EODC Forum2021, June 8-10, Vienna, Austria [Online]

The Weight of Nations

High resolution material stock mapping on national scales

David Frantz[1], Franz Schug[1], Dominik Wiedenhofer[2], Doris Virág[2], André Baumgart[2], Sebastian van der Linden[3], Helmut Haberl[2], Patrick Hostert[1]

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[3] University of Greifswald

This research has received funding from the the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (MAT_STOCKS, grant agreement No 741950)

The MAT_STOCKS project

Understanding the Role of Material Stock Patterns for the Transformation to a Sustainable Society (MAT_STOCKS) is **locating patterns of material stock** distribution.

Project is based in the **Institute for Social Ecology** (SEC) at **University of Natural Resources and Life Sciences** (BOKU) in Vienna.

Project Websites

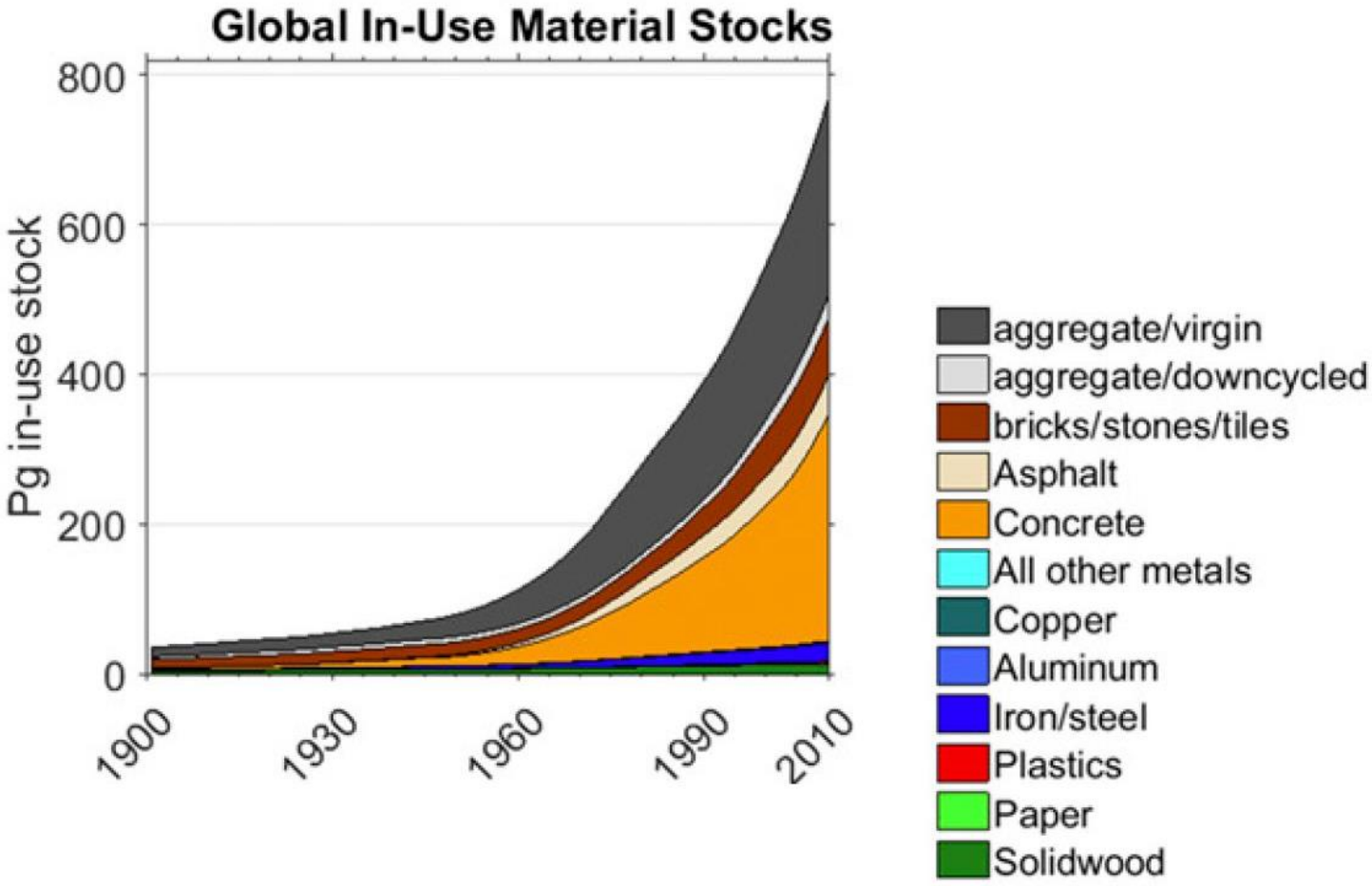
https://www.geographie.hu-berlin.de/en/professorships/eol/projects/matstocks/mat_stocks

https://boku.ac.at/understanding-the-role-of-material-stock-patterns-for-the-transformation-to-a-sustainable-society-mat-stocks

What are societies' material stocks?

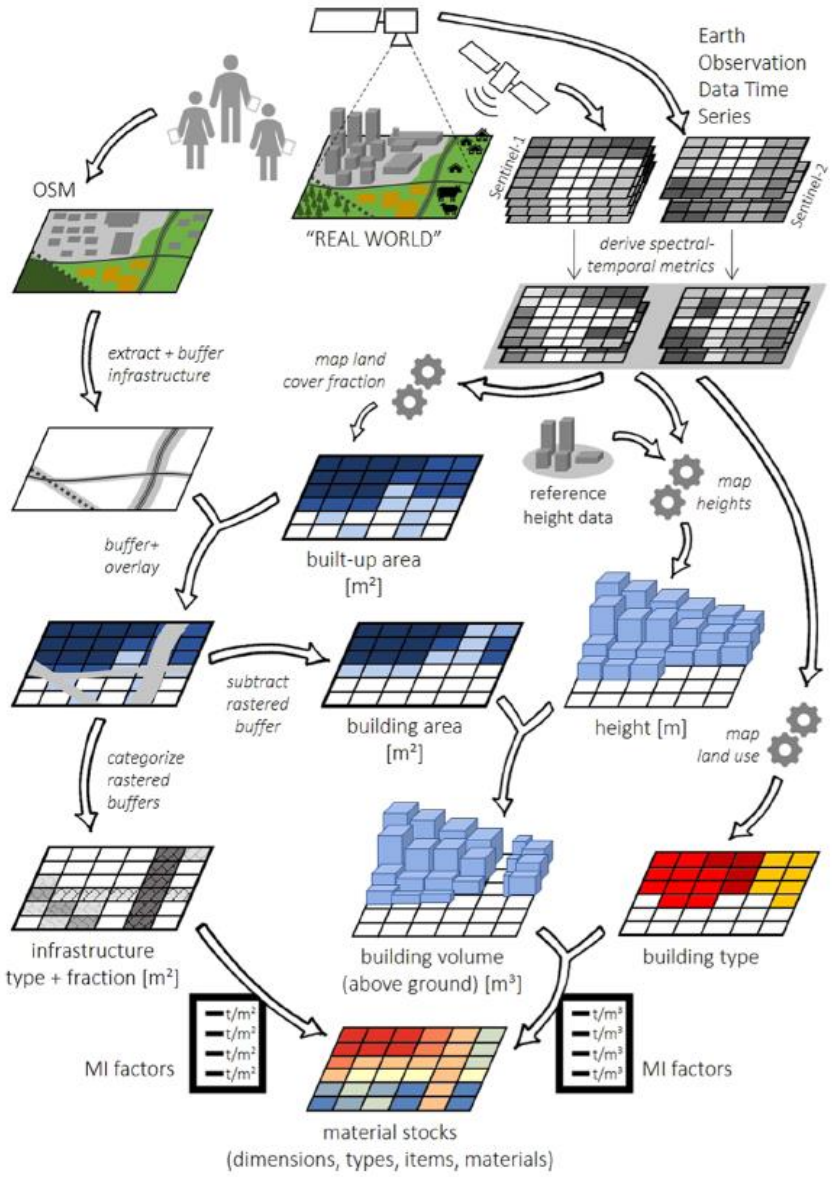
Photo: Brussels © Helmut Haberl, 2017

The MAT_STOCKS project



- Global **material stock accumulation** since 1950 is important
- Besides **concrete**, sand/gravel, metals and asphalt are the most used materials for stock accumulation.
- There are **regional differences**.
- Currently on a **nation-wide** level only.

Kraussmann et al. (2017), PNAS, 114



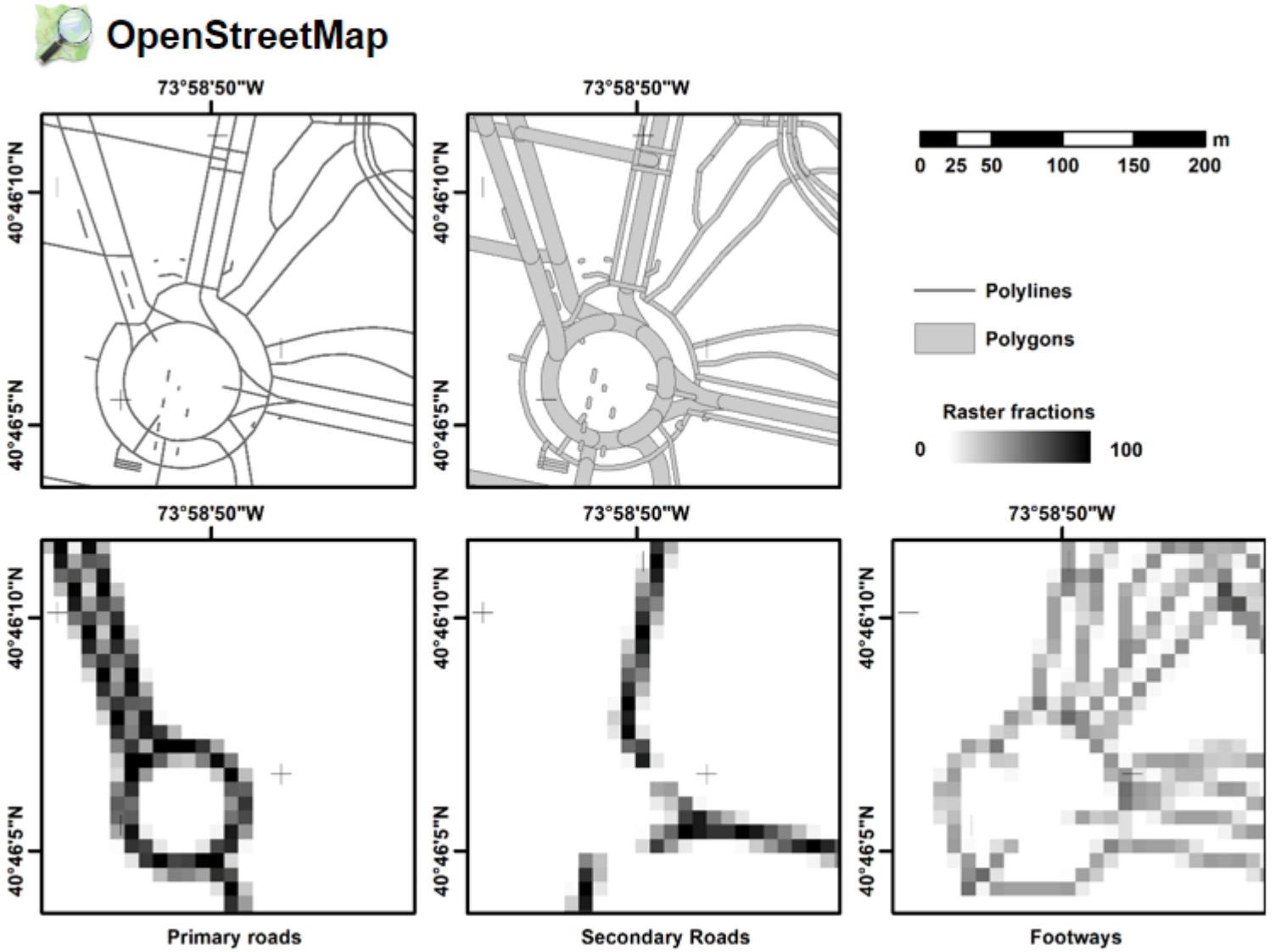
Stock-driven Bottom-Up Mapping

- Integration of Earth Observation data,
- OpenStreetMap geodata (OSM),
- construction design manuals and regulations,
- material intensity (MI) factors

- Pilot study: highly detailed material stock maps for Austria and Germany

H. Haberl, D. Wiedenhofer, F. Schug, **D. Frantz**, D. Virág, C. Plutzar, K. Gruhler, J. Lederer, G. Schiller, T. Fishman, M. Lanau, A. Gattringer, T. Kemper, G. Liu, H. Tanikawa, S. van der Linden & P. Hostert (2021): High-Resolution Maps of Material Stocks in Buildings and Infrastructures in Austria and Germany. *Environmental Science & Technology*. https://doi.org/10.1021/acs.est.0c05642

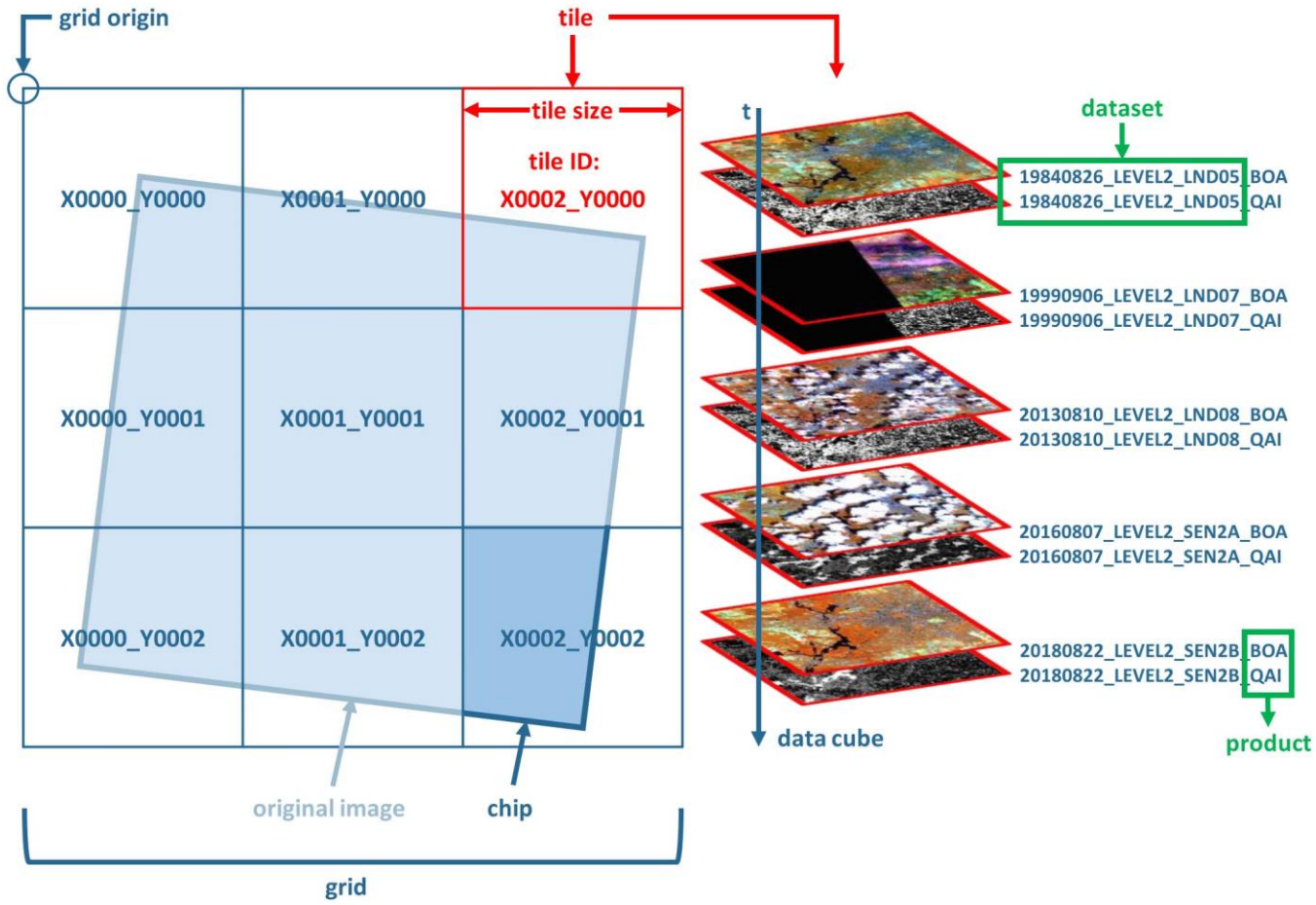
1) Infrastructure Area



- Street and rail network extracted from OSM
- Type-specific Buffer widths from construction design manuals and regulations
- Reclassified to key categories
- Converted to raster with fractional cover resampling → 100% = 100m²

- **area for each street and rail category [m²]**

2) Building Volume from EO data



FORCE
Framework for Operational Radiometric Correction for Environmental Monitoring

HUMBOLDT-UNIVERSITÄT ZU BERLIN

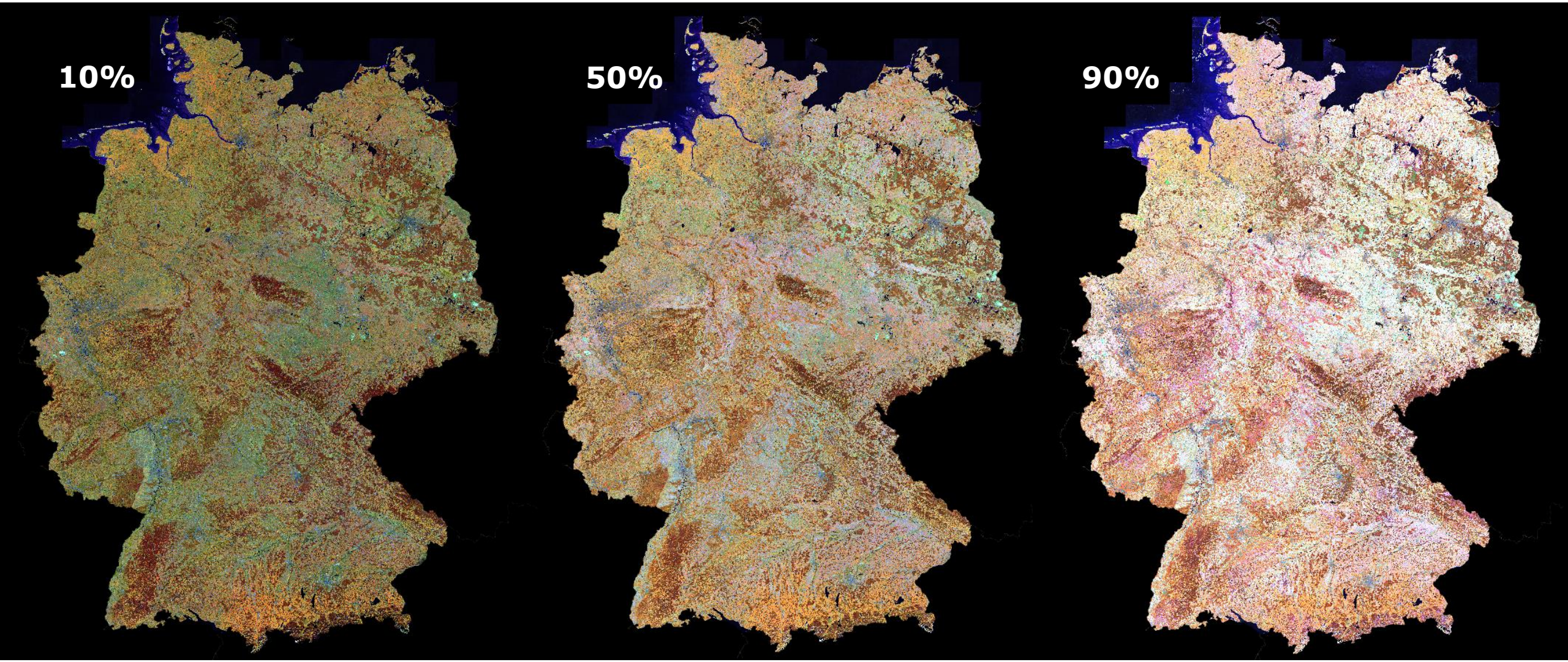
TU WIEN

eodc

VIENNA SCIENTIFIC CLUSTER

Analysis Ready Data

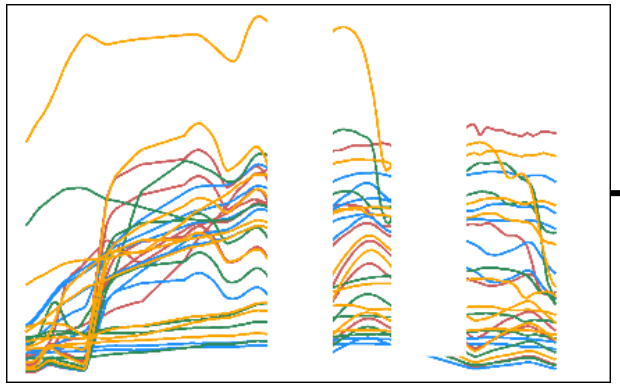
2) Building Volume from EO data



RGB = NIR / SWIR1 / RED [same stretch for all]

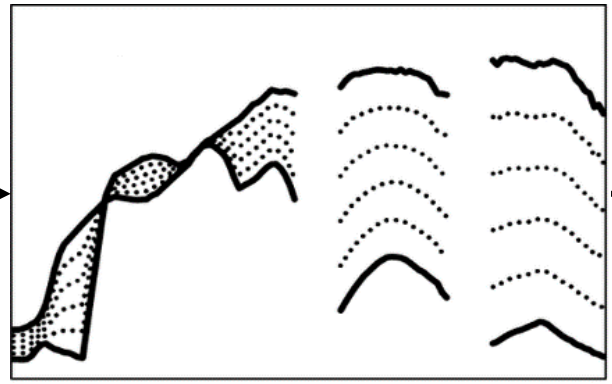
2.1) Building Area: regression-based unmixing

Endmember library

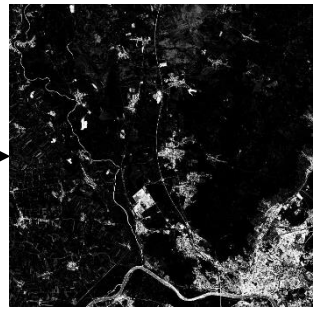


Synthetic spectral mixing

SynthMix
Synthetically mixed training data

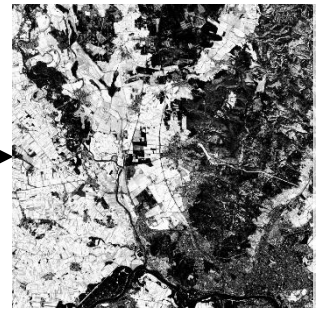


Regression-based Unmixing: SVM



built-up

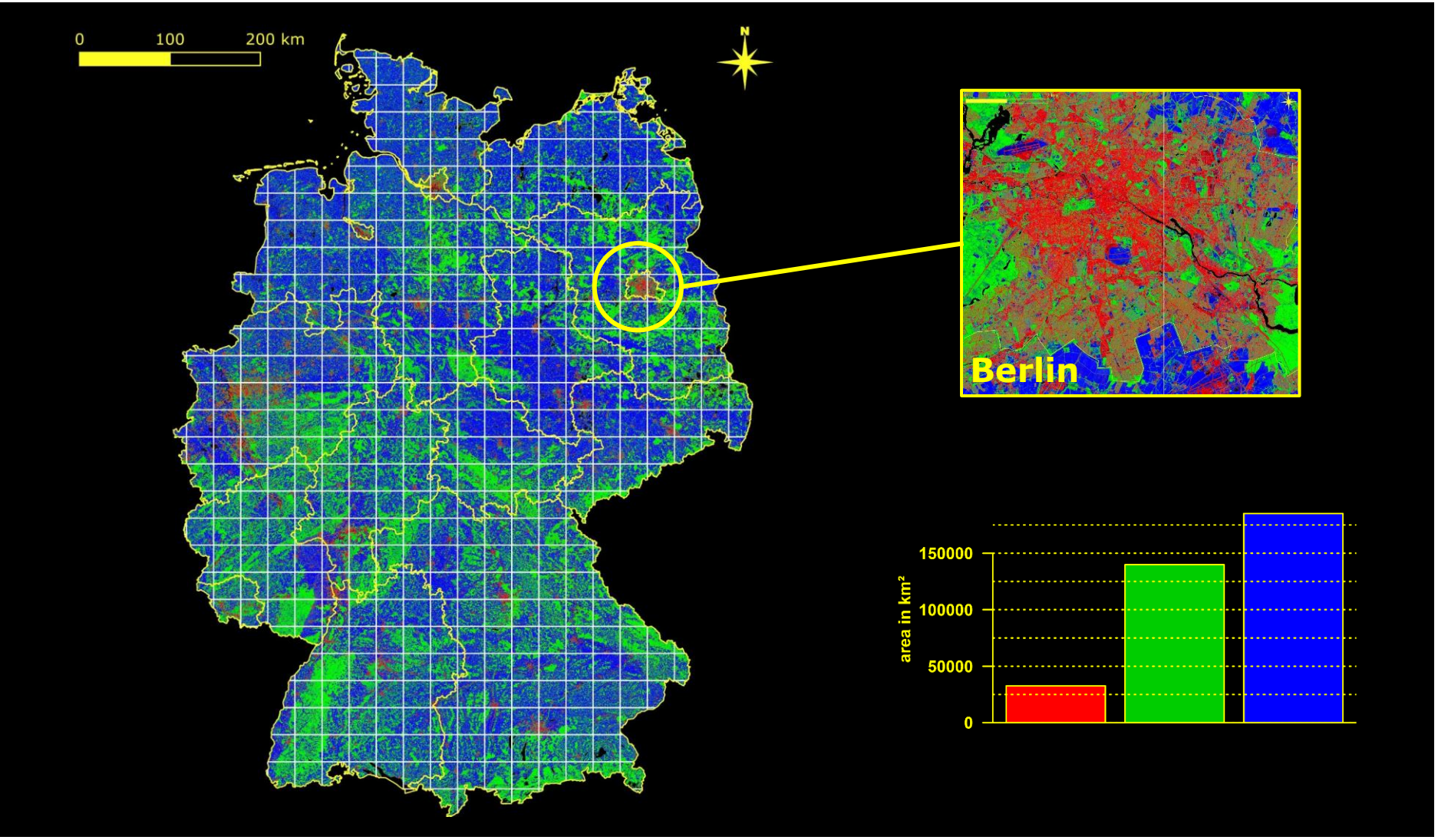
woody veg



non-woody veg

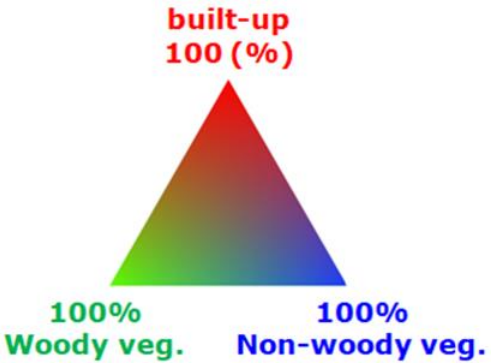
Okujeni et al. 2017, doi 10.1109/JSTARS.2016.2634859
Okujeni et al. 2018, doi.org/10.1016/j.rse.2018.07.011

2.1) Building Area: regression-based unmixing



Sensors:
Sentinel-2A
Sentinel-2B
Sentinel-1A
Sentinel-1B

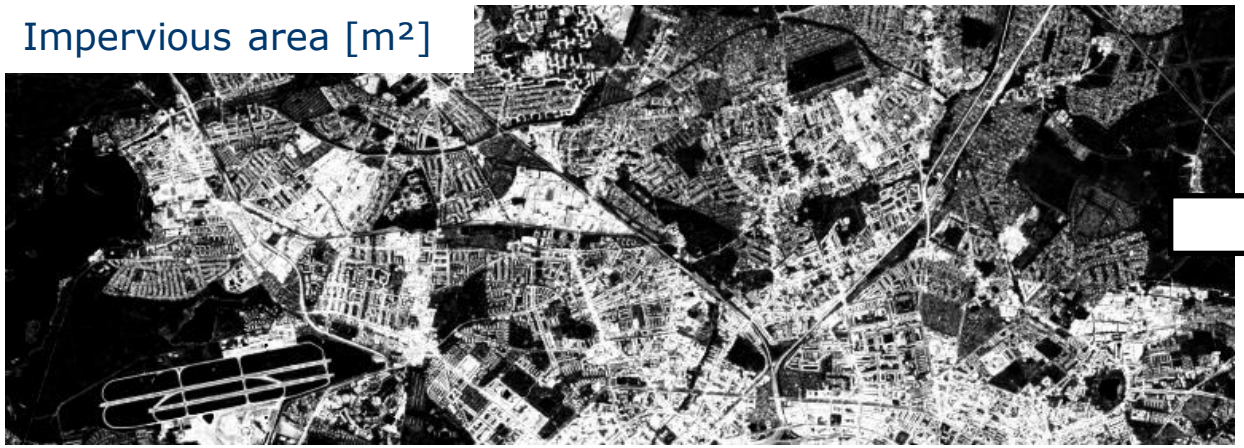
Time:
2017/18



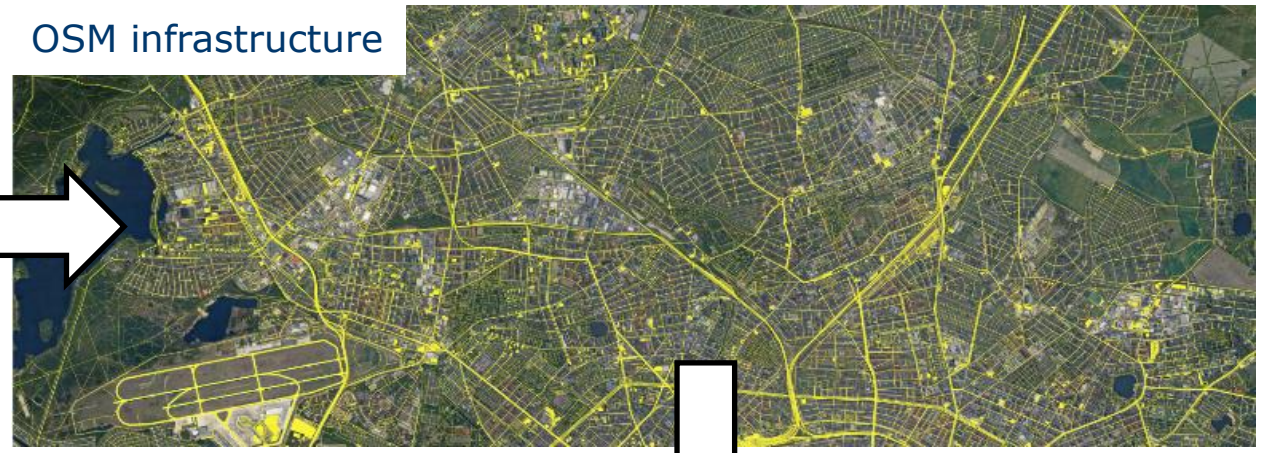
Schug, **Frantz**, Okujeni, van der Linden, Hostert (2020). Mapping urban-rural gradients of settlements and vegetation at national scale using Sentinel-2 spectral-temporal metrics and regression-based unmixing with synthetic training data. *Remote Sensing of Environment*

2.1) Building Area: from impervious to building area

Impervious area [m²]

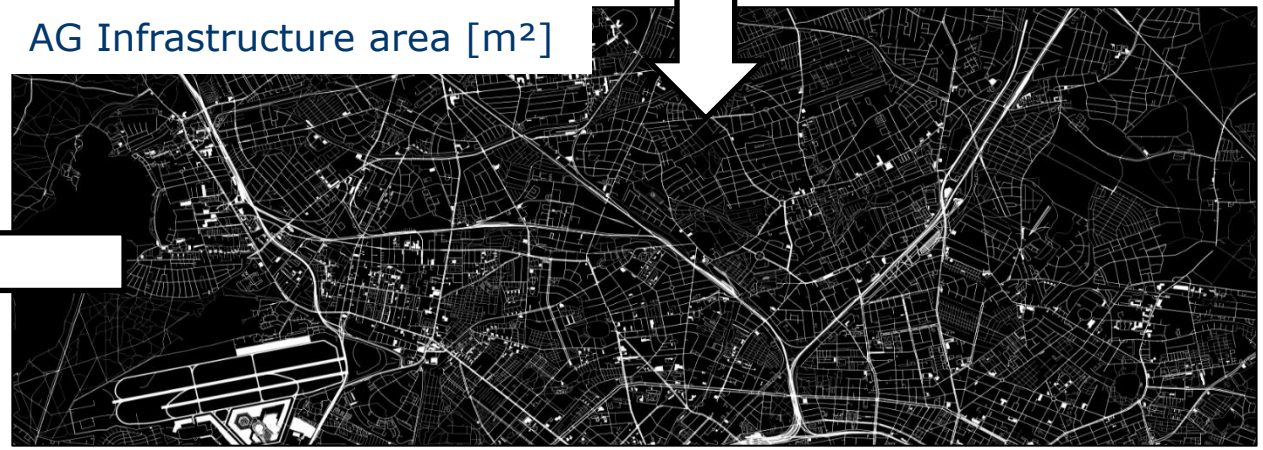


OSM infrastructure

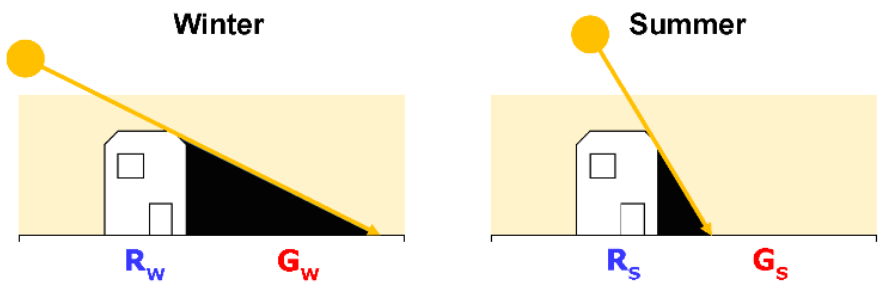


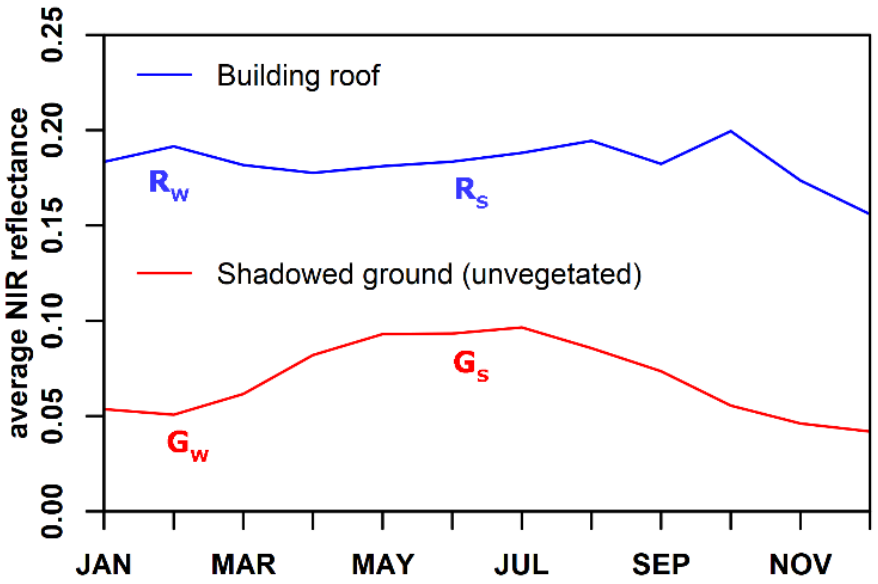
Building area [m²]

AG Infrastructure area [m²]

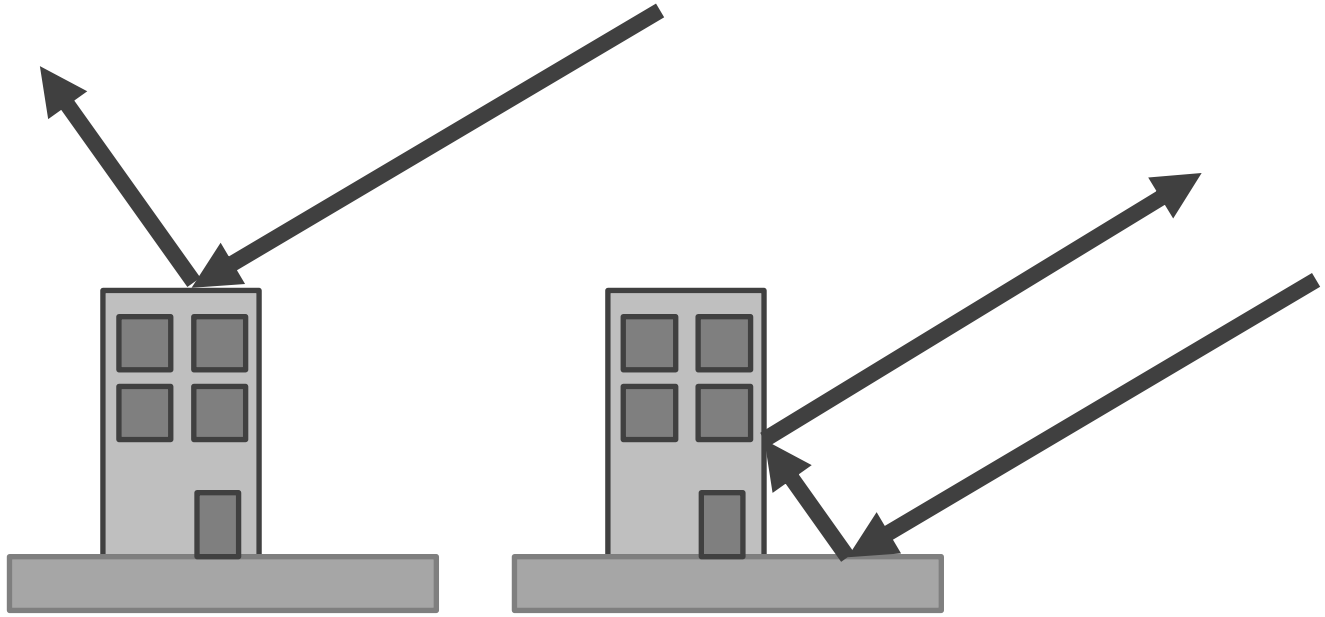


2.2) Building Height: feature space



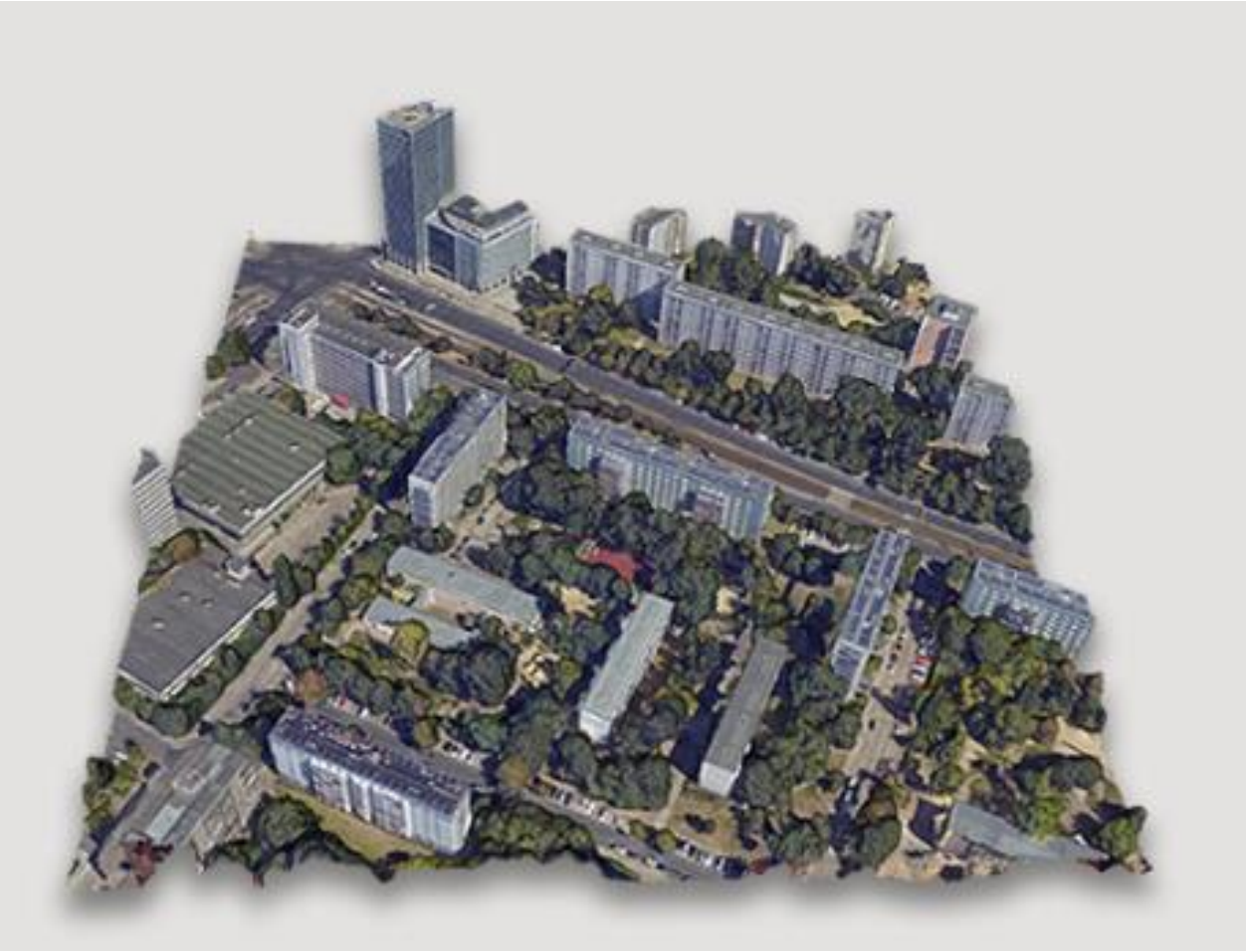


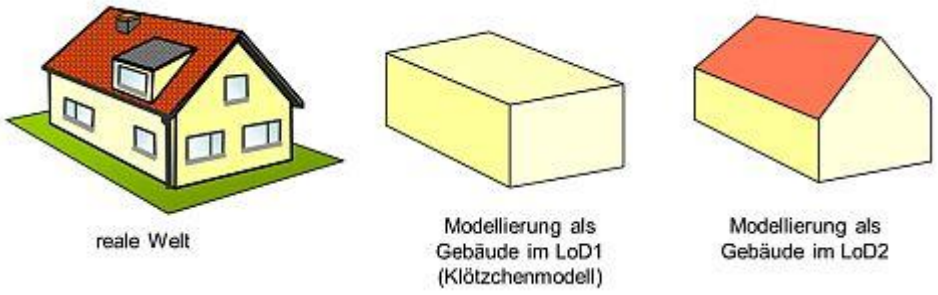
- Synergistic use of S1 and S2 time series
  - optical data: roof materials + shadow phenology
  - radar data: geometry



2.2) Building Height: training data

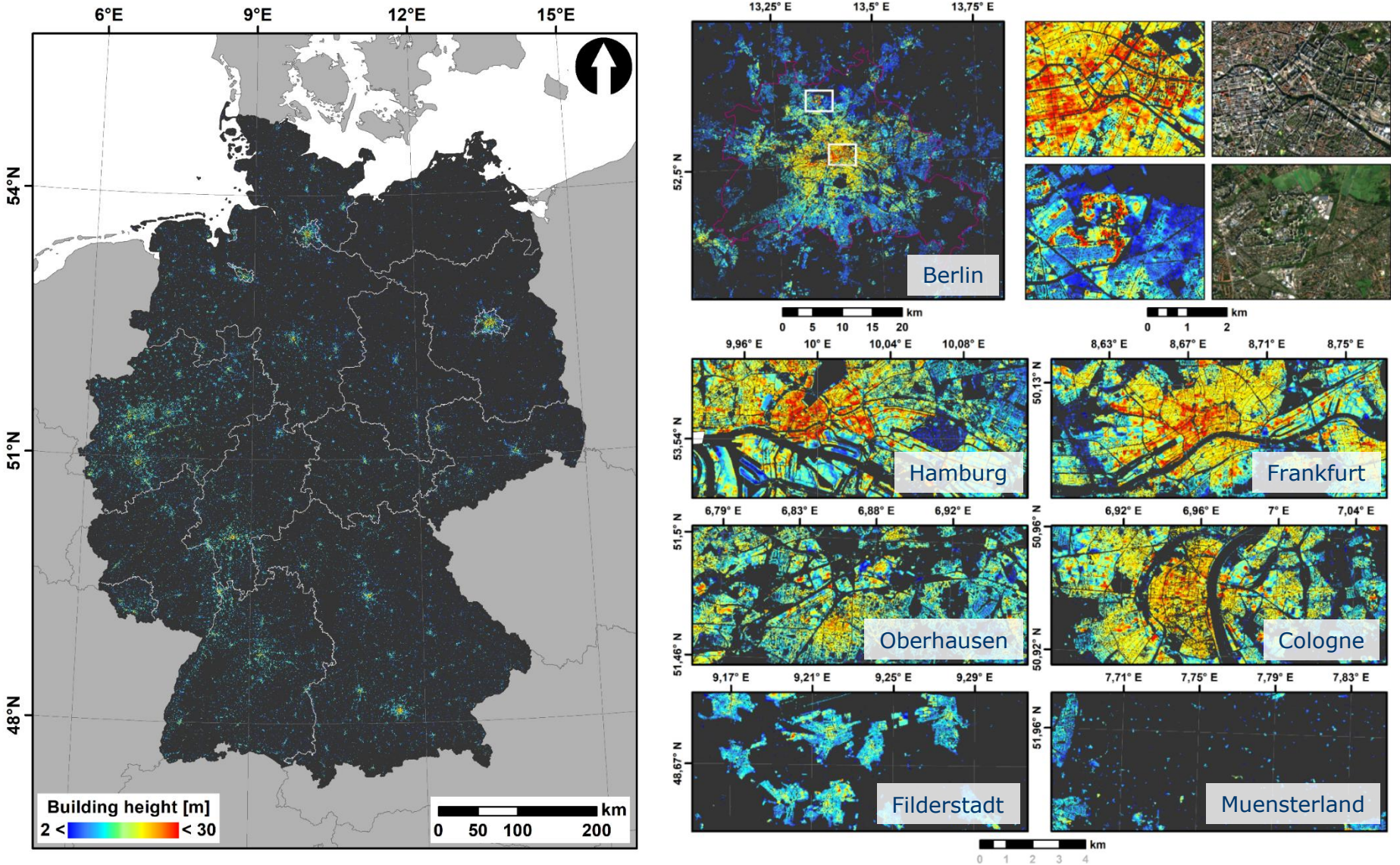
Training and validation from 3D Building Models, based on cadastre and airborne laser scanning





Site	Year	Buildings
Berlin	**2014 (99.9%)** **2015 (0.1%)**	**540,172**
Hamburg	2016	374,99
Potsdam	2012	44,832
North Rhine Westphalia	2018 (39%) 2019 (61%)	11,498,734
Thuringia	2018 (13%) 2019 (57%) 2020 (30%)	2,241,792

2.2) Building Height



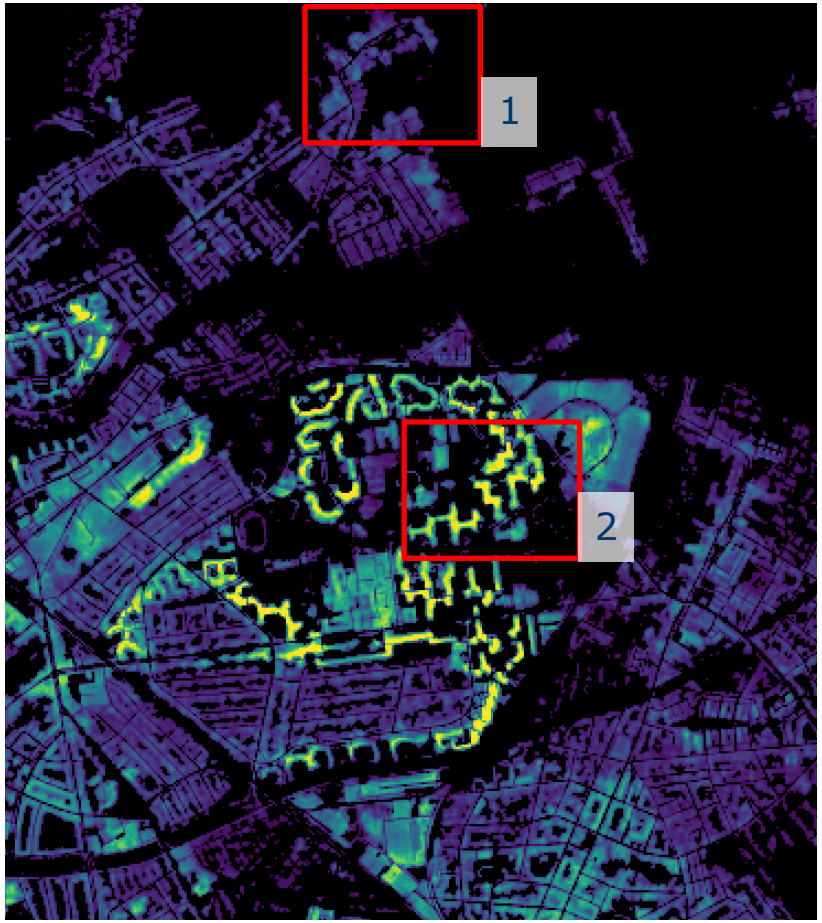
Sensors:
Sentinel-2A
Sentinel-2B
Sentinel-1A
Sentinel-1B

Time:
2017/18

Frantz, Schug, Okujeni, Navacchi, Wagner, van der Linden, Hostert (2021): National-scale mapping of building height using Sentinel-1 and Sentinel-2 time series. *Remote Sensing of Environment* 252.

2.3) Building Volume

Building Area [m²] x Building Height [m] = Building Volume [m³]



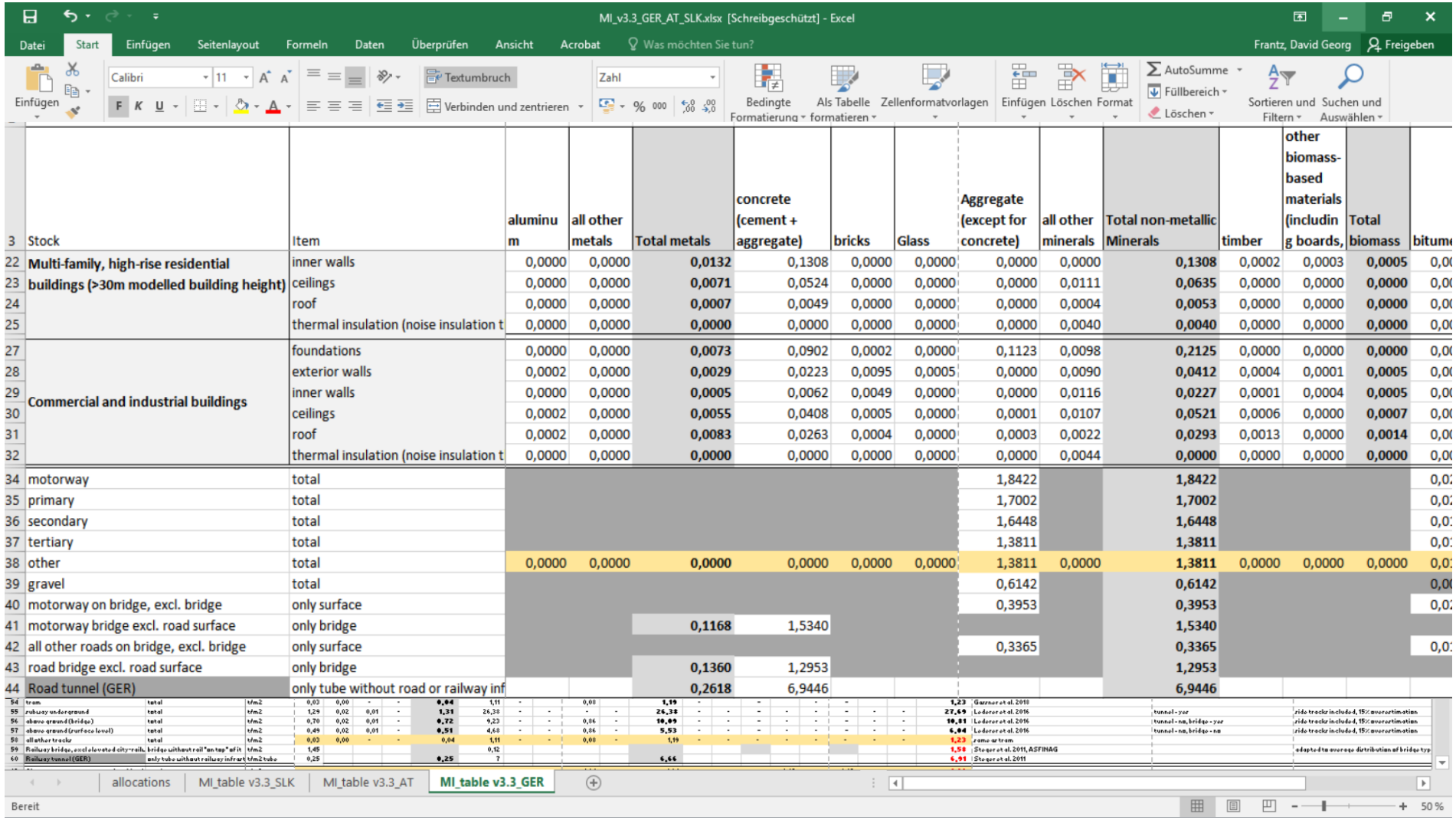
2.4) Building Type

Random Forest classification to map residential and non-residential building types

Ca. 1200 samples from two regions in Ger.

OA: ~80% (based on 30% of the samples)

3) Material Intensity Factors: MI [t/m²], [t/m³]



MI_v3.3_GER_AT_SLK.xlsx [Schreibgeschützt] - Excel

3	Stock	Item	aluminum	all other metals	Total metals	concrete (cement + aggregate)	bricks	Glass	Aggregate (except for concrete)	all other minerals	Total non-metallic Minerals	timber	other biomass-based materials (including boards,	Total biomass	bitume
22	**Multi-family, high-rise residential buildings (>30m modelled building height)**	inner walls	0,0000	0,0000	**0,0132**	0,1308	0,0000	0,0000	0,0000	0,0000	**0,1308**	0,0002	0,0003	**0,0005**	0,0
23		ceilings	0,0000	0,0000	**0,0071**	0,0524	0,0000	0,0000	0,0000	0,0111	**0,0635**	0,0000	0,0000	**0,0000**	0,0
24		roof	0,0000	0,0000	**0,0007**	0,0049	0,0000	0,0000	0,0000	0,0004	**0,0053**	0,0000	0,0000	**0,0000**	0,0
25		thermal insulation (noise insulation t	0,0000	0,0000	**0,0000**	0,0000	0,0000	0,0000	0,0000	0,0040	**0,0040**	0,0000	0,0000	**0,0000**	0,0
27	**Commercial and industrial buildings**	foundations	0,0000	0,0000	**0,0073**	0,0902	0,0002	0,0000	0,1123	0,0098	**0,2125**	0,0000	0,0000	**0,0000**	0,0
28		exterior walls	0,0002	0,0000	**0,0029**	0,0223	0,0095	0,0005	0,0000	0,0090	**0,0412**	0,0004	0,0001	**0,0005**	0,0
29		inner walls	0,0000	0,0000	**0,0005**	0,0062	0,0049	0,0000	0,0000	0,0116	**0,0227**	0,0001	0,0004	**0,0005**	0,0
30		ceilings	0,0002	0,0000	**0,0055**	0,0408	0,0005	0,0000	0,0001	0,0107	**0,0521**	0,0006	0,0000	**0,0007**	0,0
31		roof	0,0002	0,0000	**0,0083**	0,0263	0,0004	0,0000	0,0003	0,0022	**0,0293**	0,0013	0,0000	**0,0014**	0,0
32		thermal insulation (noise insulation t	0,0000	0,0000	**0,0000**	0,0000	0,0000	0,0000	0,0000	0,0044	**0,0000**	0,0000	0,0000	**0,0000**	0,0
34	motorway	total							1,8422		**1,8422**				0,0
35	primary	total							1,7002		**1,7002**				0,0
36	secondary	total							1,6448		**1,6448**				0,0
37	tertiary	total							1,3811		**1,3811**				0,0
38	other	total	0,0000	0,0000	**0,0000**	0,0000	0,0000	0,0000	1,3811	0,0000	**1,3811**	0,0000	0,0000	0,0000	0,0
39	gravel	total							0,6142		**0,6142**				0,0
40	motorway on bridge, excl. bridge	only surface							0,3953		**0,3953**				0,0
41	motorway bridge excl. road surface	only bridge			**0,1168**	1,5340					**1,5340**				
42	all other roads on bridge, excl. bridge	only surface							0,3365		**0,3365**				0,0
43	road bridge excl. road surface	only bridge			**0,1360**	1,2953					**1,2953**				
44	Road tunnel (GER)	only tube without road or railway inf			**0,2618**	6,9446					**6,9446**				

allocations | MI_table v3.3_SLK | MI_table v3.3_AT | MI_table v3.3_GER

Bereit

Universität für Bodenkultur Wien
Department für Wirtschafts- und Sozialwissenschaften
Institute of Social Ecology

3) Material Intensity Factors

motorways m²	x	MI concrete	MI bricks	MI steel	MI …	=	t
primary roads m²	x	MI concrete	MI bricks	MI steel	MI …	=	t
foot paths m²	x	MI concrete	MI bricks	MI steel	MI …	=	t
rails m²	x	MI concrete	MI bricks	MI steel	MI …	=	t
subways m²	x	MI concrete	MI bricks	MI steel	MI …	=	t
single-family m³	x	MI concrete	MI bricks	MI steel	MI …	=	t
multi-family m³	x	MI concrete	MI bricks	MI steel	MI …	=	t
…	x	MI concrete	MI bricks	MI steel	MI …	=	t

Σ = Total Material Stocks

- **resource consumption:**

AT: ~540 t/cap

DE: ~450 t/cap

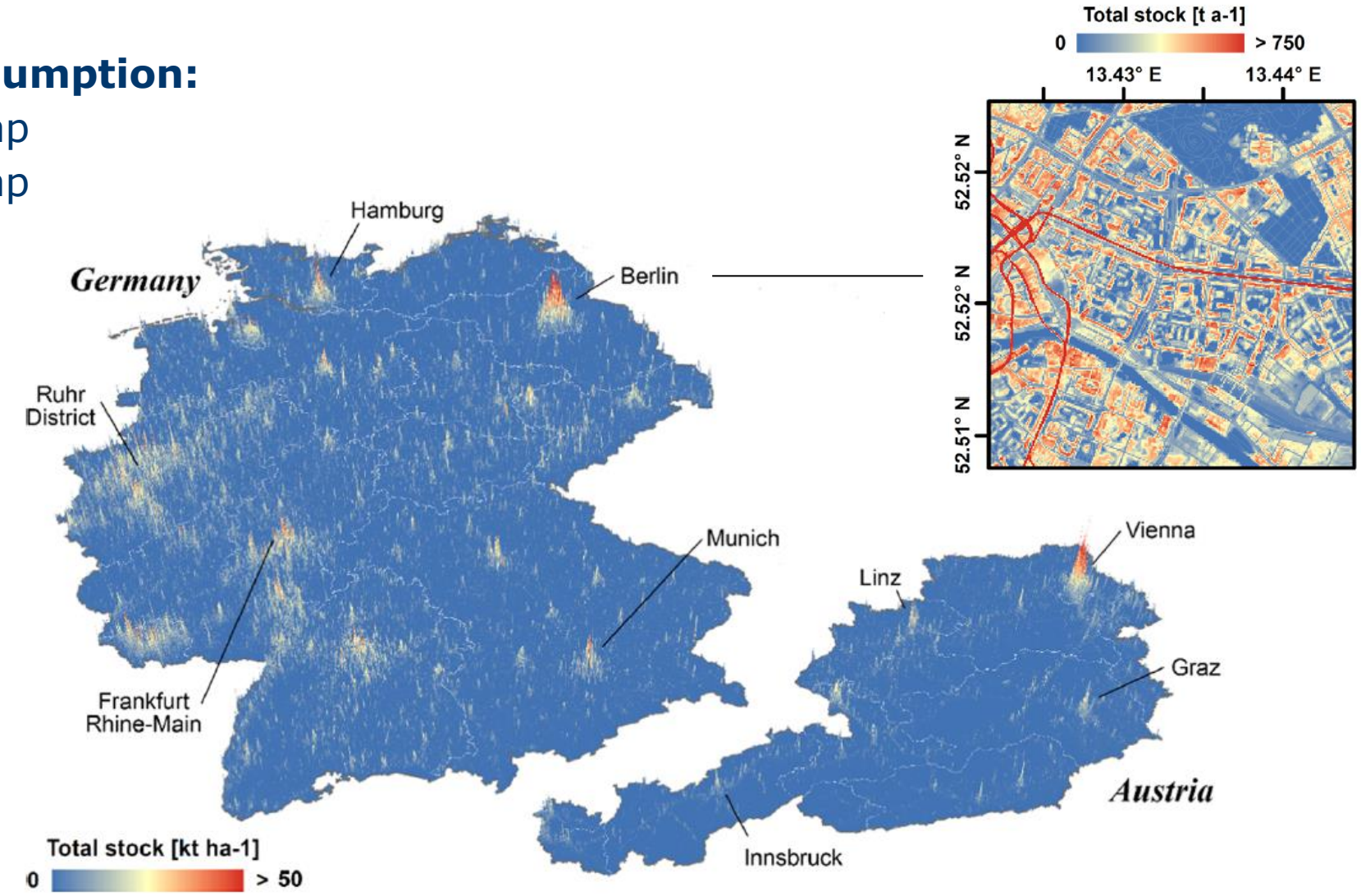
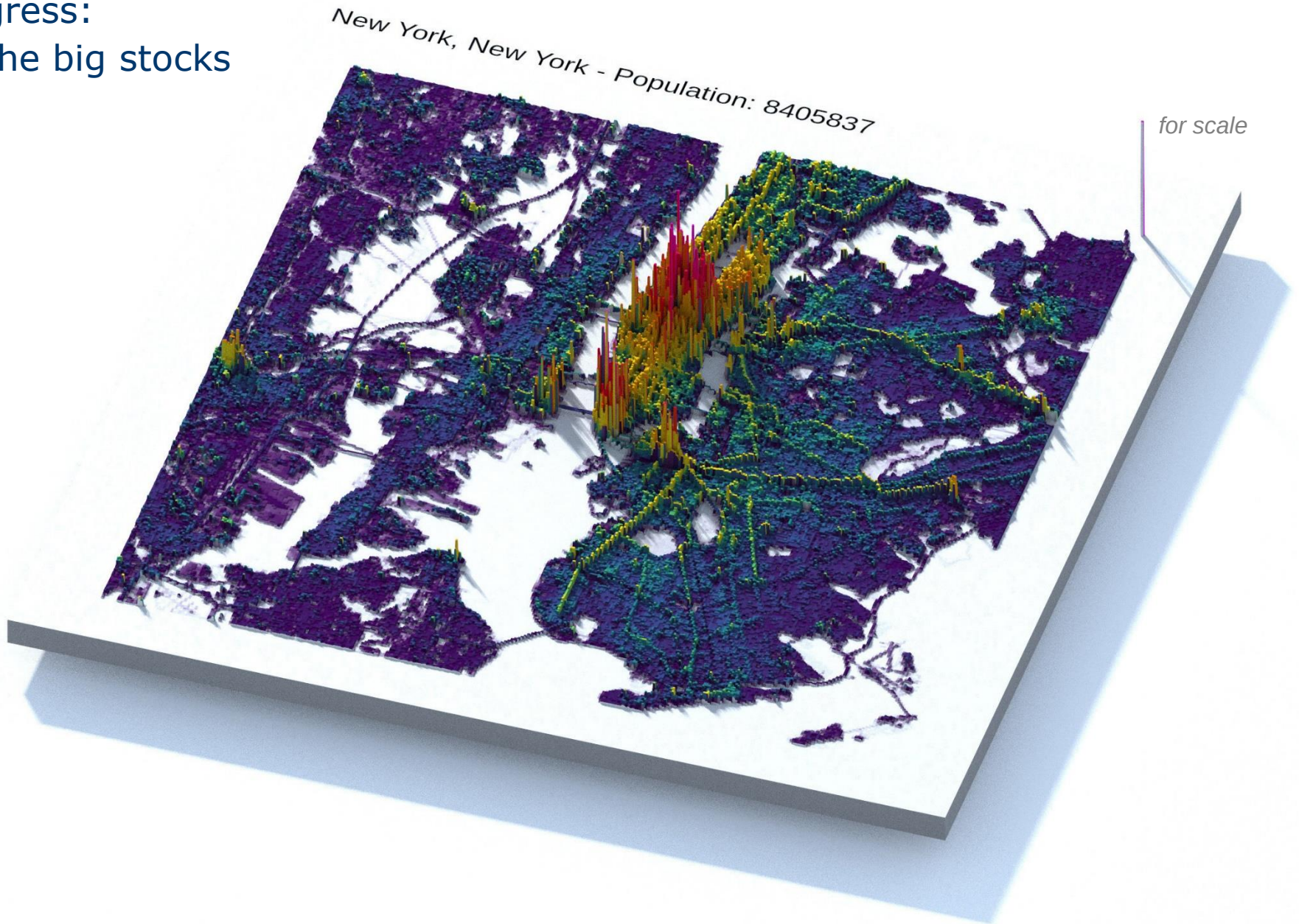
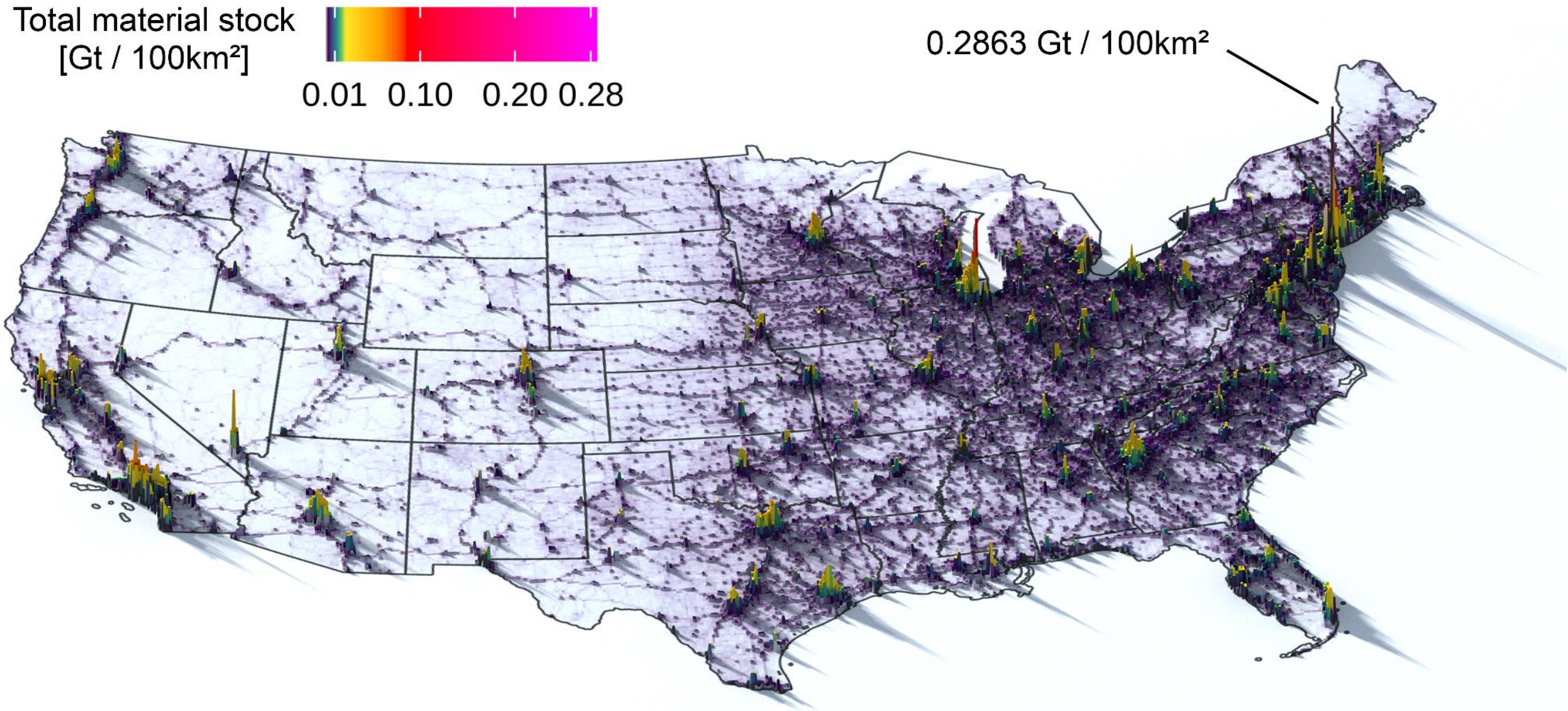


Figure 2. Three-dimensional maps of total material stocks in buildings and infrastructures in Germany and Austria (2018; 100 m resolution), measured as kt/ha (1 kt = 1000 metric tons; 1 ha = 10^4 m^2 = 0.01 km^2).

Work in progress:
going after the big stocks




Total material stock
[Gt / 100km²]
0.01 0.10 0.20 0.28
0.2863 Gt / 100km²

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web hu.berlin/eo-lab
twitter.com/HumboldtEOLab
twitter.com/d__frantz

Thank you for your attention!

FORCE
https://github.com/davidfrantz/force

Related Work:

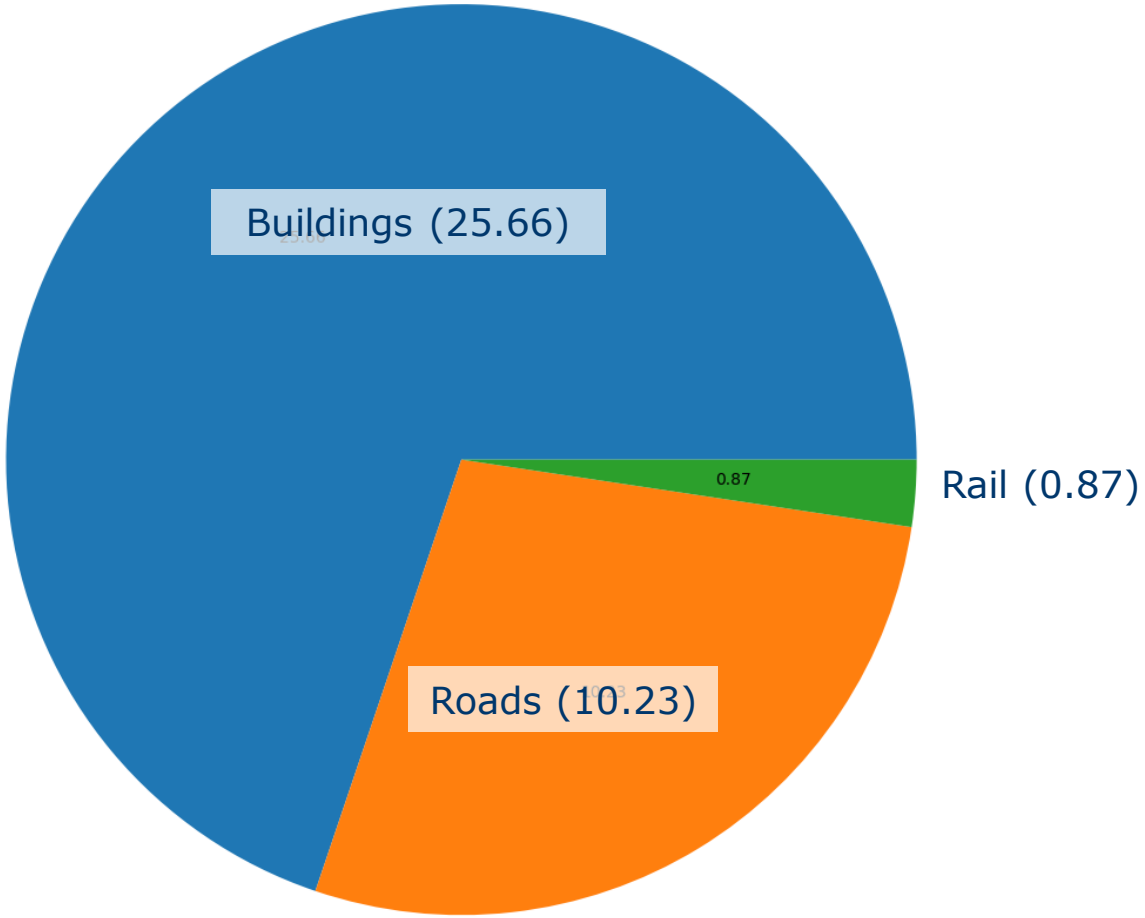
- Frantz. D. (2019). FORCE – Landsat + Sentinel-2 Analysis Ready Data and beyond: Remote Sensing
- Frantz, D., et al. (2021). National-scale mapping of building height using Sentinel-1+2 time series. RSE
- Haberl, H., et al. (2021). High-Resolution Maps of Material Stocks in Buildings and Infrastructures in Austria and Germany. EST
- Okujeni, A., et al. (2017). Ensemble Learning From Synthetically Mixed Training Data for Quantifying Urban Land Cover With Support Vector Regression. IEEE JSTARS
- Schug, F., et al. (2020). Mapping urban-rural gradients of settlements and vegetation at national scale using Sentinel-2 spectral-temporal metrics and regression-based unmixing with synthetic training data. RSE

European Research Council
Established by the European Commission

This research has received funding from the the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (MAT_STOCKS, grant agreement No 741950)

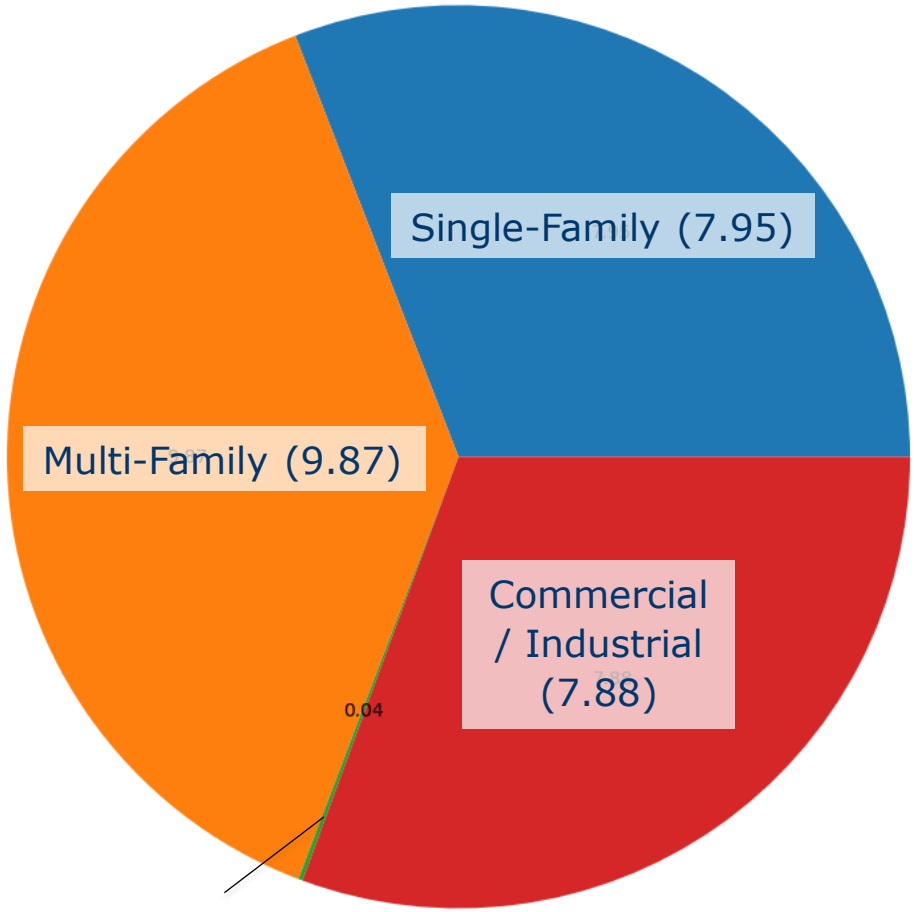
Material Stocks (in Gt)

Types



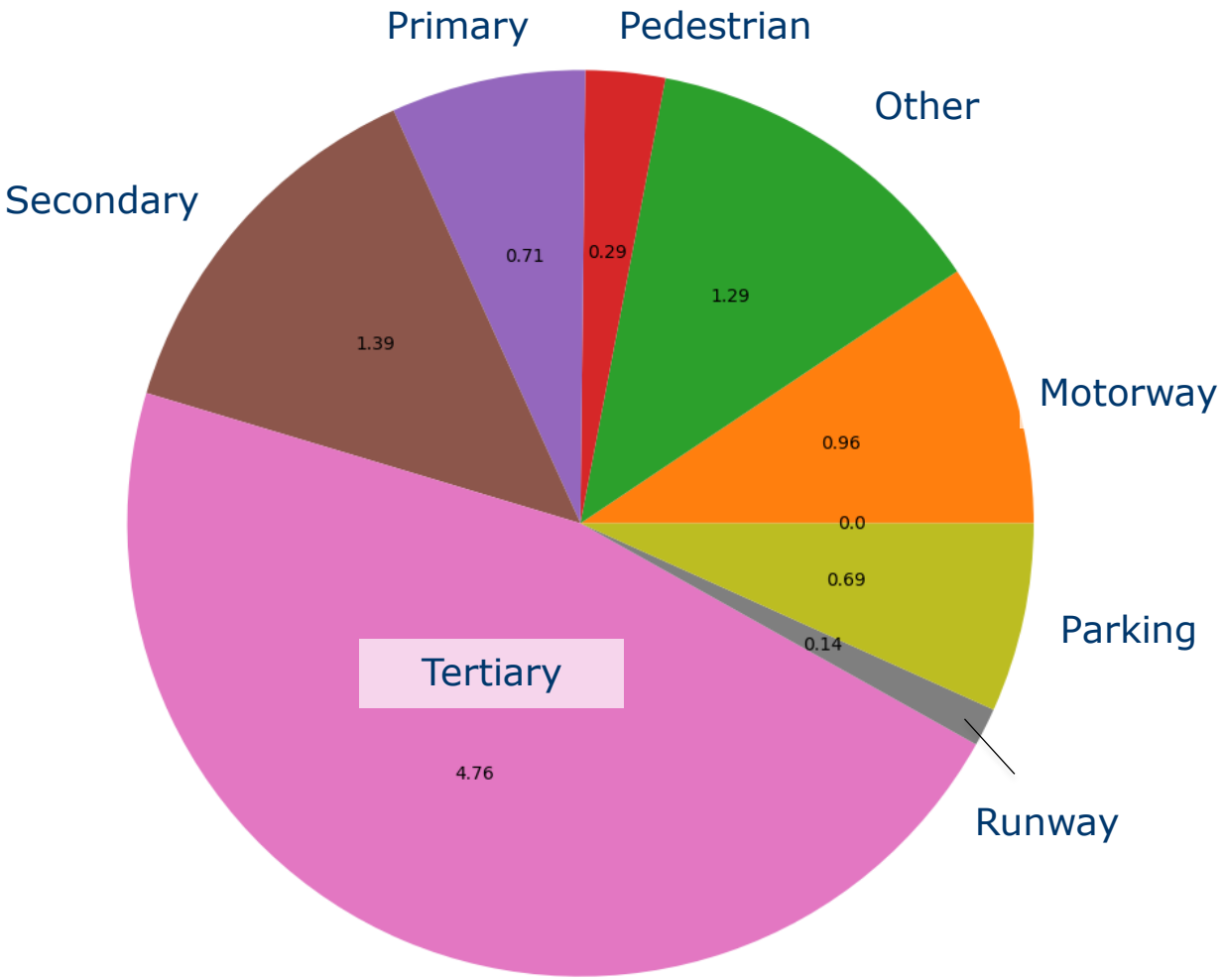
Material Stocks (in Gt)

Buildings



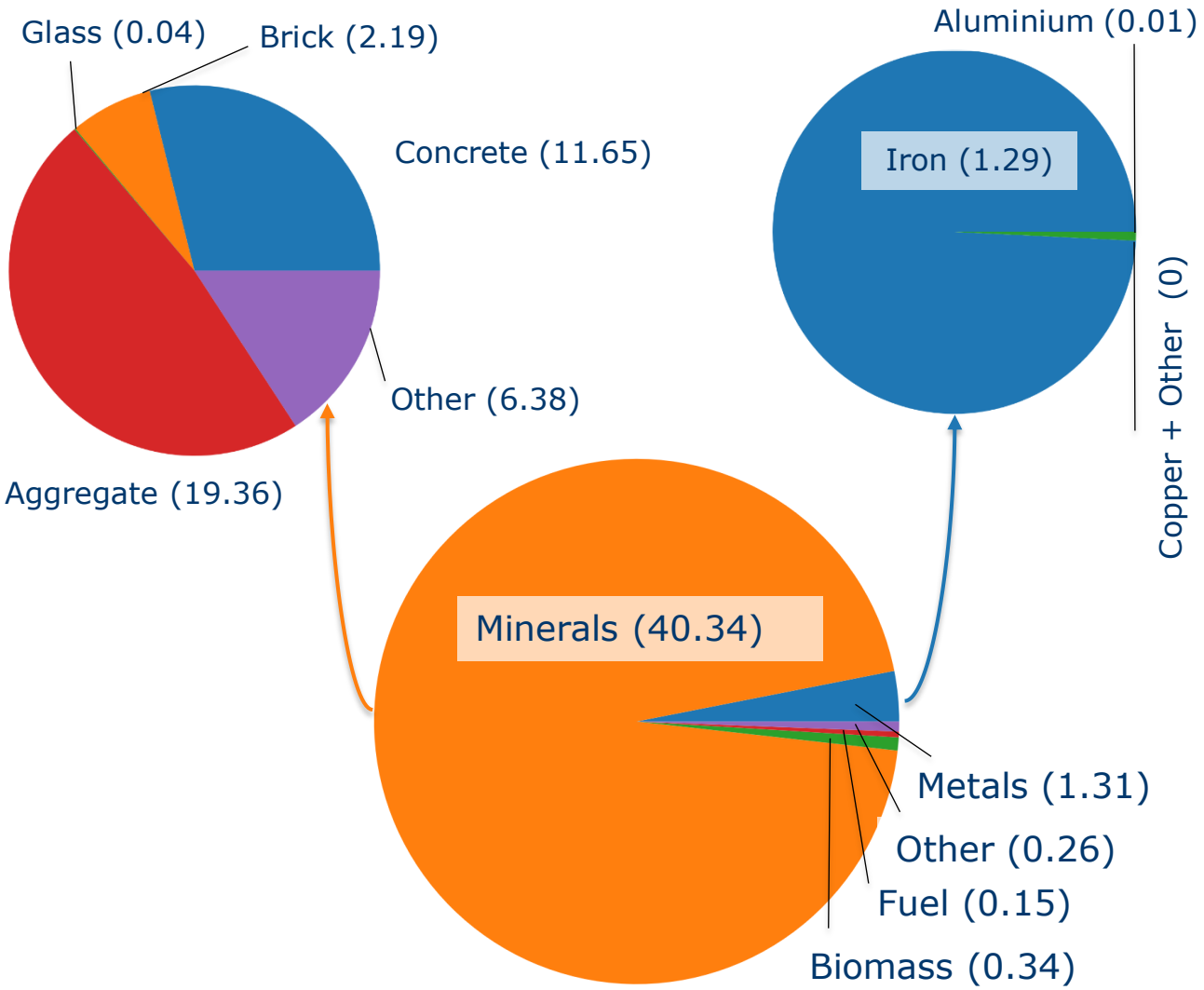
Material Stocks (in Gt)

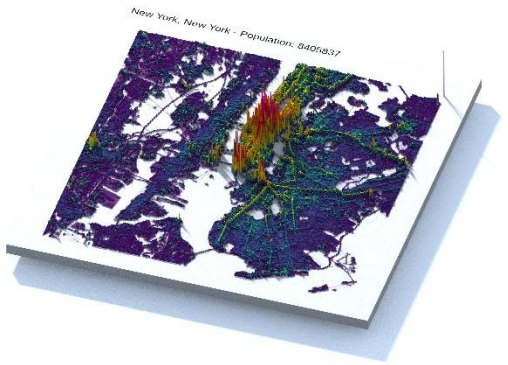
Roads

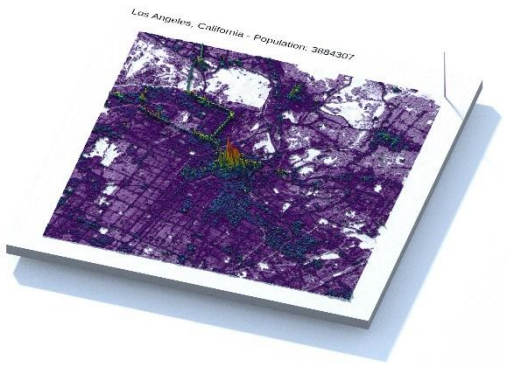


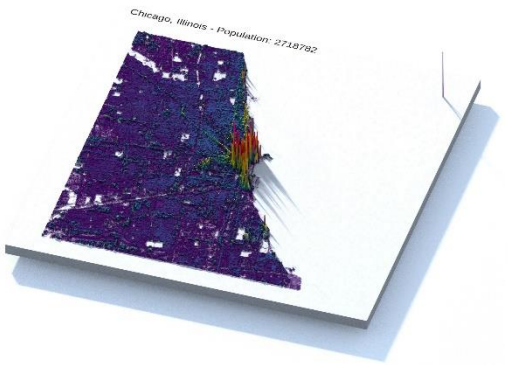
Material Stocks (in Gt)

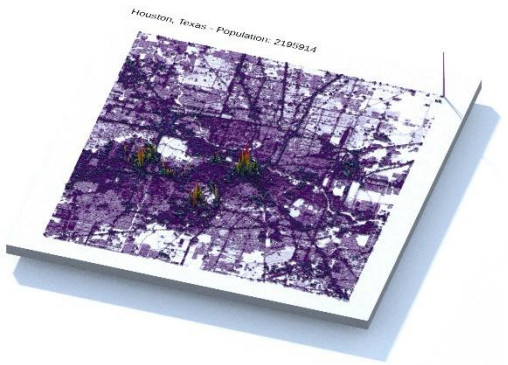
Materials

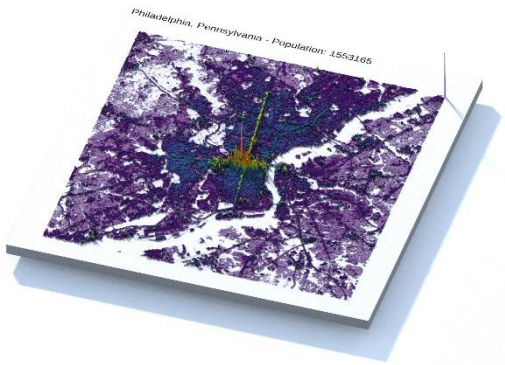



New York, New York - Population: 8405837


Los Angeles, California - Population: 3884307


Chicago, Illinois - Population: 2718782


Houston, Texas - Population: 2195914


Philadelphia, Pennsylvania - Population: 1553165


Phoenix, Arizona - Population: 1513367


San Antonio, Texas - Population: 1409019


San Diego, California - Population: 1355896

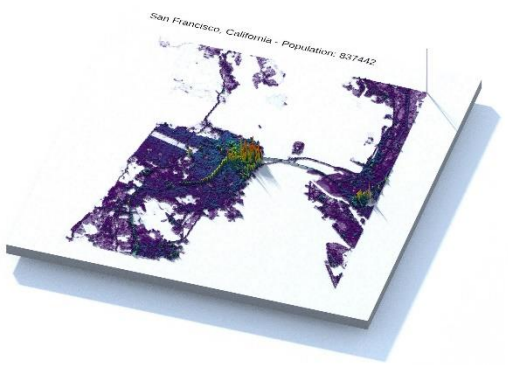

Dallas, Texas - Population: 1257676


San Jose, California - Population: 998537


Austin, Texas - Population: 885400


Indianapolis, Indiana - Population: 843393


Jacksonville, Florida - Population: 842583


San Francisco, California - Population: 837442


Columbus, Ohio - Population: 822553