construct all possible association links as surfaces with a non-empty intersection (top left Fig.)
2. Filter links with an intersection surface below a threshold parameter
3. Filter links with an intersection surface too small relatively to matched surfaces (rate parameter)
4. Construct all m-n links as connected clusters in the remaining bipartite graph (bottom left Fig.)

→ implemented in the geoxygene java library (Bucher et al., 2012) by (Mustiere, 2002)

Building evolution data: Study area



HU-DE® of 2011, 2021, basemap © OpenStreetMap contributors

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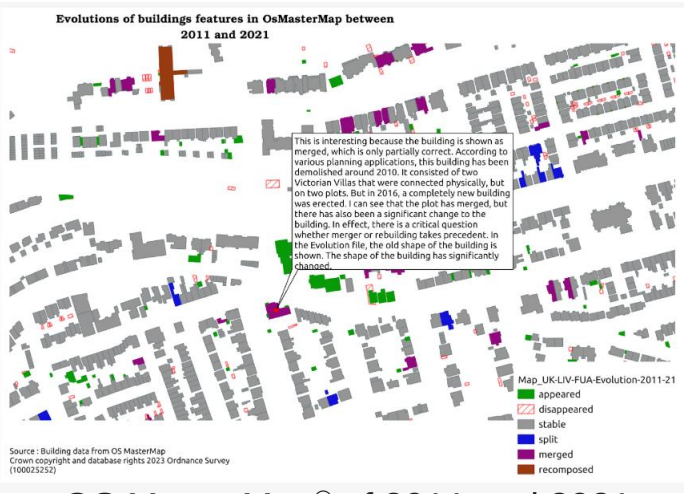

OS MasterMap® of 2011 and 2021

Data Matching challenges

1. **Two main data matching challenges:**

   → Vector Matching algorithms require parameters and optimisation, and provide varying performances in different context

   → Need for large and specific ground-truth datasets for both matching links and building evolution

2. **Two main research goals:**

   → To design and develop a web application that enables efficient annotation and validation of matching links between vector datasets.

   → To identify and evaluate the algorithms and parameter settings that most accurately detect true building changes across diverse urban contexts and countries.

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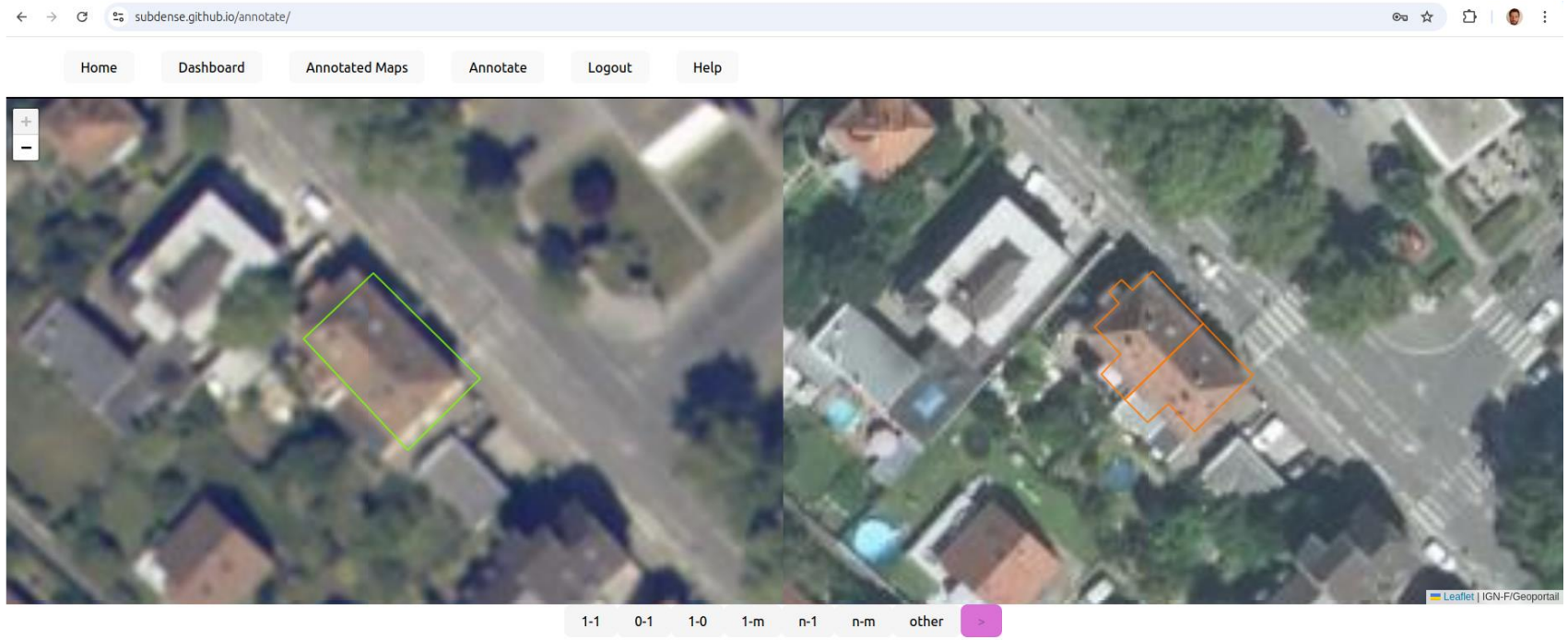
Contribution 2: Ground –truth data annotation

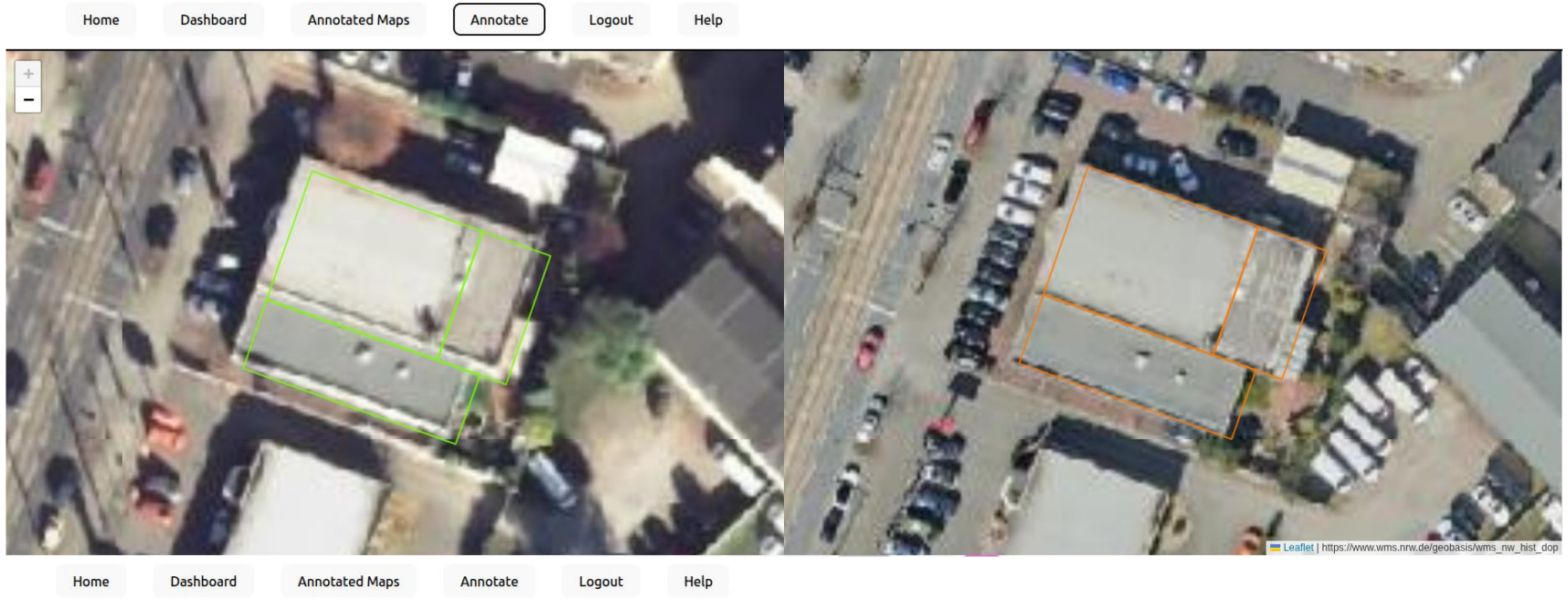
1. Fully based on git and javascript: no database nor server management, automatically deployed through github pages
2. Handles multi-user collaboration, with authentication given by writing rights on the git repository
3. Provides a dashboard to summarise user progress and overall progress
4. Allows annotating two vector datasets, with aerial photographs for ground-truth validation



Two-stages annotation process

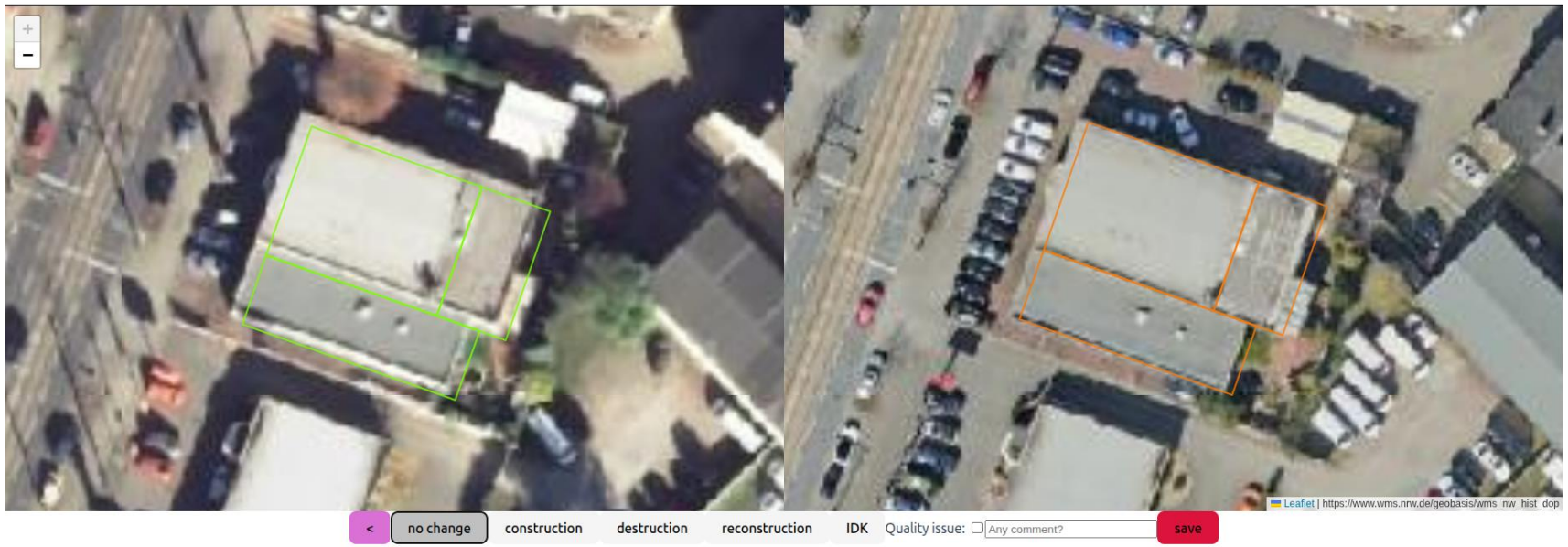
Stage 1:

- type of matching link:
  1-1, 0-1, 1-0, 1-m, n-1, n-m.



Stage 2:

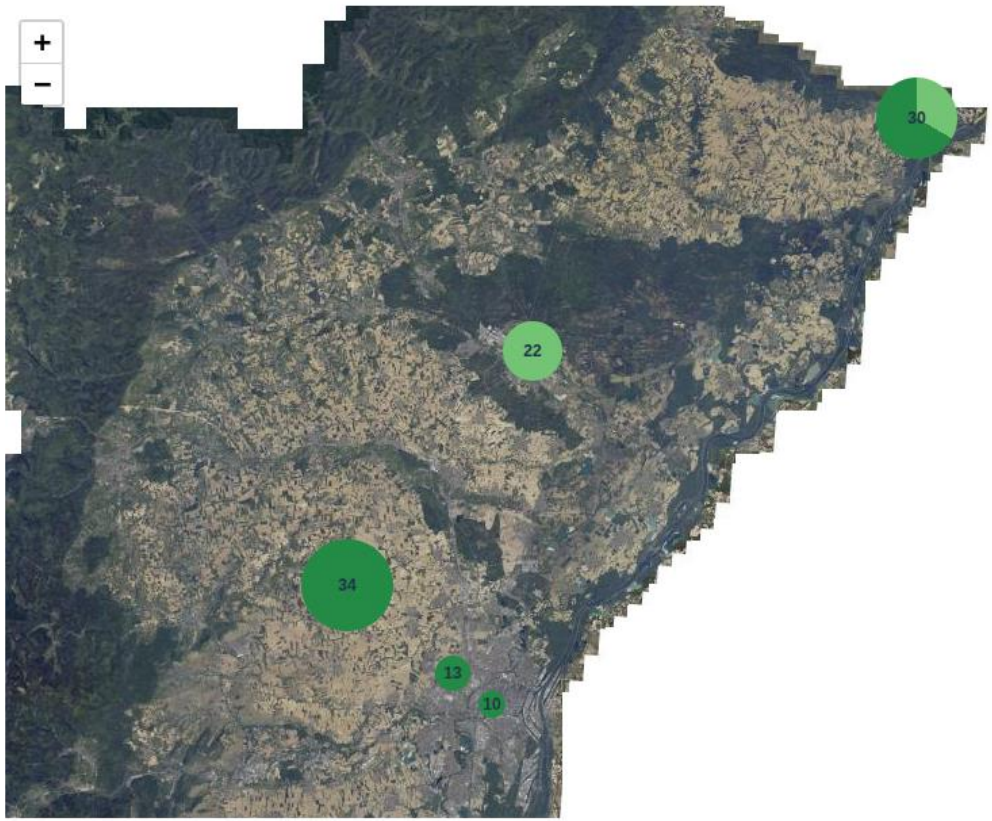
- type of real world evolution:
  no change, construction, destruction, reconstruction, don't know, as well as ale for a quality issue, and comment.



Dashboard and maps to monitor progress

Home | Dashboard | Annotated Maps | Annotate | Logout | Help

Annotated Maps



Deployment - first pilot – work in progress

1. Sampling: samples of 100 points, each covering a 500-meter radius used to collect building data
2. Spatial area: Functional urban areas of **Strasbourg and Dortmund**, for the period **2011–2021**
3. Contributors: Subdense researchers, specialists in urban densification and national datasets.

Example of a construction in Strasbourg: 0-1 true link

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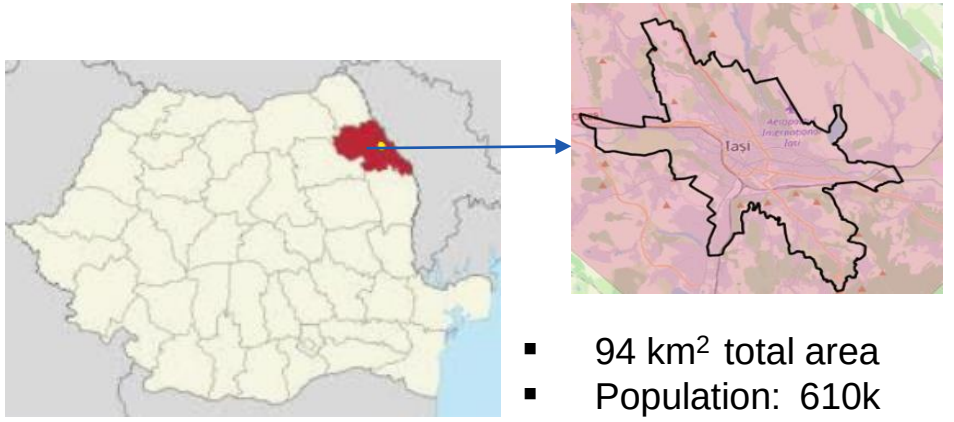
Reproducibility in another EU country

Motivation

Rapid urban densification in Iași, Romania, driven by residential and functional changes

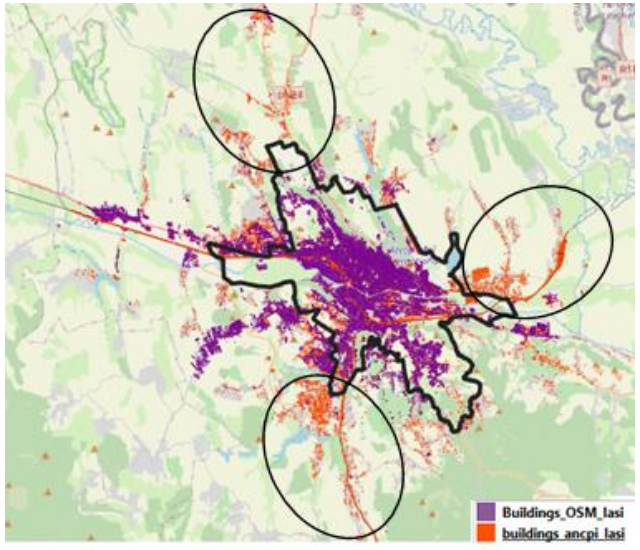
Existing building footprint datasets are outdated, incomplete or inconsistent

Limited availability of reliable historical data for densification analysis



- 94 km^2 total area
- Population: 610k inhab. In 2023

ANCPI (2018) vs. OSM (2025)



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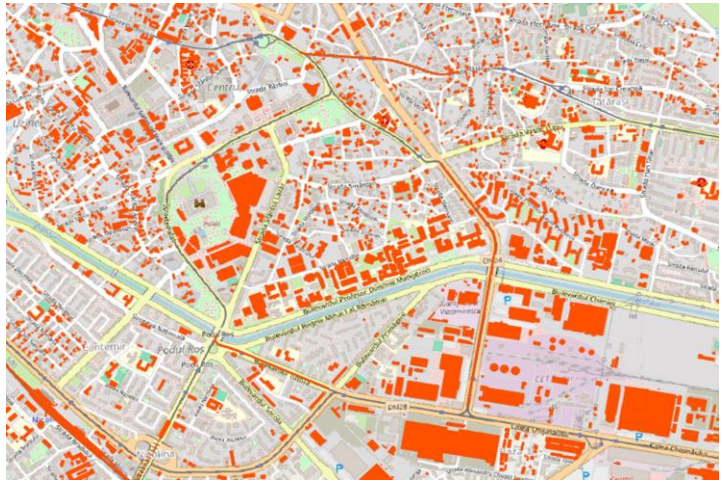
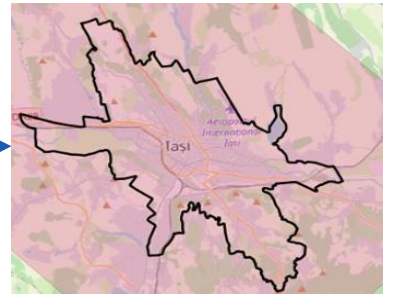


Buildings_OSM_Iasi
buildings_ancpi_Iasi

How to reproduce the proposed process to Romania?



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Enrich SUBDENSE Framework

Generates building footprints directly from orthophotos

Combines semantic segmentation (FLAIR-HUB) and polygonization (PFFL)

Produces comparable and reproducible building change datasets

Analyse densification

Processing

Input Data

Building footprints **t1 and t2**

⇩

STEP 4

Multi-Temporal Building Matching

Matching building footprints between dates

Processing

Input Data

Orthophotos **2011, 2024**

STEP 1

Semantic Segmentation

FLAIR HUB (2011, 2024)

U-Net Model (2011)

STEP 2

Building Class Extraction

Building Masks

STEP 3

Polygonization (PFFL)

Vector Building Footprint

STEP 4

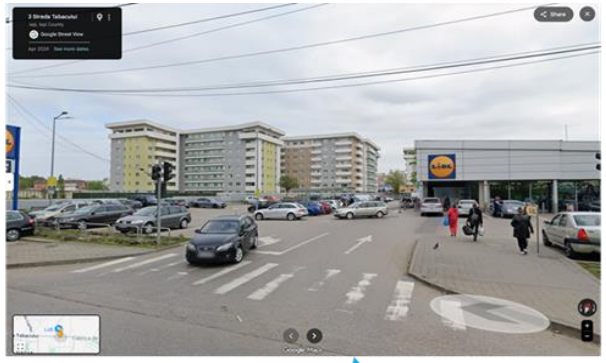
Multi-Temporal Building Matching

Matching building footprints between dates

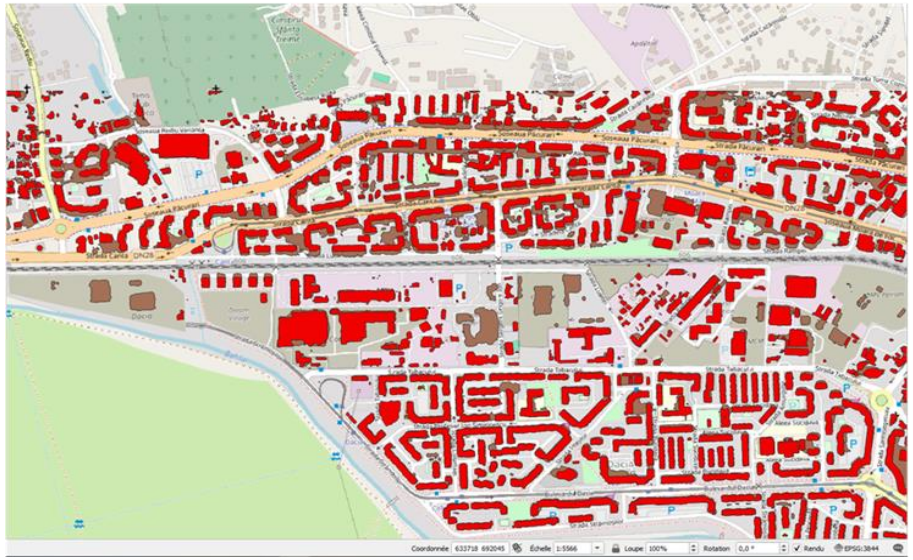
(Crenganis, L., Stoian C., et al, accepted, ISPRS'2026)

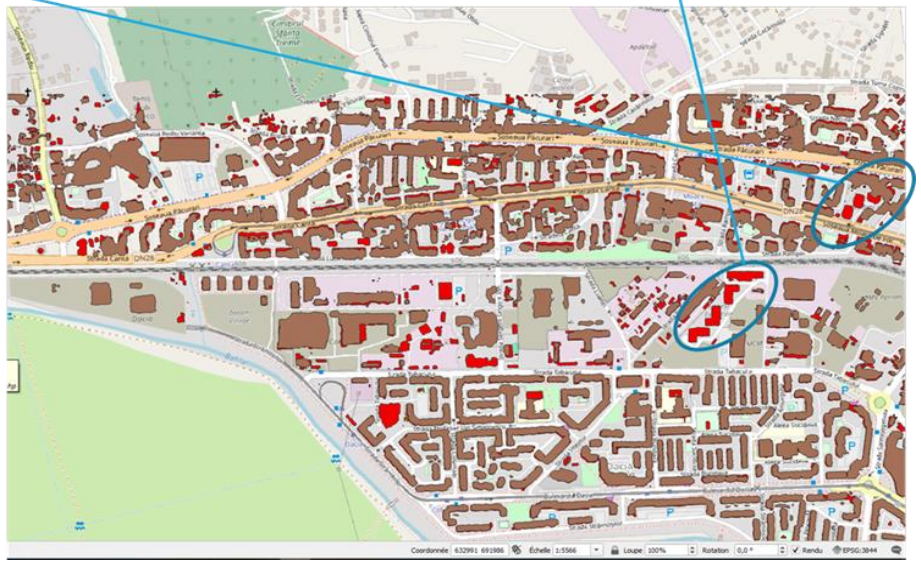
Example – building footprint generation

Buildings PFFL orthophotos 2024-2011



Buildings PFFL orthophotos 2011-2024





2024

2011

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Conclusion and future work

- Open source dashboard for urban densification to help different types of user to collaborate and compare densification patterns and drivers across countries
  - Annotator
    - Open-source web app to annotate matching links (https://github.com/subdense/annotate)
    - Proof-of-concept of a “serverless” deployment with user input through git
  - Data matching to build evolution data
  - Reproducibility → complete the Subdense workflow

- The main weakness is the validation, not yet fully performed
  - Building footprint generation in Iasi, Romania
  - Building evolution across four countries

Conclusion and **future work**

- Annotator
  - Annotation campaigns to produce a large-scale ground-truth dataset
  - More generic and configurable application: annotate raster data, other polygonal data (land plots), lines vector data, etc.

- Data matching to build evolution data based on multi-modeling
  - Optimization using the ground truth in OpenMOLE
  - Include other matching algorithms in the benchmark

Conclusion and **future work**

- Extension of SimPLU to simulate new buildings at the parcels scale by taking into account German urban planning regulations; in progress

Example in Munich

Credit: H. Verstraete

Thank you to LASTIG co-authors !

Juste Raimbault
Research fellow
STRUDEL team
Matching algorithms benchmark, dashboard, simulation models

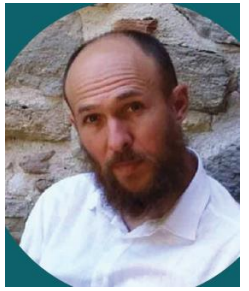
Mouhamadou Ndim
Engineer, CDD18 mois,
MEIG team
Dashboard designer and developer

Julien Perret
Senior research fellow
Équipe STRUDEL
Data integration, diachronic analysis, simulation, architecture

Ana-Maria Raimond
Senior research fellow,
MEIG team
Data-matching, data integration, change detection analysis

Bénédicte Bucher
Senior research fellow
MEIG Team
Dashboard : Metadata, architecture

Vera Gotze
Post-doc
STRUDEL team
Densification patterns, urban densification



Constantin Stoian
Engineer
MEIG team
Reproducibility, building mapping

UMR LASTIG
Université Gustave Eiffel, IGN, ENSG
www.umr-lastig.fr

Héloïse Verstraete
Research engineer
STRUDEL team

Paul Guardiola
Master student
STRUDEL team

Thank you for your attention !

Ana-Maria Raimond
Directrice de Recherche
ana-maria.raimond@ign.Fr

UMR LASTIG
Université Gustave Eiffel, IGN, ENSG
www.umr-lastig.fr