Deutsche Gesellschaft für Geographie | DGfG

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European Research Council
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The weight of nations

National-scale material stock maps based on Sentinel-1+2, OSM, and material intensity factors

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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?

Metals
- Iron / steel
- copper
- aluminium

Minerals
- Concrete
- Bricks
- Glass
- Aggregate

Biomass
- Timber

Petroleum products
- Bitumen

Insulation

What are societies' material stocks?

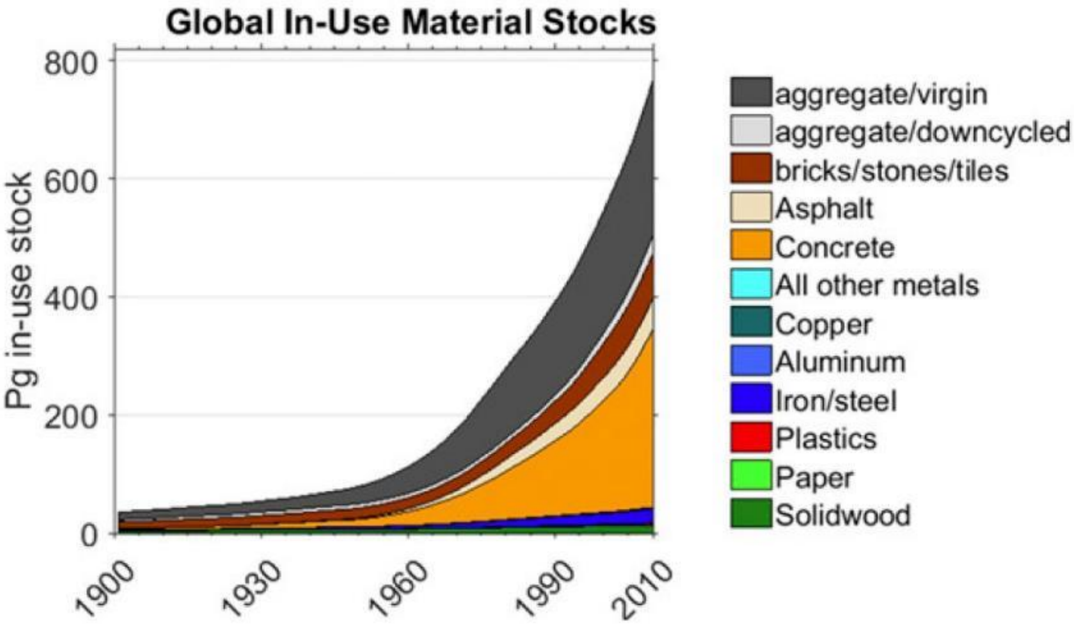
Mobility infrastructure

- Motorways
- Primary streets
- Footpaths
- Railways
- Subways
- Parking spaces

Buildings

- Residential buildings
- Commercial buildings
- Skyscrapers
- Industrial buildings
- Lightweight buildings

The great acceleration



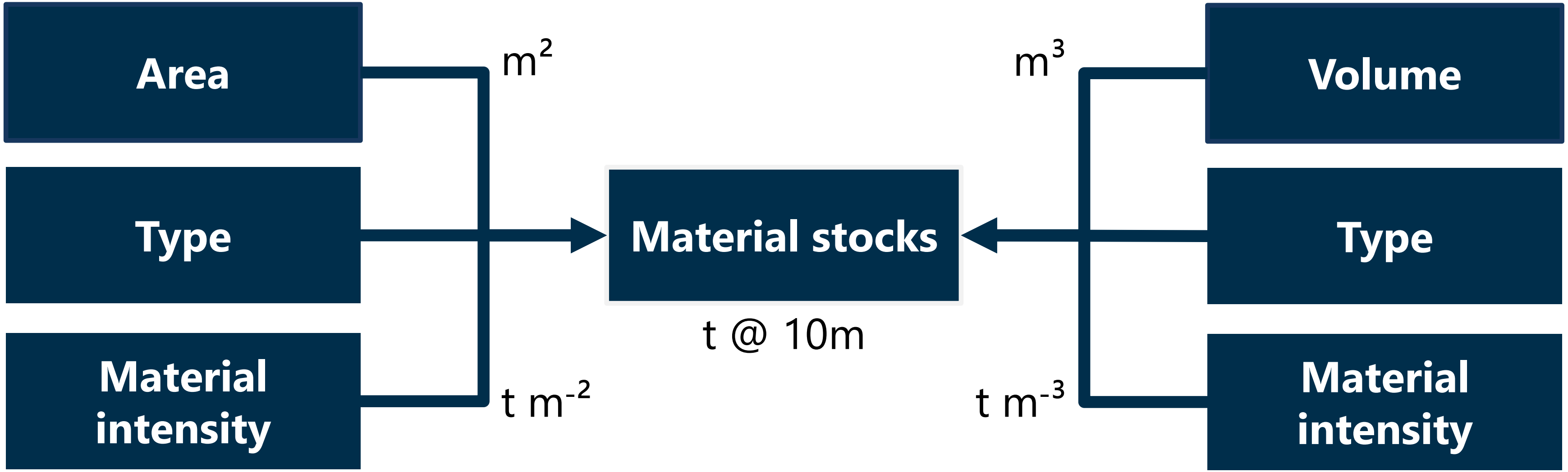
- Global **material stocks accumulation** since 1950
- Besides **concrete**, sand/gravel, metals and asphalt are the most used materials for stock accumulation.
- There are **regional differences**.
- Currently on a **nation-wide** level only

Kraussmann et al. (2017), PNAS, 114

Stock-driven bottom-up mapping

Mobility Infrastructure

Buildings



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

Mobility infrastructure: crowd-sourced GIS data

PLOS | ONE

The world's user-generated road map is more than 80% complete

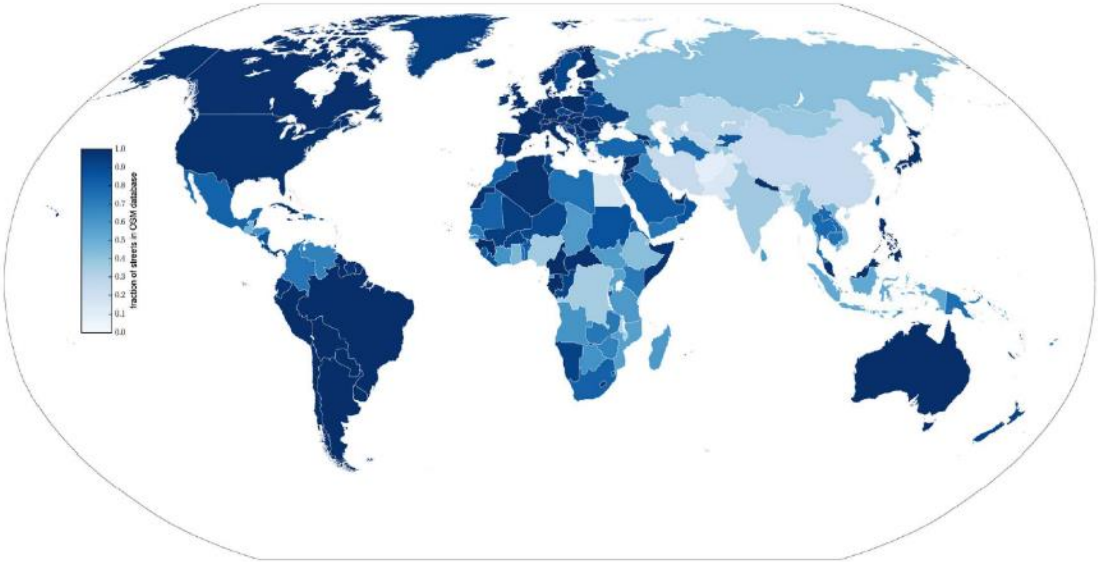
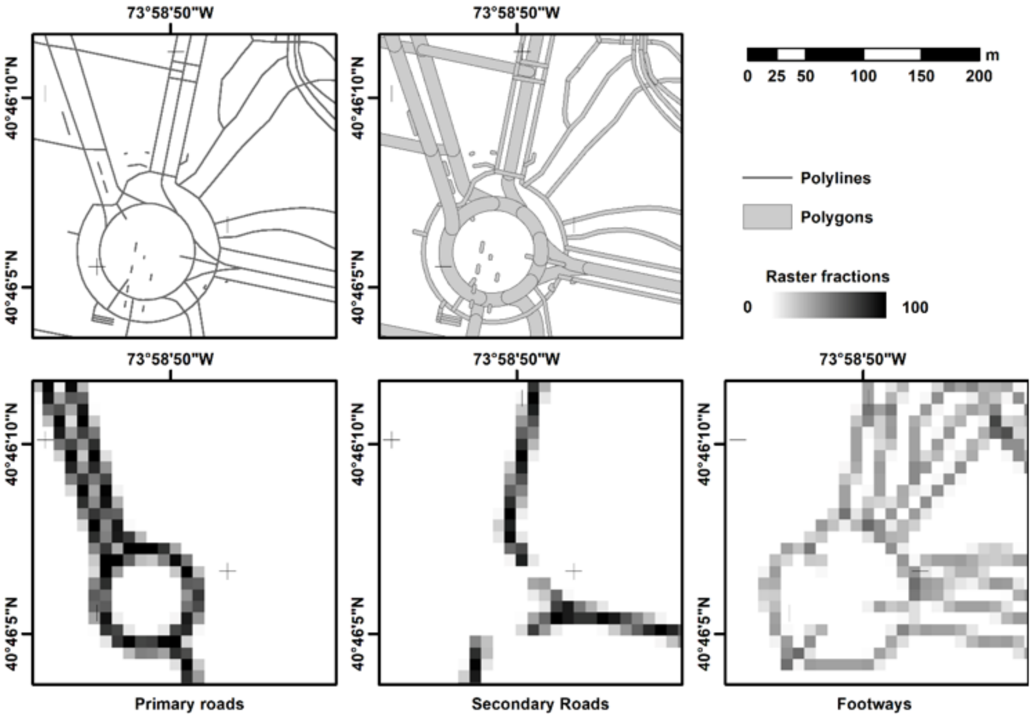


Fig 5. Completeness of the OSM dataset, by country, January 2016. The fraction complete is estimated by the parametric model, where that estimate falls within five percentage points or the 95% confidence interval of the multilevel model. Otherwise, the multilevel model is used.

https://doi.org/10.1371/journal.pone.0180698.g005

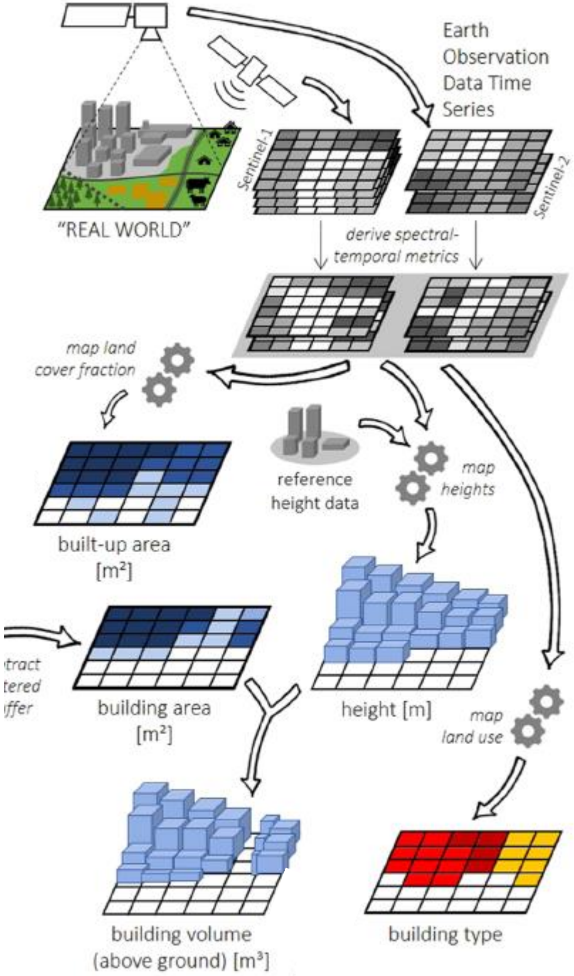
Barrington-Leigh C, Millard-Ball A (2017): The world's user-generated road map is more than 80% complete. *PLoS ONE* 12(8); doi: 10.1371/journal.pone.0180698

Mobility infrastructure: crowd-sourced GIS data



- Road 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 road and rail category [m²]**

Buildings: Earth Observation



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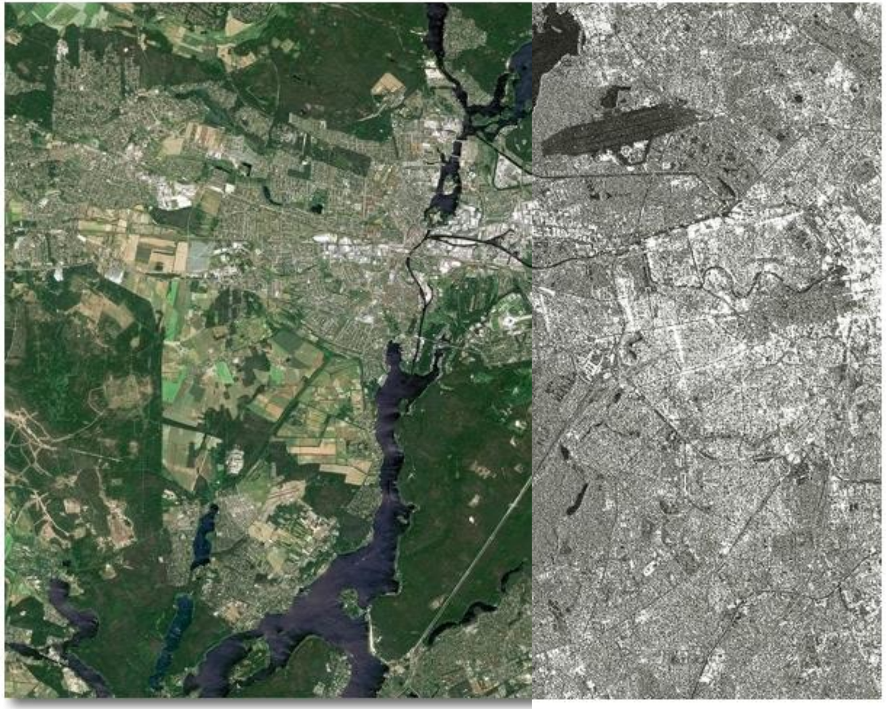
Earth Observation data: Sentinel-1+2A/B



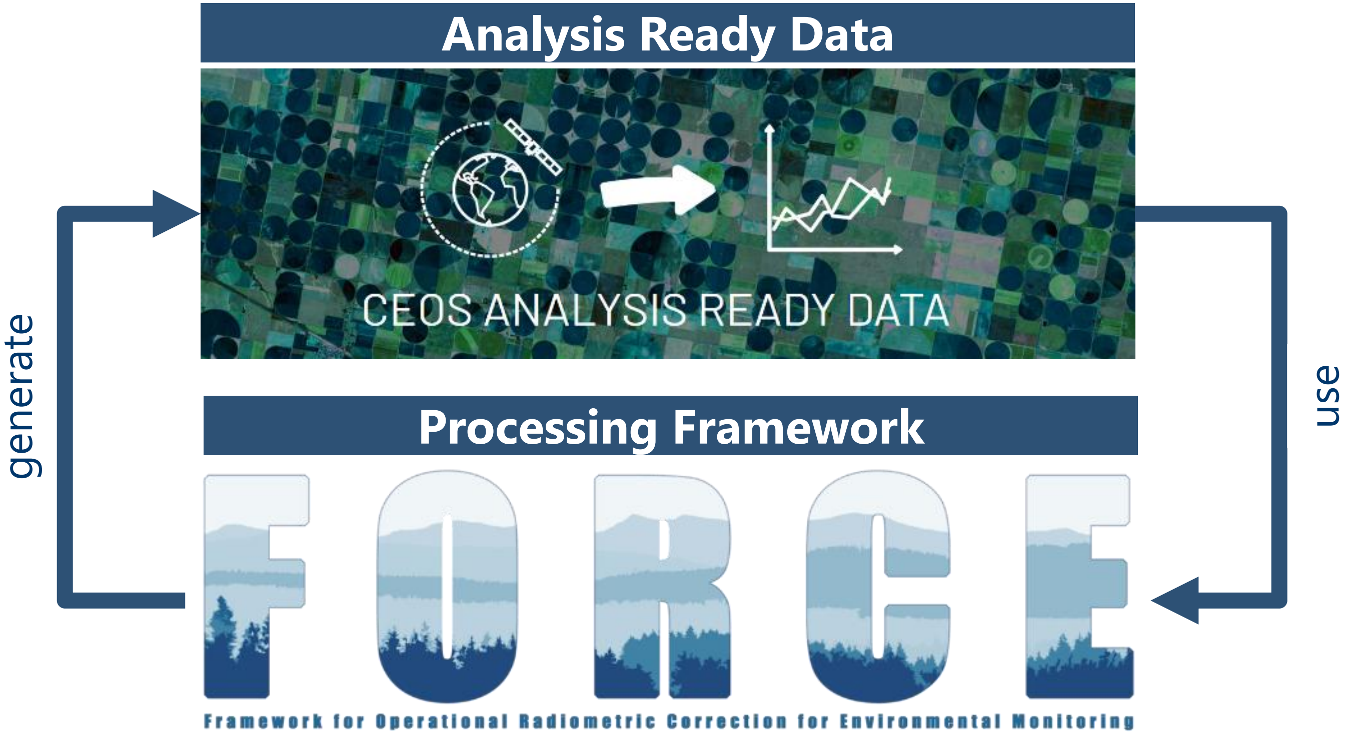
Synthetic Aperture Radar (SAR)
Multispectral imager

~5 days repeat frequency

10-20m spatial resolution

10 spectral bands
2 polarizations

Sentinel-2A/B ARD



Frantz (2019). FORCE—Landsat + Sentinel-2 Analysis Ready Data and Beyond. *Remote Sensing* 11

Sentinel-1A/B ARD-like

Analysis Ready Data

use

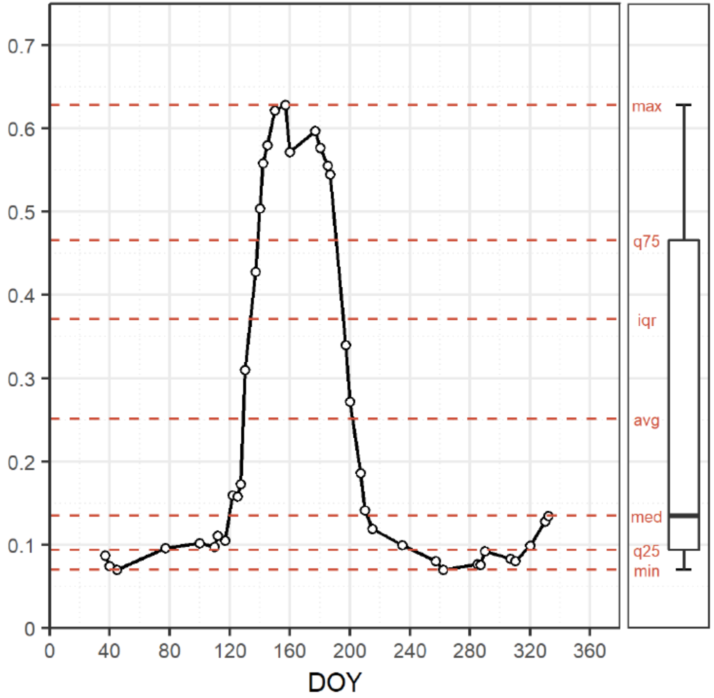
Processing Framework

FORCE

Framework for Operational Radiometric Correction for Environmental Monitoring

Frantz (2019). FORCE—Landsat + Sentinel-2 Analysis Ready Data and Beyond. *Remote Sensing* 11

EO features



Spectral Temporal Metrics =
statistical aggregation of all observations

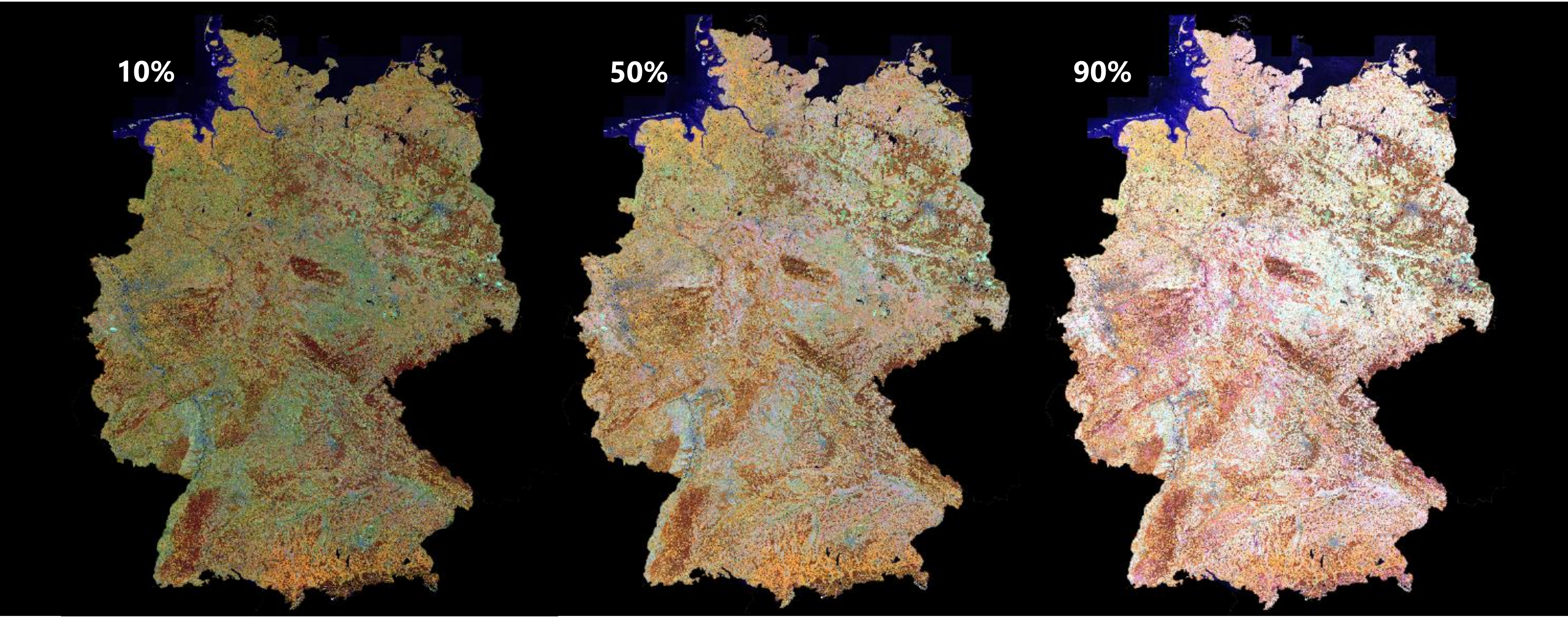
A full year of data

Sentinel-1: all observations

Sentinel-2: all clear-sky observations (excl. clouds, cloud shadows and snow)

Ernst (2020): Implications of Sentinel-2 observation density on land cover classification accuracies. *MSc thesis* (Hostert, **Frantz**)

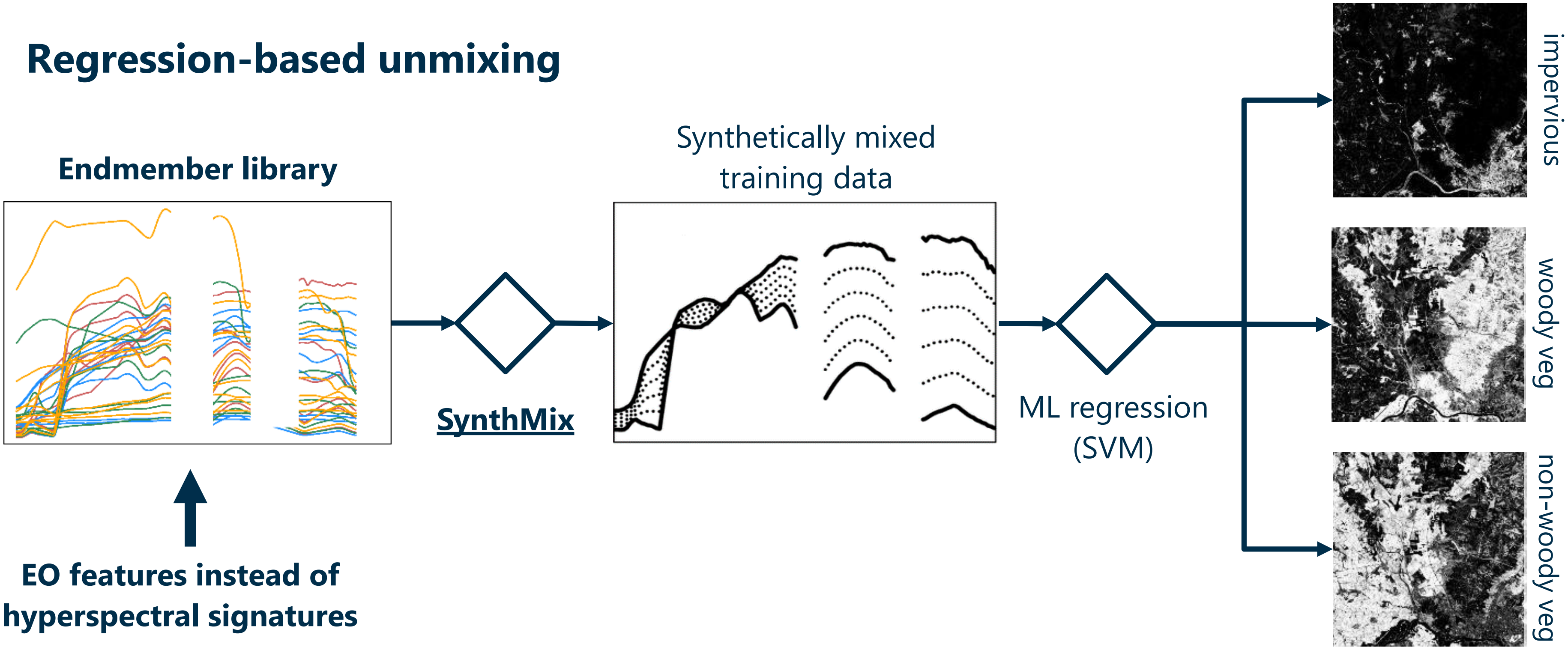
EO features



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

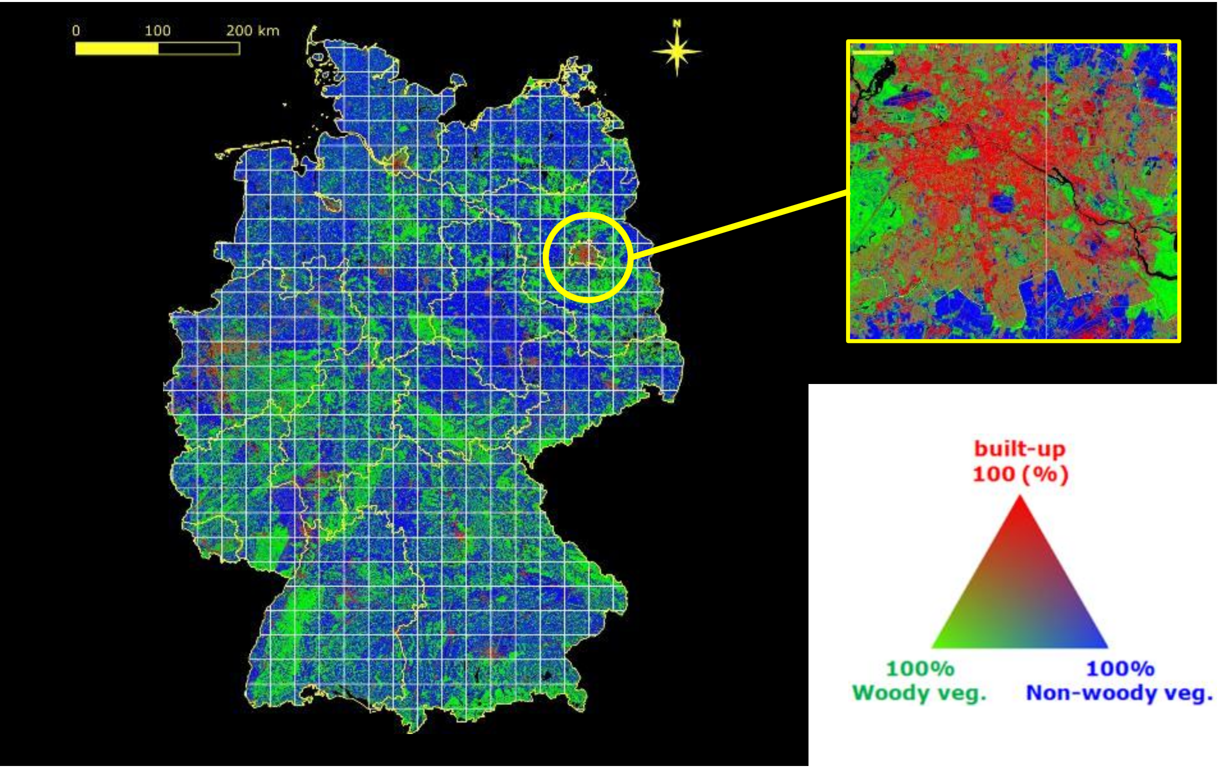
Impervious area

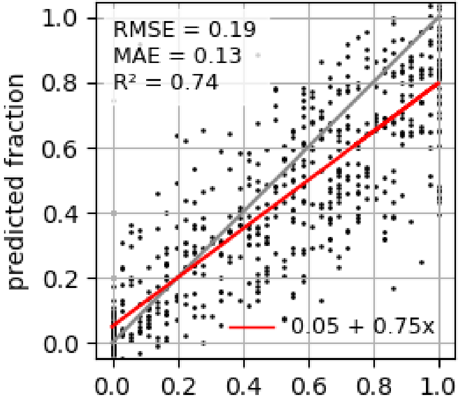
Regression-based unmixing



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

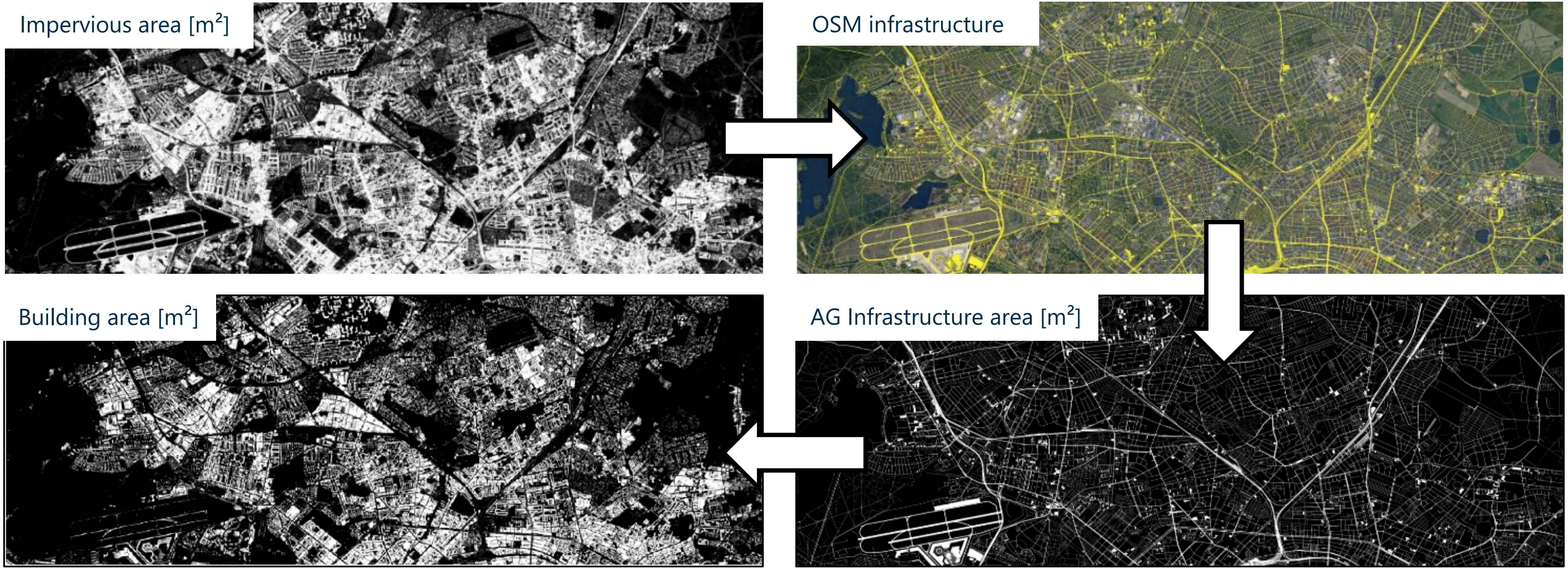
Impervious area



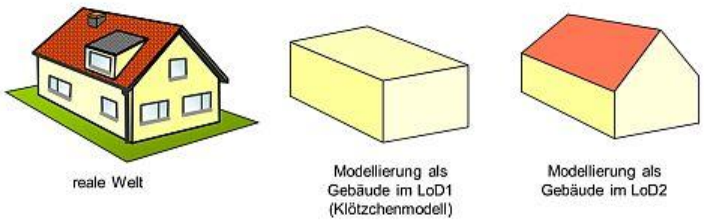


Schug, **Frantz**, Okujeni, van der Linden, Hostert (2020). Mapping urban-rural gradients of settlements and vegetation at national scale using Sentinel-2 spectral-temporal metrics and regression-based unmixing with synthetic training data. *Remote Sensing of Environment*

Impervious area → Building area

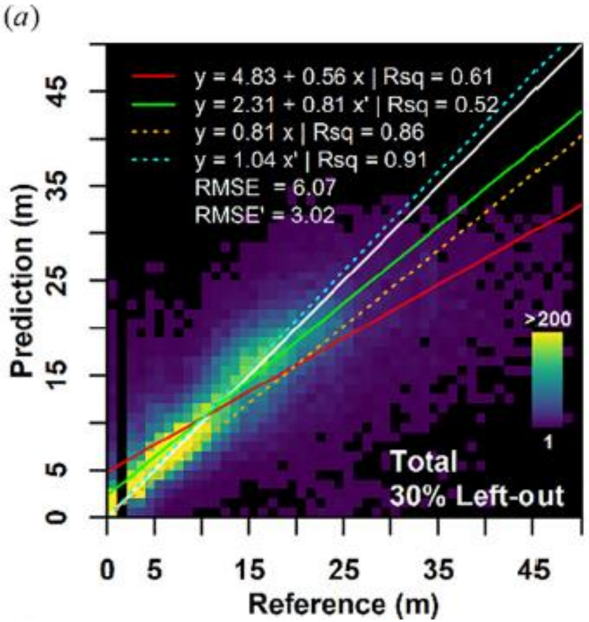


Building height



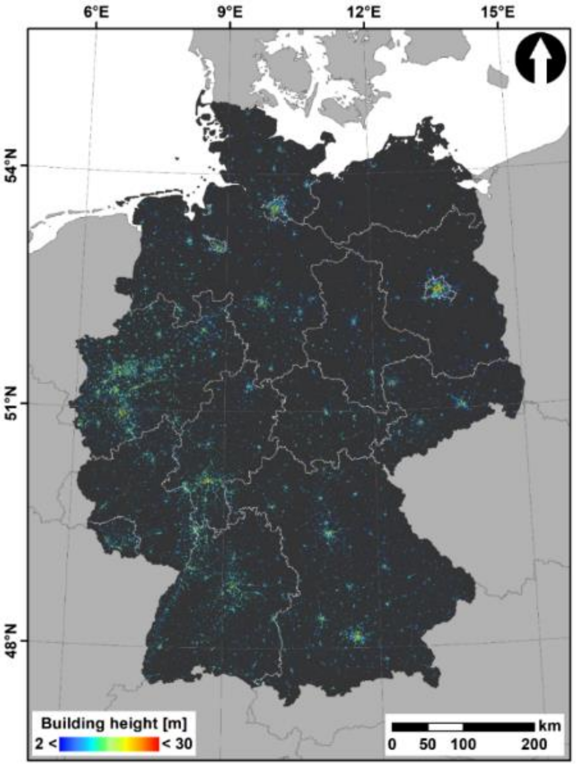
Training and validation from 3D Building Models, based on cadastre and airborne laser scanning

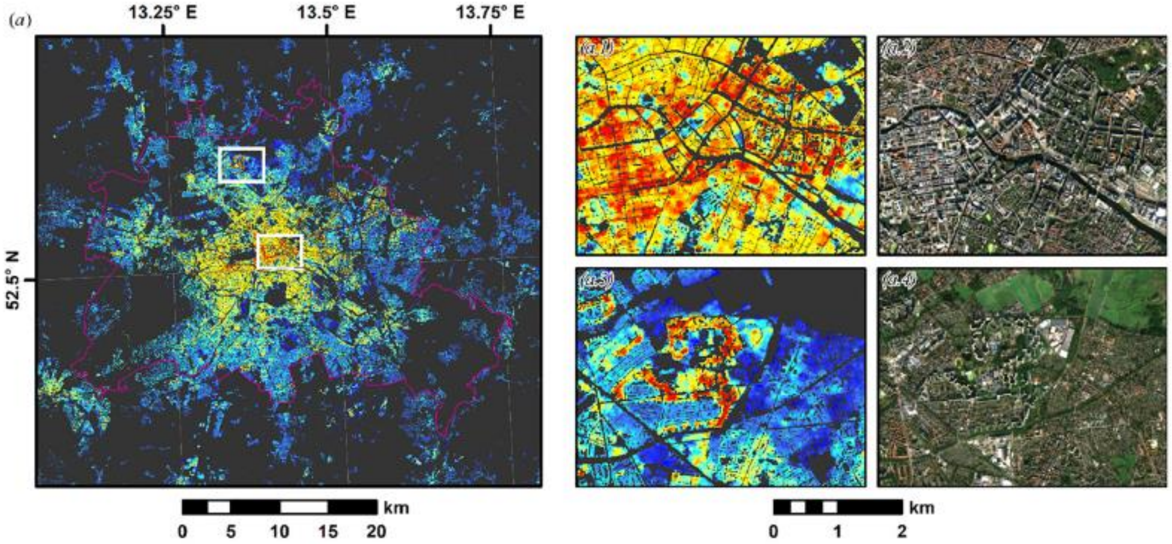
Site	Year	Buildings
Berlin	2014 (99.9%) 2015 (0.1%)	540,172
Hamburg	2016	374,99
Potsdam	2012	44,832
North Rhine Westphalia	2018 (39%) 2019 (61%)	11,498,734
Thuringia	2018 (13%) 2019 (57%) 2020 (30%)	2,241,792



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.

Building height

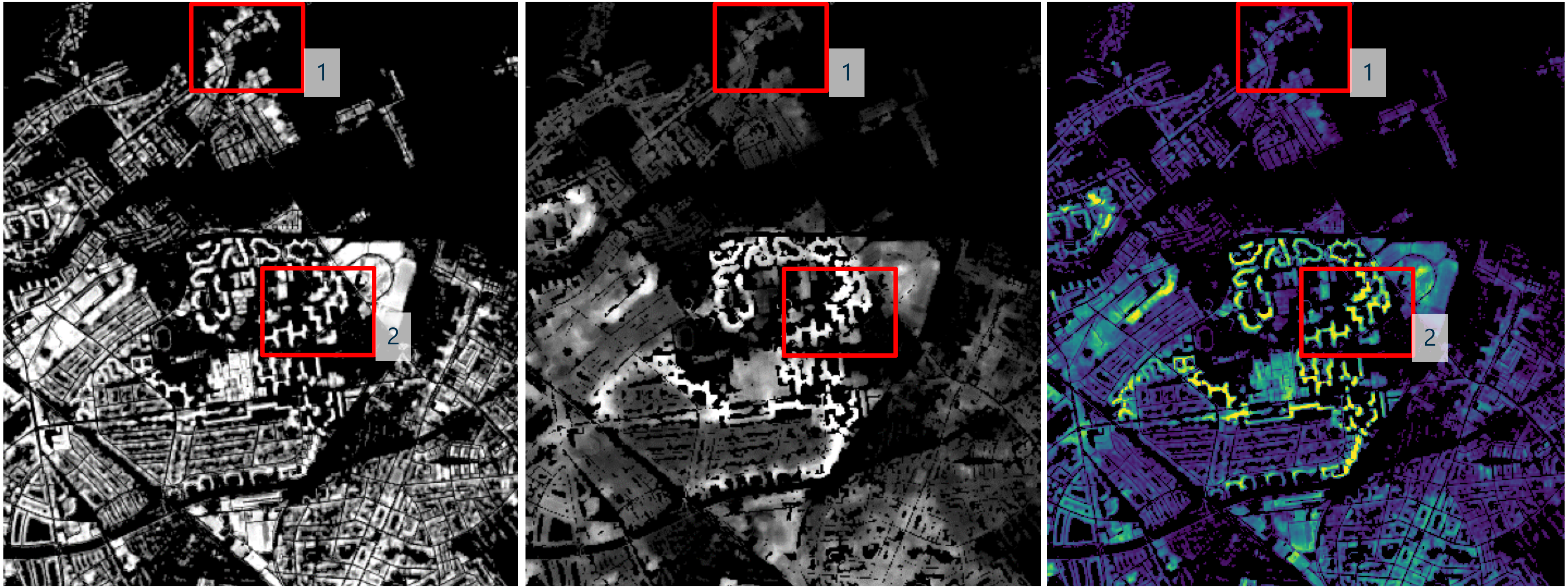




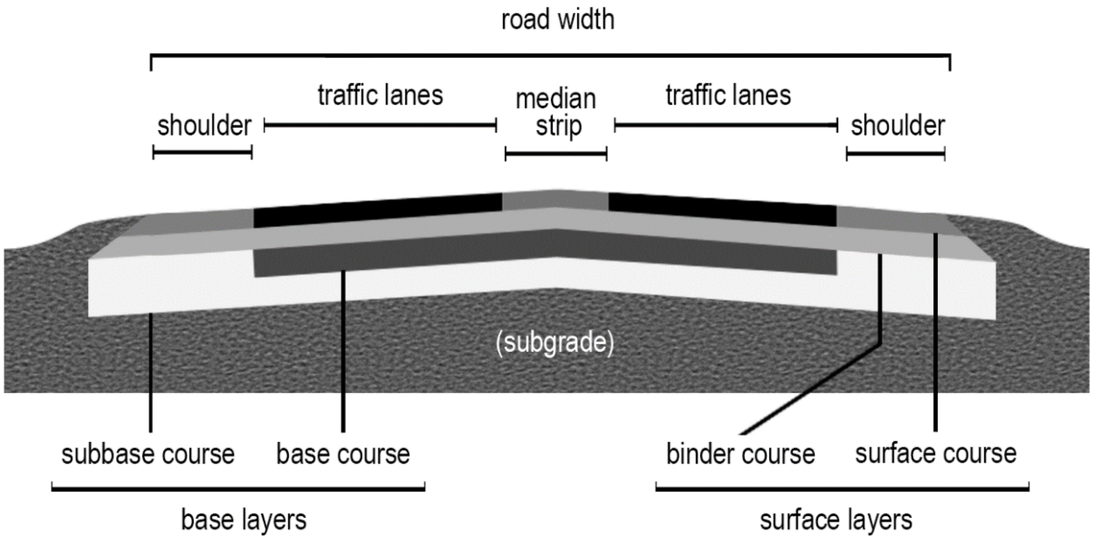
Frantz, Schug, Okujeni, Navacchi, Wagner, van der Linden, Hostert (2021): National-scale mapping of building height using Sentinel-1 and Sentinel-2 time series. *Remote Sensing of Environment* 252.

Building volume

Building Area [m^2] x Building Height [m] = above-ground Building Volume [m^3]



Material Intensity (MI) factors



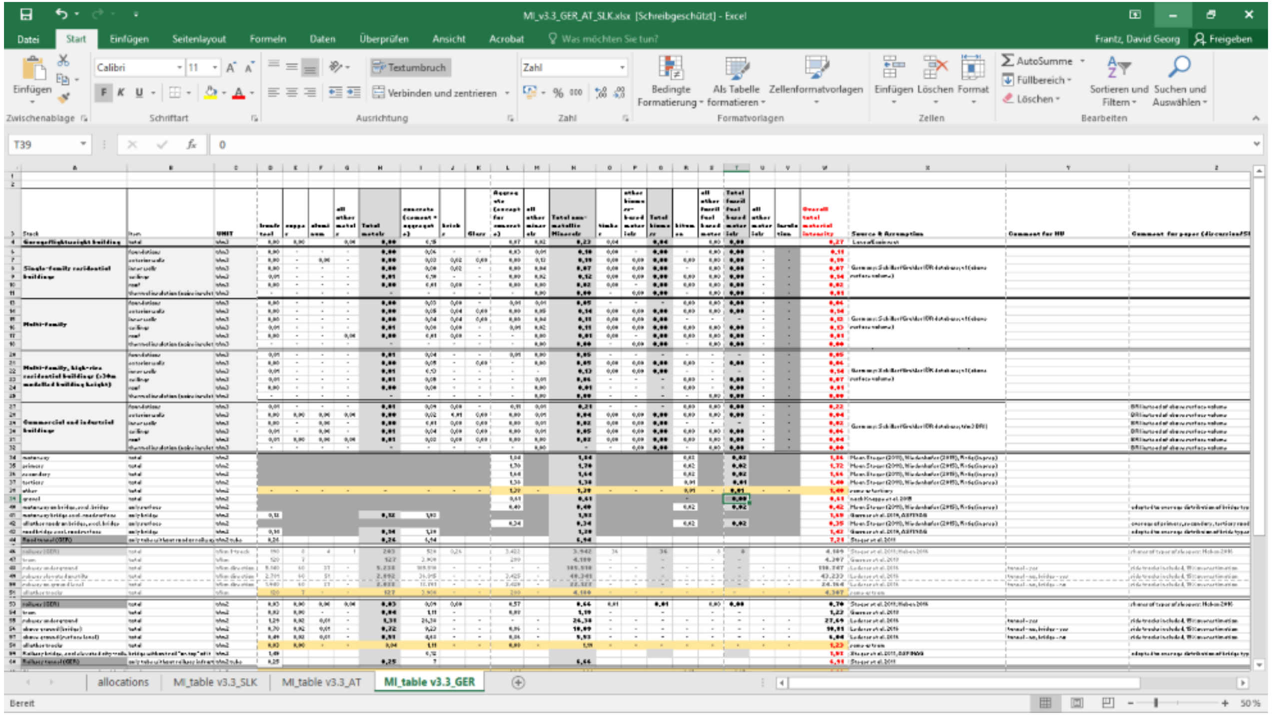
Screening of construction manuals, design guidelines and scientific literature

Recalculation to match EO/GIS-based definitions used in our study

MI per usable floor area or gross building volume to MI per aboveground building volume → **t m^{-3}**

MI per street/rail km to MI per area → **t m^{-2}**

Material Intensity (MI) factors

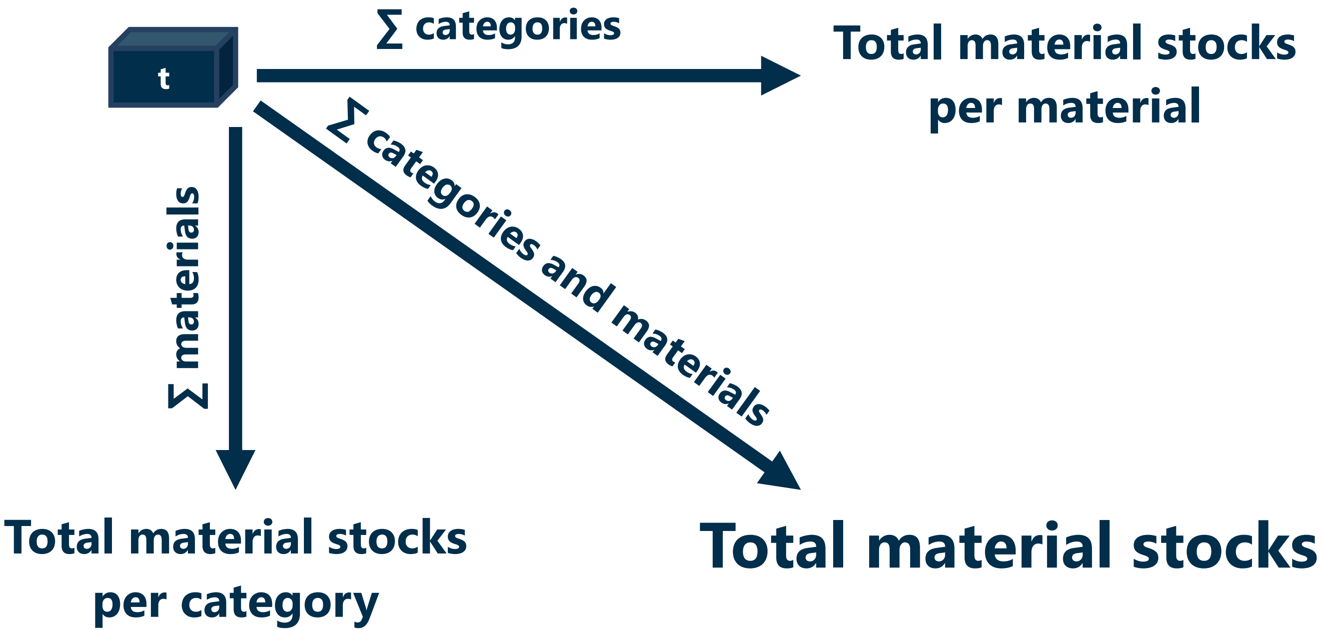


Universität für Bodenkultur Wien
Department für Wirtschafts- und Sozialwissenschaften
Institute of Social Ecology

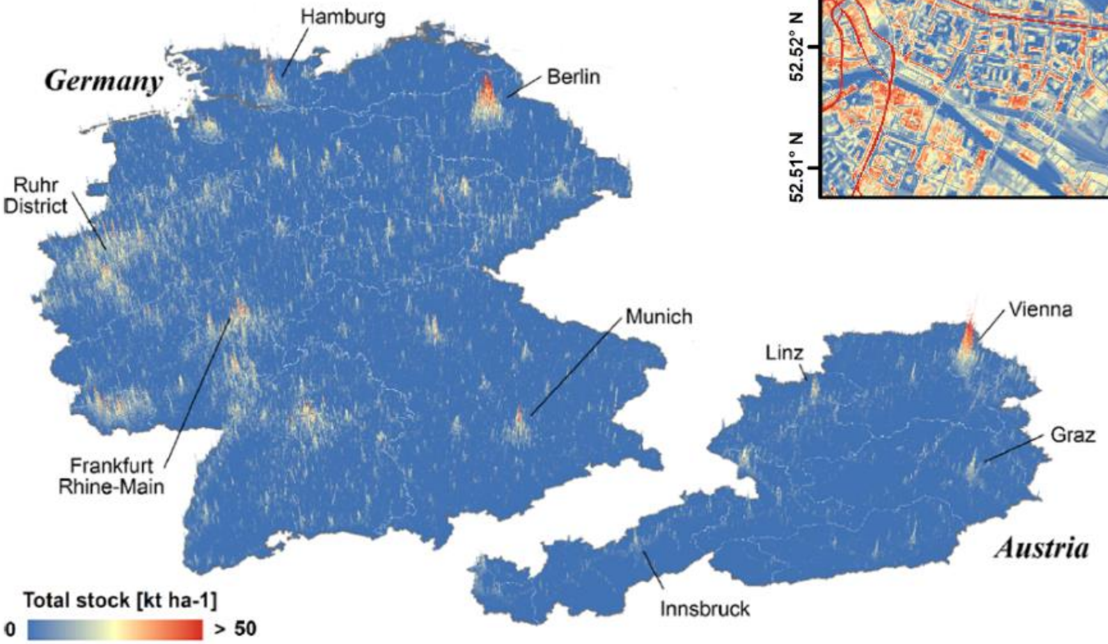
Material stocks

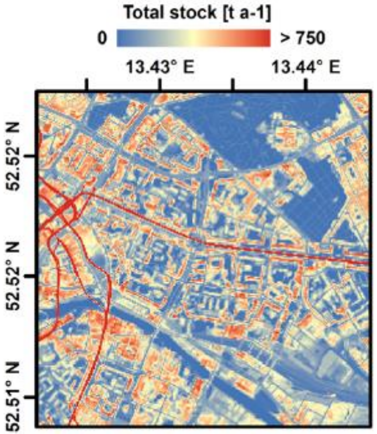
motorways m^2	x	MI concrete	MI bricks	MI steel	MI …	=	t
primary roads m^2	x	MI concrete	MI bricks	MI steel	MI …	=	t
foot paths m^2	x	MI concrete	MI bricks	MI steel	MI …	=	t
rails m^2	x	MI concrete	MI bricks	MI steel	MI …	=	t
subways m^2	x	MI concrete	MI bricks	MI steel	MI …	=	t
single-family m^3	x	MI concrete	MI bricks	MI steel	MI …	=	t
multi-family m^3	x	MI concrete	MI bricks	MI steel	MI …	=	t
…	x	MI concrete	MI bricks	MI steel	MI …	=	t

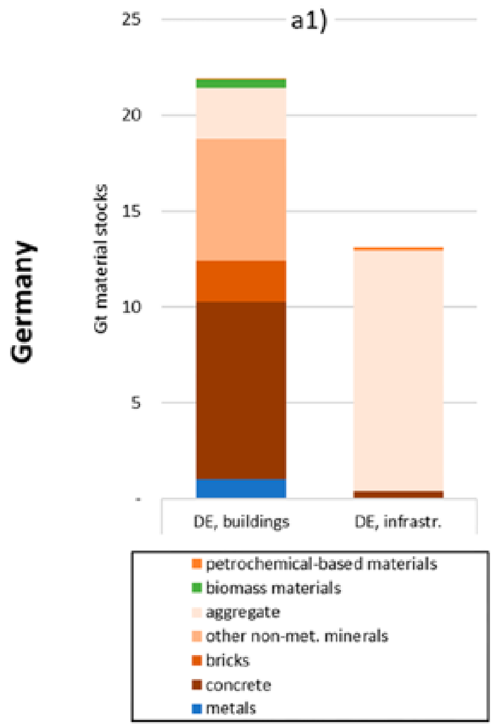
Material stocks



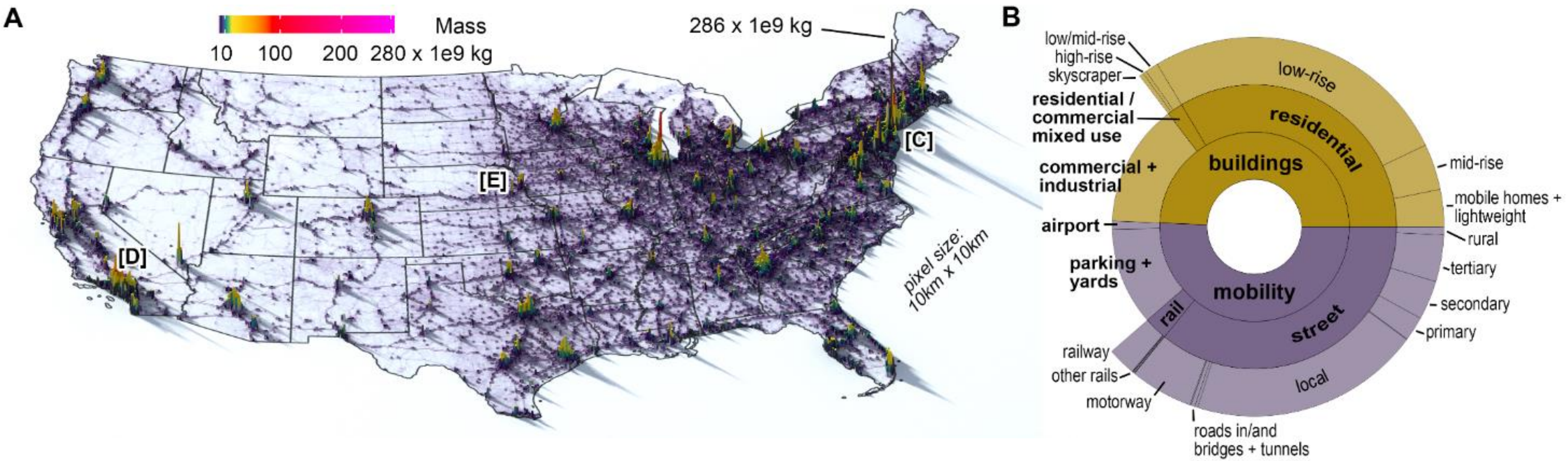
Material stocks



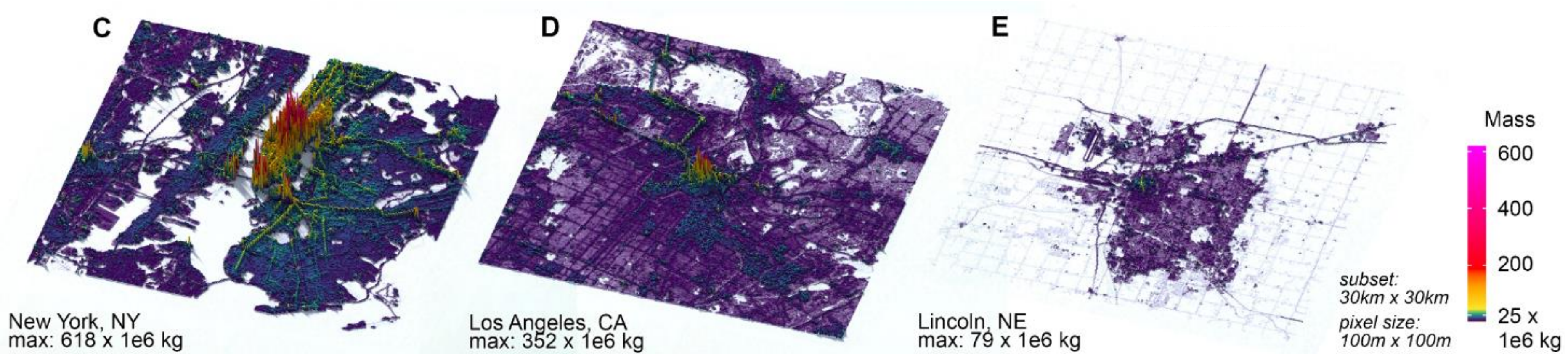




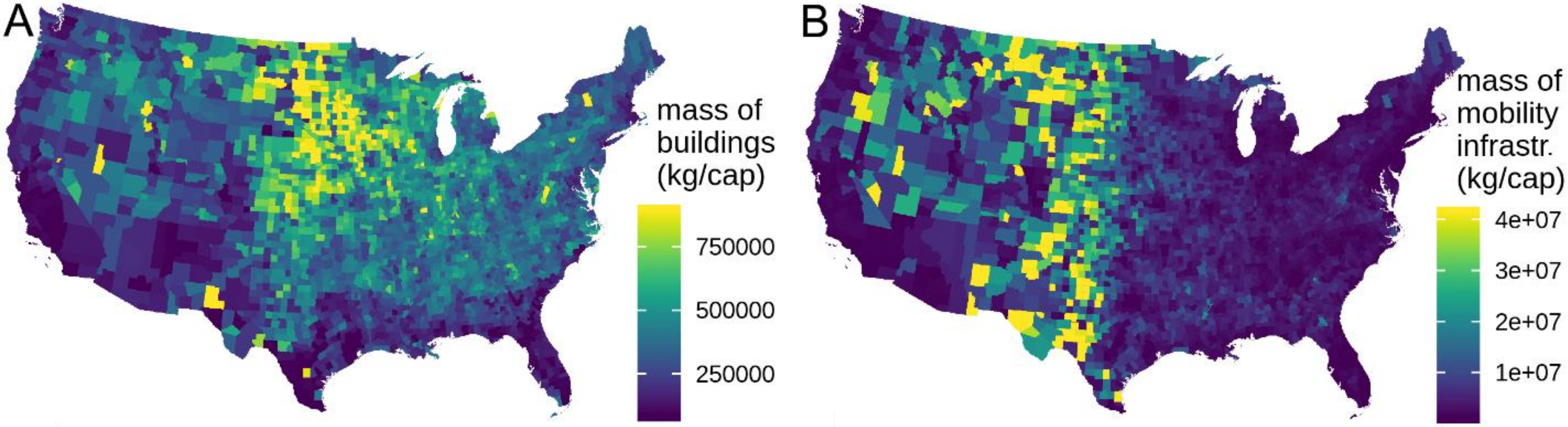
Material stocks for the CONUS



Material stocks for the CONUS



Material stocks for the CONUS



Stock consumption:

AT: ~540 t/cap

DE: ~450 t/cap

US: ~390 t/cap

Thank you for your attention!

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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

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
- Schug, F., et al. (2021): Gridded population mapping for Germany based on building density, height and type from Earth Observation data using census disaggregation and bottom-up estimates. *PLOS ONE*

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