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Spatiality in building stock analysis

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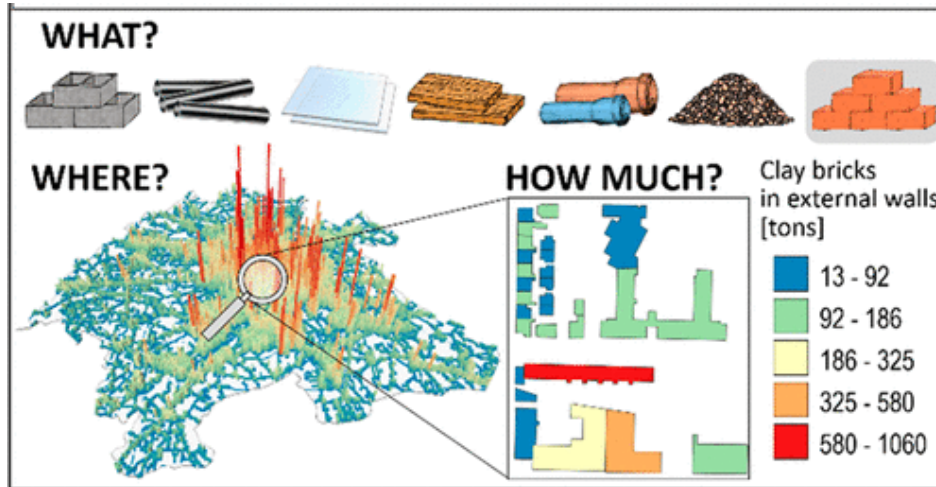
BSc in Architecture, TU Delft

Stocks: Why are they important?

- Material stocks induce long-term dynamics of resource use
- Material stocks can predict and localize future waste/resources
- Secondary materials mine (urban mining)
- Reduce embodied environmental impacts of the construction sector

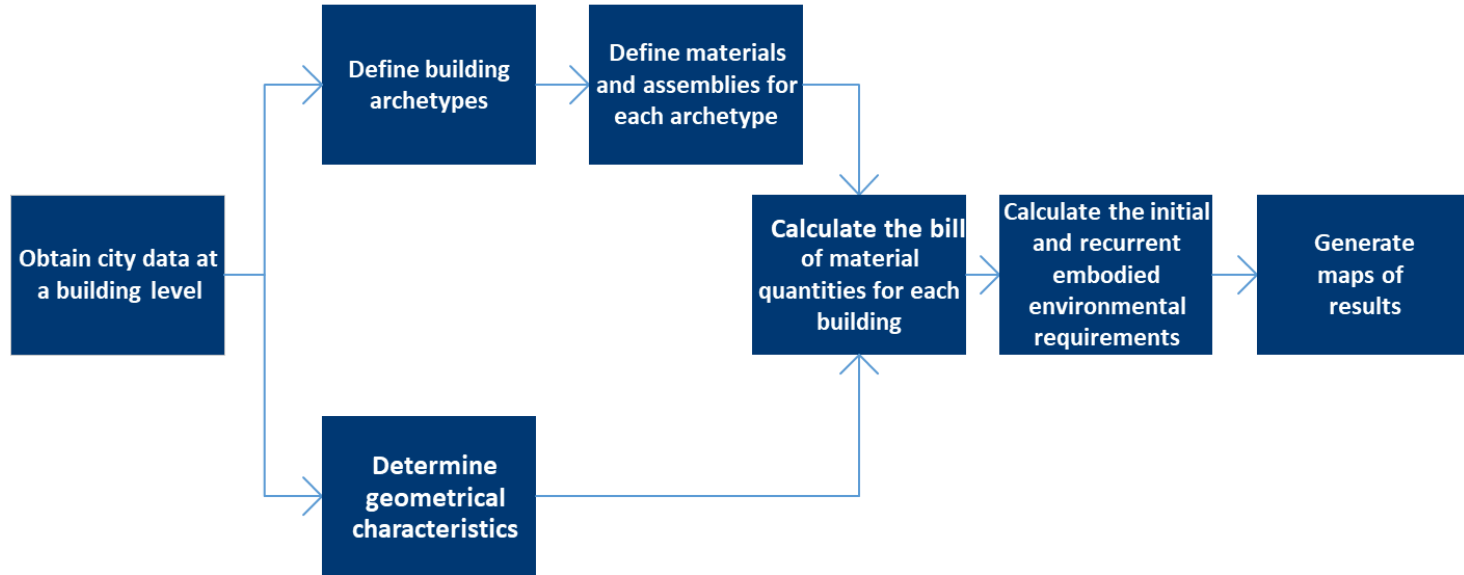
Spatial stock analysis

- Bottom-up approach consists of measuring the current dimensions of the infrastructure (e.g., **buildings**, road) and converting them into mass



Spatial stock analysis (bottom-up)

- General steps



My PhD: Spatial building stock analysis for advancing the circular economy

- **Material spatiality:** How material and energy flows are organized and managed across different regions using physical and measurable aspects of space such as distances, land use, and institutionalized boundaries

My PhD: Spatial building stock analysis for advancing the circular economy

- **Material spatiality:** How material and energy flows are organized and managed across different regions using physical and measurable aspects of space such as distances, land use, and institutionalized boundaries
- **Social spatiality:** Relational arrangement of stocks in places. Shaped by interactions among actors, networks, and institutions, and constantly produced and redefined through boundaries, power, and governance structures



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Mapping operational and embodied emissions in relation to household and ownership profiles with bottom-up building stock analysis: The case of Vaud, Switzerland

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ABSTRACT

We conducted a bottom-up, spatially explicit building stock analysis to examine the social and spatial heterogeneity of operational and embodied emissions of residential buildings in Canton Vaud, Switzerland. Variations emerged between locations, household profiles and ownership types. Urban households exhibited lower embodied emissions per resident, but higher annual operational emissions (1500–1900 kg CO₂/resident), compared to rural households, which showed greater overall variation (1200–2200 kg CO₂/resident). Ownership patterns were less geographically distinct but stratified by type: mixed-ownership buildings exhibited the highest embodied energy, largest material stock and the most modern buildings, whereas community-owned buildings showed the widest variation in annual operational emissions (1500–2300 kg CO₂/resident). Our findings suggest that tailoring emission-reduction interventions to specific social and physical housing contexts would enhance the materials-energy nexus in the built environment. We discuss avenues for reducing energy losses, closing material loops, and incorporating sufficiency into building stock management.

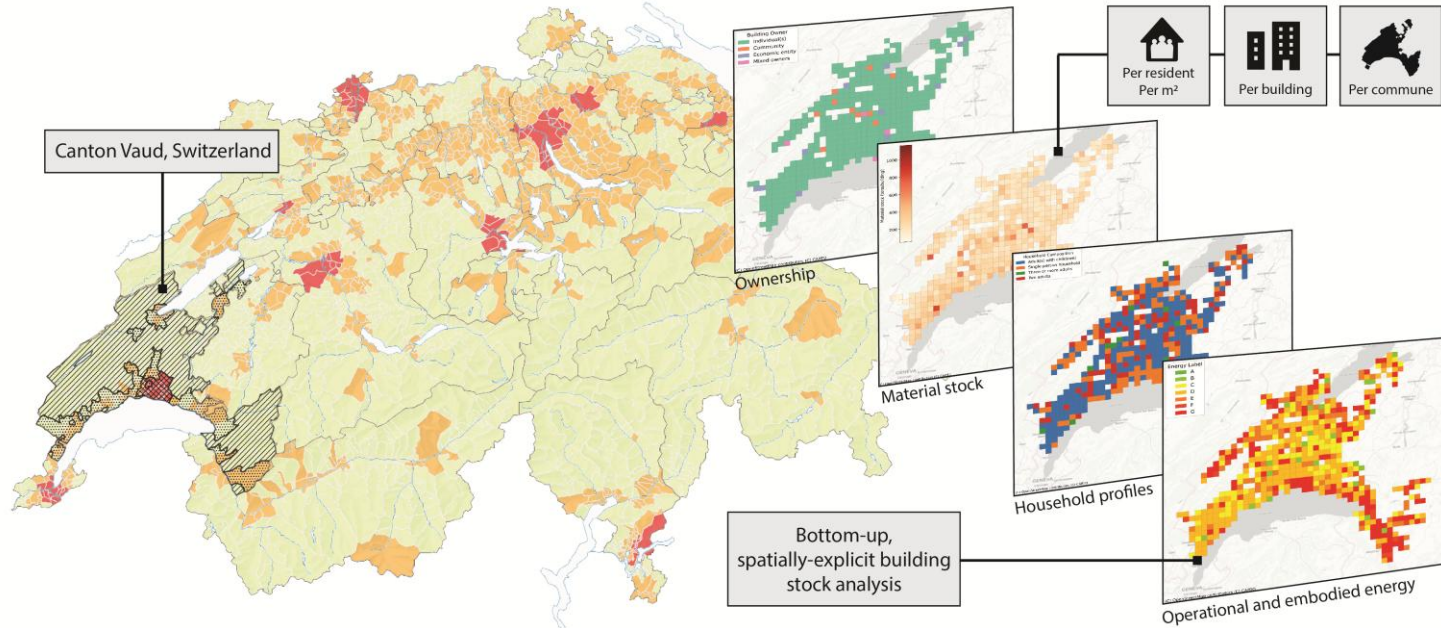
1. Introduction

The built environment provides necessary services such as shelter and mobility for the well-being of people. However, current building and planning practices for construction and demolition, the use of appliances and equipment, and the heating, cooling and lighting of buildings contribute to nearly one-third of global final energy consumption and 38 % of global greenhouse gas emissions (IEA, 2023; UNEP, 2020). As the climate crisis unfolds and disparities in access to services increase, urgent measures are needed to mitigate environmental

2017; Pauliuk and Müller, 2014).

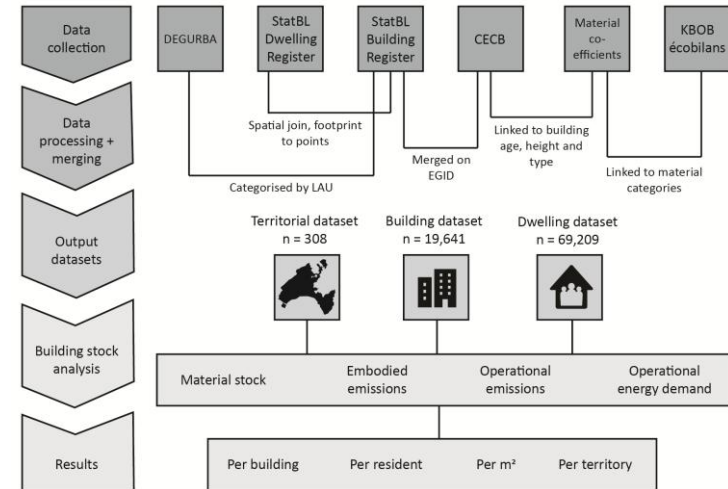
Building stock analysis quantifies and qualifies the material and energy intensity of buildings across a territory to inform resource and environmental policy (Lanau et al., 2019). The lifecycle of the building stock is determined by more than physical factors; it is influenced by exogenous factors such as urbanisation patterns, and endogenous factors such as inhabitants' behaviour (Thomsen and van der Flier, 2011). It is therefore challenging to capture contextual drivers, impacts, and potentials of a territory without linking the building stock to its social and spatial context (Marin and De Meulder, 2018; Lanau et al., 2019). The

Mapping operational and embodied emissions in relation to household and ownership profiles



Static, bottom-up, spatially-explicit residential building stock analysis of canton Vaud

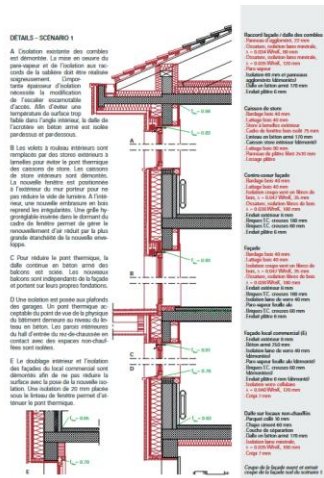
- Quantified material composition of buildings and embodied emissions
- Quantified operational energy demand and emissions
- Dataset = approximately 15% of the total residential building stock in Vaud



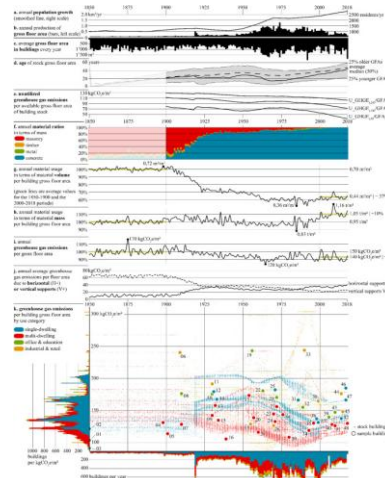
Material composition of buildings

- Triangulating between data at different scales in order to calculate the material intensity of Swiss buildings (kg/m²)

Detailed case studies



City scale information

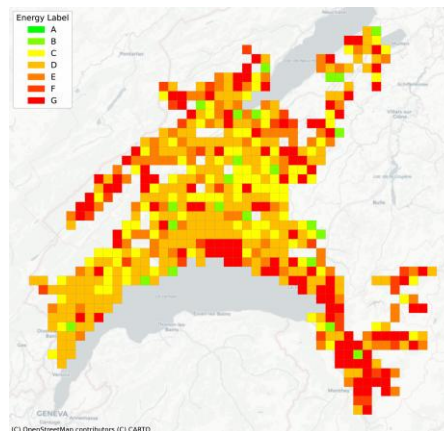


Material intensity per building archetype

Single-family building (kg/m ²)	< 1900	1900-1945	1946-1960	1961-1975	1976-2000	> 2000
Concrete Min	52.95	114.13	349.68	539.58	573.36	496.67
Concrete Max	84.25	181.56	556.31	858.43	912.17	790.16
Brick Min	608.28	563.82	346.24	150.41	105.01	121.09
Brick Max	967.72	896.98	550.83	239.30	167.06	192.64
Combustible Min	4.99	5.18	6.52	11.61	13.24	20.91
Combustible Max	7.94	8.24	10.38	18.46	21.06	33.27
Timber Min	38.44	32.95	16.47	9.84	10.30	10.52
Timber Max	61.15	52.42	26.21	15.65	16.38	16.74
Metal Min	14.96	14.96	22.44	26.18	33.66	29.92
Metal Max	23.80	23.80	35.70	41.65	53.55	47.60
Mineral Min	133.76	137.28	183.04	137.28	121.44	98.56
Mineral Max	212.80	218.40	291.20	218.40	193.20	156.80

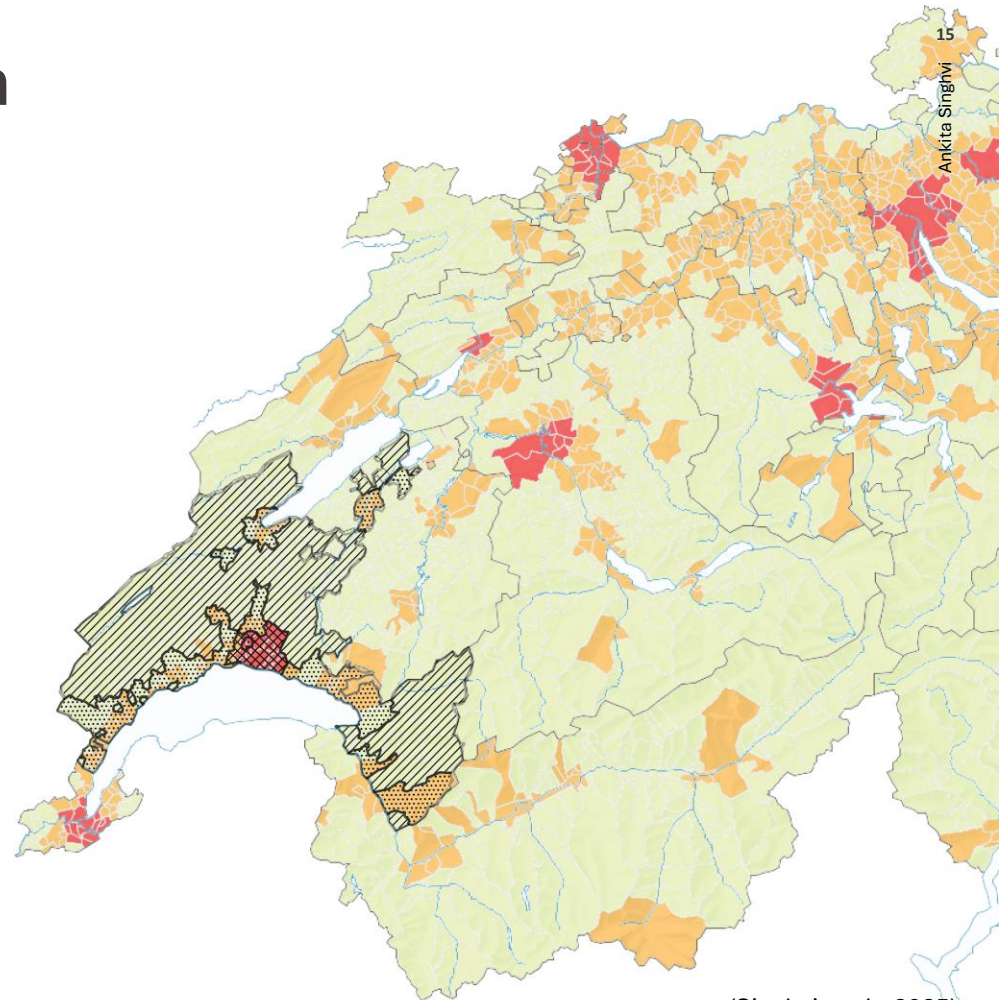
Operational emissions of buildings

- CECB shared information on building envelopes, heating systems, and energy consumption for over 130,000 buildings in Switzerland (as of August 2022)
- Mandatory in canton Vaud at the sale of a house



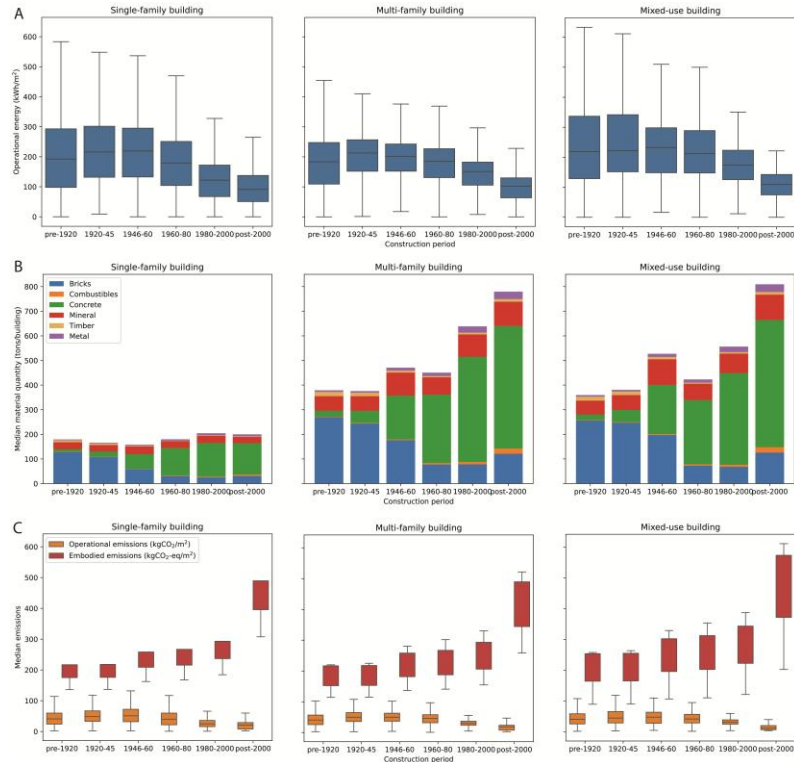
Territorial classification

- OFS delineates the degree of urbanity for a location based on a combination of geographical contiguity and population density, in accordance with definitions set by Eurostat and the OECD
- We used geographic data on local administrative units (*communes*) and their classification as: cities, towns and suburbs, or rural areas



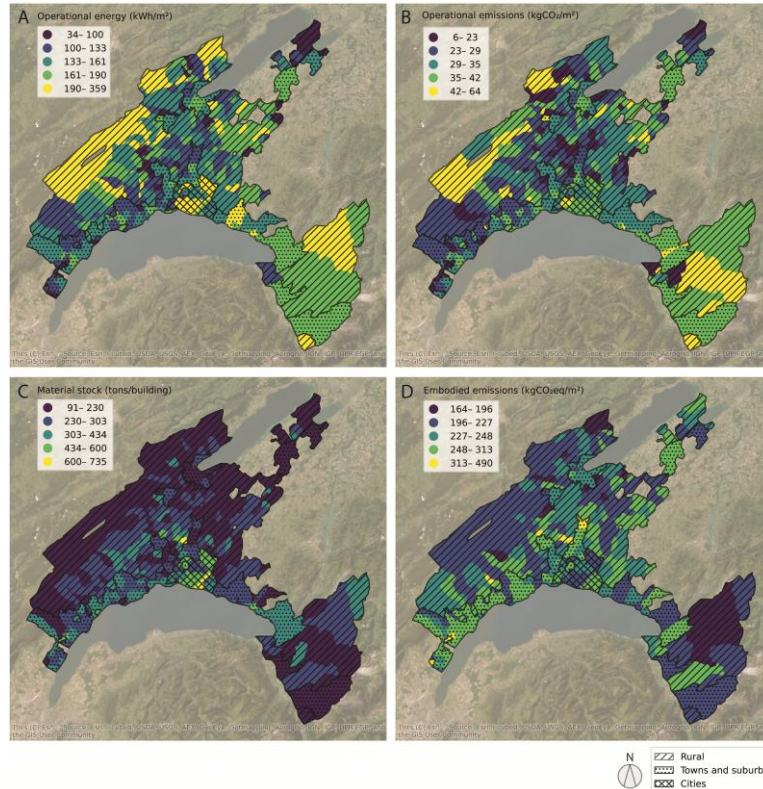
(Singhvi et al., 2025)

Results: Material and energy intensity per construction period and per building category



Panel A shows the median annual operational energy demand (kWh/m²). Panel B shows the median material stock per building (tons/building). Panel C shows the median operational (kg CO₂/m²) and embodied emissions (kg CO₂-eq/m²).

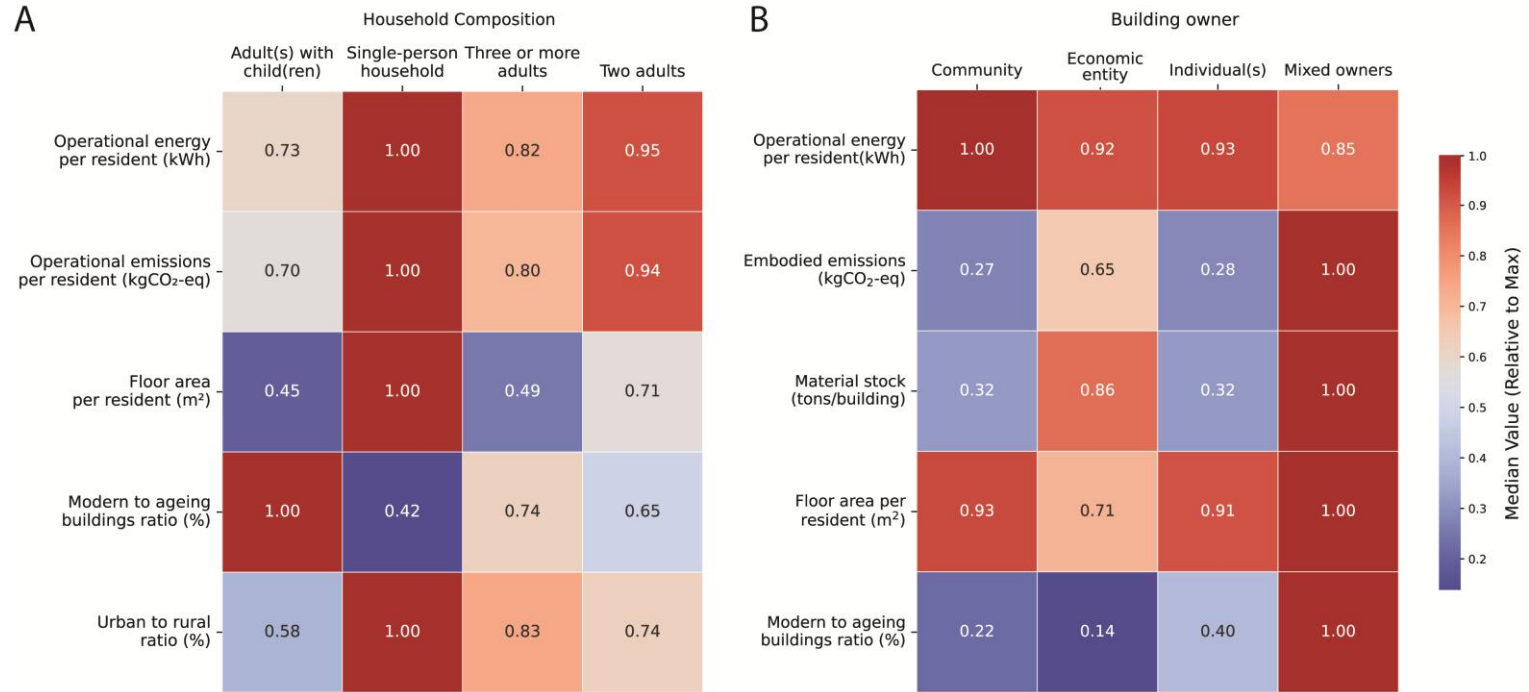
Results: Spatial distribution of material and energy profiles across communes in canton Vaud



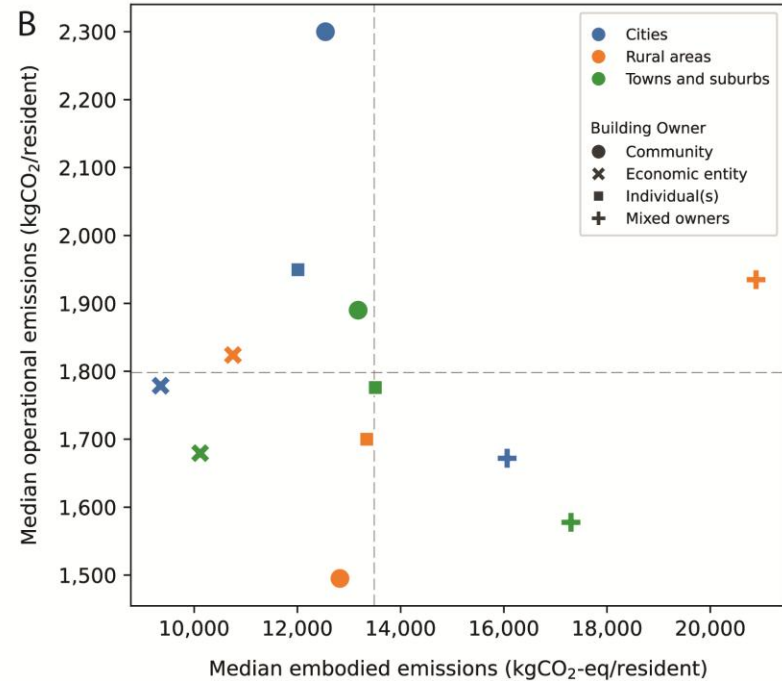
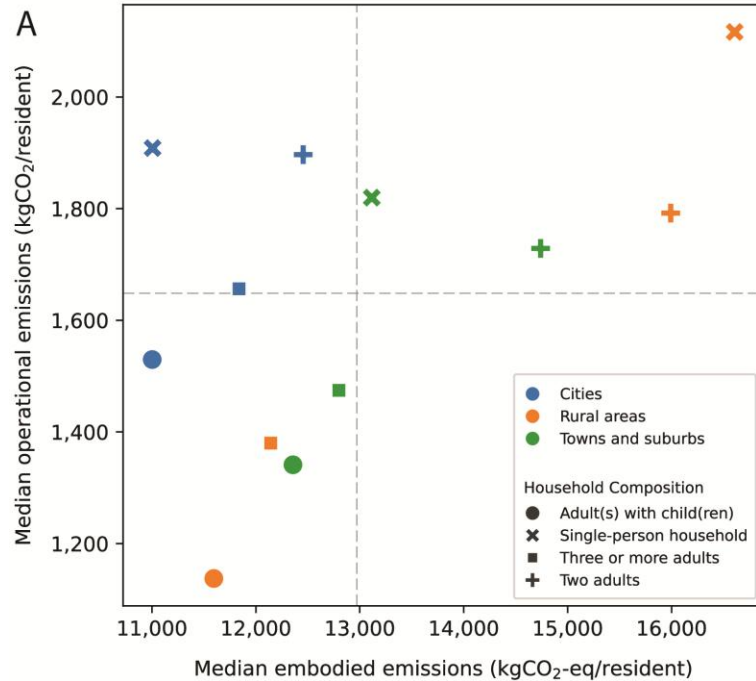
Panel A shows the median annual operational energy demand (kWh/m²). Panel B visualises median annual operational emissions (kg CO₂/m²). Panel C shows median material stock (tons/building). Panel D shows the median embodied carbon (kg CO₂-eq/m²).

(Singhvi et al., 2025)

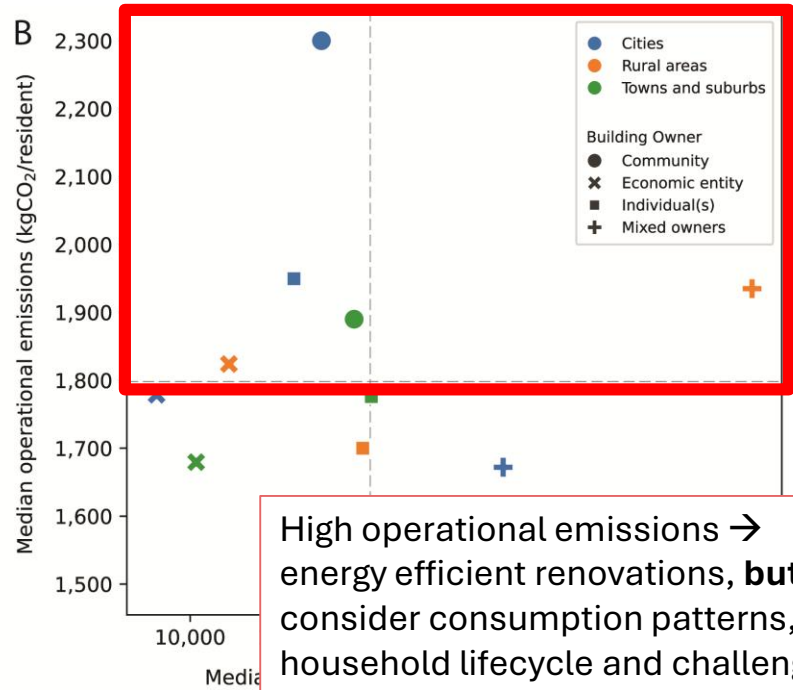
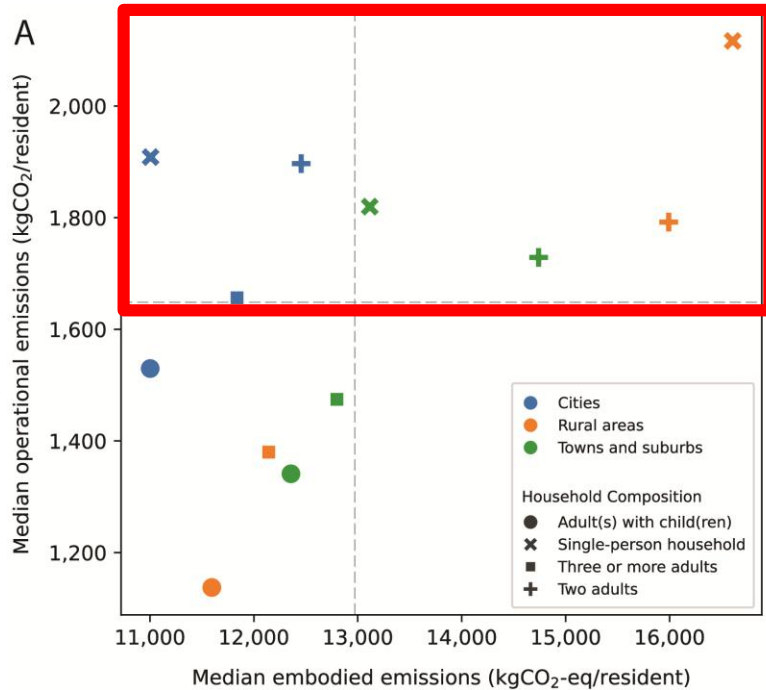
Results: Comparative analysis of occupancy patterns



Results: Relationship between embodied and operational emissions per resident, and location

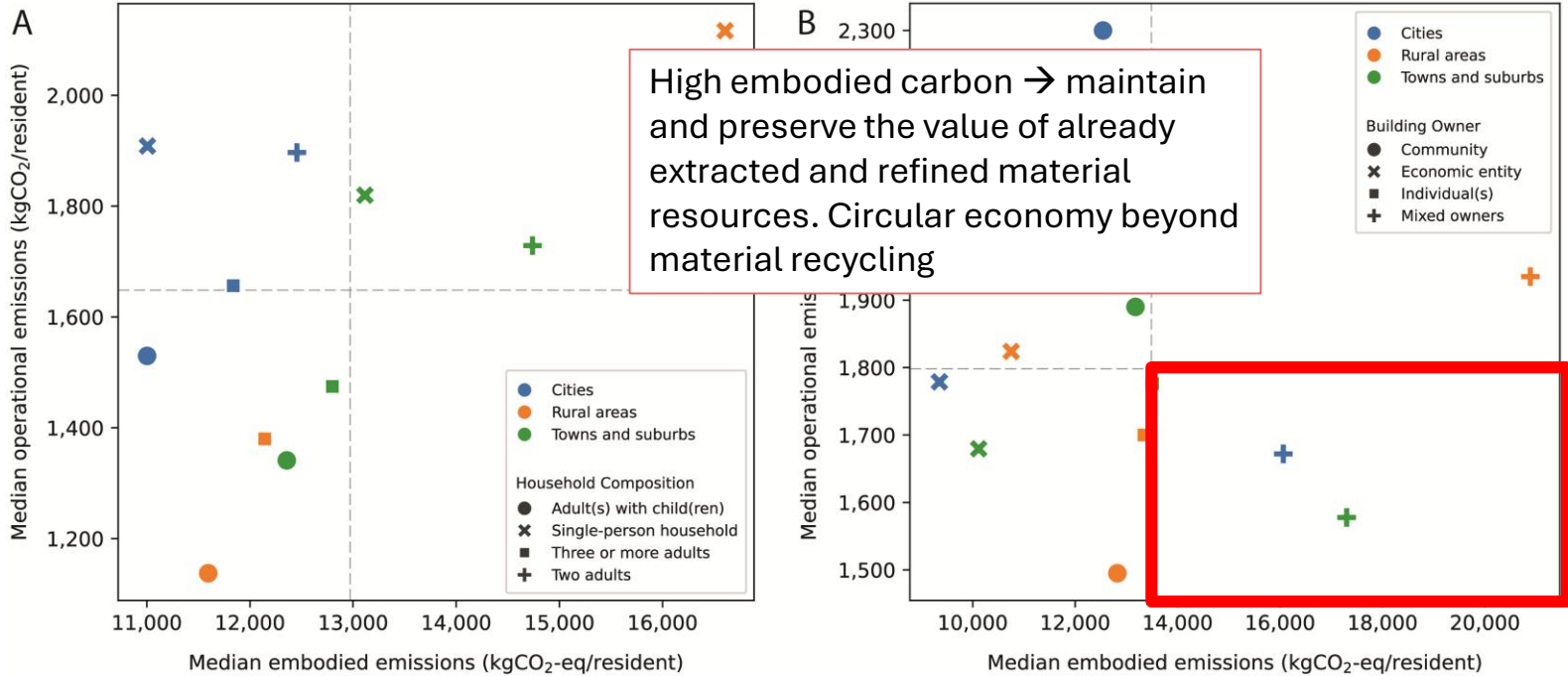


What does this mean?

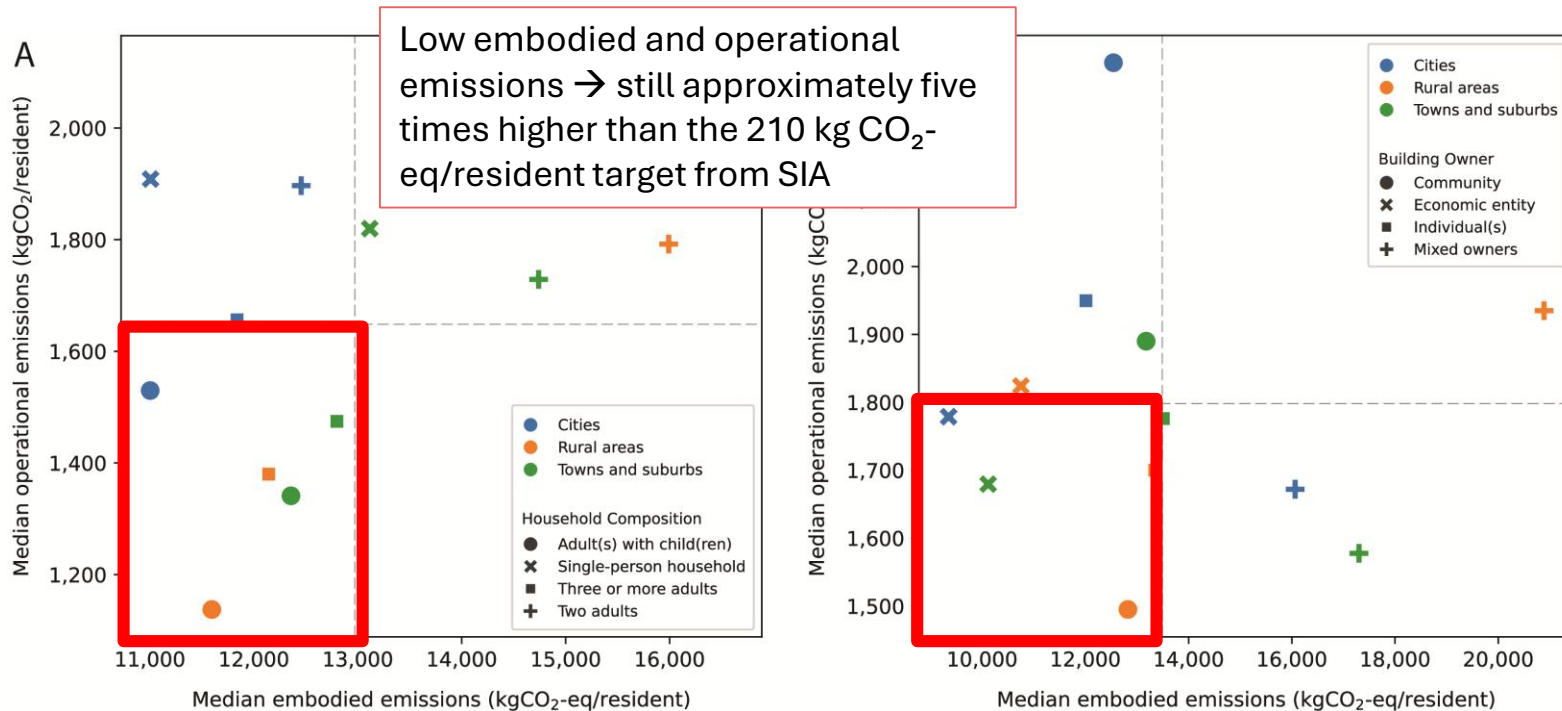


High operational emissions → energy efficient renovations, **but:** consider consumption patterns, household lifecycle and challenges of coordination

What does this mean?



What does this mean?



Key take-aways, why social dimensions are relevant in MFA & stock analyses:

- Technical characteristics alone do not explain emission patterns
 - Construction period cannot fully account for differences in operational emissions. Even buildings with a modern envelope can have high emissions because of the number of inhabitants, behavioral rebound effects, comfort expectations
- Material stocks are unevenly distributed across building owners
 - Ownership types (private individuals, economic entities, mixed groups) hold very different shares of old vs. new buildings, shaping who controls high-carbon stocks and who bears the burden of future retrofit or demolition decisions.
- Enables indicators and monitoring of per capita changes
 - As single-person households continue to rise, interventions must target reducing resource and energy consumption per resident, not just per square metre, to meet emission targets

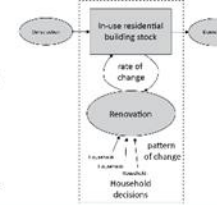
From static to dynamic building stock model

- Current rates and patterns of energy efficient renovation in residential building stock with panel survey data
- How are the rates and patterns of energy-efficient renovation in the residential building stock characterised across different household-dwelling relationships?

■ <http://dx.doi.org/10.2139/ssrn.5739082>

Why start from the household?

- Renovation activities such as maintenance, refurbishments, retrofits and replacements are typically modeled on the basis of materials reaching the end of their service life, or by regular maintenance intervals in accordance with building age
- However, this approach overlooks how and why actors adapt the built environment over time to meet their evolving needs (Brand, 1996; Kohler & Hasler, 2002)
- Considering the heterogeneity of household situations could contribute to more equitable climate policy (i.e. subsidy distribution) and better characterise the relationship between household and building characteristics in relation to renovation measures



What does survey data offer?

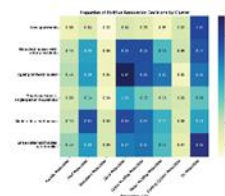
- Captures self-reported occupant renovation activities, intentions and attitudes missing from administrative or technical building datasets
- We conducted a household survey in the Lemaniaque region in Switzerland and France
- The clustering analysis was conducted on the complete responses from 1666 participants that are homeowners



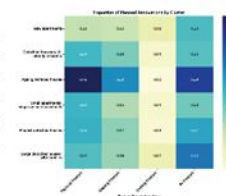
Resulting clusters

- Post-2010 moderately sized apartments with high-earning families that moved in recently
- Large detached suburban and rural houses, mixed occupancy and construction periods, high earning families
- Pre-1960s large terraced houses with environmentally concerned families, visible occupation periods
- Modestly sized apartments constructed 1970s-2000s with a large share of mixed income single-person households
- Modest detached suburban houses constructed 1970s-2000s with settled couples living 10+ years
- Elderly couples (55+) settled 10+ years in large detached suburban houses constructed 1970s-2000s

Renovation actions per cluster



Renovation intentions per cluster



Implications for building stock

Intervention	Proportion of total renovation work by cluster				Rate of change
	Post-2010	Pre-1960s	1970s-2000s	1970s-2000s	
Energy efficiency	0.15	0.10	0.12	0.18	0.15
Water efficiency	0.10	0.08	0.10	0.12	0.10
Indoor climate	0.12	0.15	0.10	0.15	0.12
Accessibility	0.05	0.08	0.05	0.08	0.05
Other	0.10	0.12	0.10	0.12	0.10

- Current renovation rates are below policy targets
- The cluster that needs renovation, small apartments with single-person households
- Cluster with renovation plans: ageing terraced houses
- Next step: factor analysis of responses on why participants are or are not intending interventions

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