The central role of material stocks for resource and energy efficiency

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Why are material stocks important? Because …

- .... they constitute all the buildings, infrastructure, machinery and devices that are used
- … they are the physical basis for production and consumption
- … they lock-in resource intensive practices for construction, maintenance and use
- … they, together with energy and material flows, provide services and contribute to wellbeing
- … they are pivotal for resource and energy efficiency, as well as a sustainable circular economy

Scientific challenge:

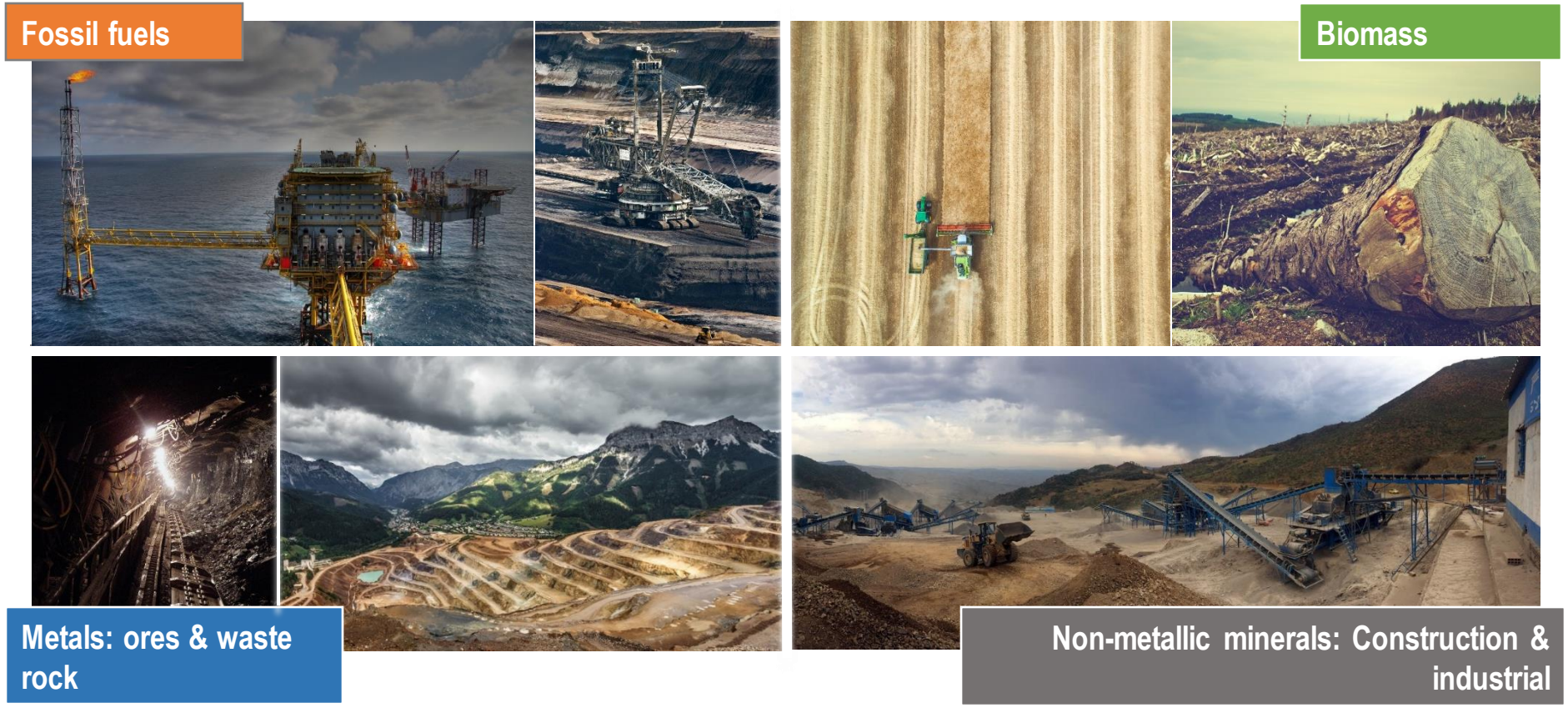
- Existing research either focused on specific stock-flow-service relations, or too aggregate
- Lacking integration of bottom-up and top-down stock-flow research; large discrepancies in results
- Lacking robustness and systematic understanding inhibits linkages to macro-economic models and other applications
- Variable system boundaries of studies inhibit economy-wide systematic integration into ew-MFA accounts and national statistics (e.g. SEEA)

→ Herein, we showcase recent progress and multiple applications aiming to tackle these challenge

Haberl, H, Wiedenhofer, D., et al. „Contributions of Sociometabolic Research to Sustainability Science“. *Nature Sustainability* (2019). https://doi.org/10.1038/s41893-019-0225-2

Lanau, Liu, Kral, Wiedenhofer, et al. ‘Taking Stock of Built Environment Stock Studies: Progress and Prospects’. *Environmental Science & Technology*, (2019). https://doi.org/10.1021/acs.est.8b06652

Systematic and comprehensive assessments are necessary: towards economy-wide material and energy stock-flow analysis



"Material Flow Accounting: Measuring Global Material Use for Sustainable Development". Krausmann et al. (2017) *Annual Review of Environment and Resources.* doi:10.1146/annurev-environ-102016-060726

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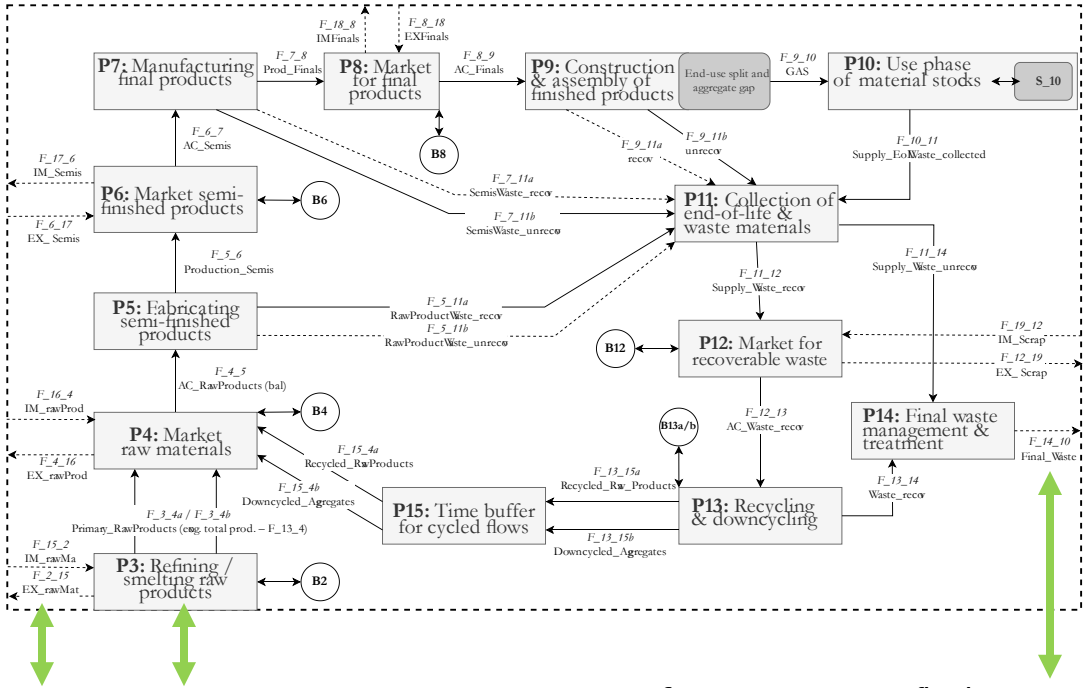
Approach 1: „top-down“ inflow-driven modelling, with an economy-wide scope

- The MISO model is a fully consistent extension for economy-wide material flow accounting (Wiedenhofer, Fishman, et al. 2019)
- Combines **accounting in excel,** with implementations in **MatLab (MISO v1) & Python (MISO v2)**
- Systematic input data uncertainty assessment
- Uncertainty propagation via Monte-Carlo Simulations & Global Sensitivity Analysis
- **MISO model version 2:** differentiation of more processes & end-uses
- Global, country-level, long-term modelling
- To be released in 2023+



Interface to ew-MFA: P0-2: the environment, domestic extraction (DE) and primary processing, as well as trade. (Plank et al. 2022). https://doi.org/10.1016/j.resconrec.2021.106122

Interface to ew-MFA: final waste links to indicator Domestic Processed Outputs (DPO)

PNAS

Global socioeconomic material stocks rise 23-fold over the 20th century and require half of annual resource use

Fridolin Krausmann[a,1], Dominik Wiedenhofer[a], Christian Lauk[a], Willi Haas[a], Hiroki Tanikawa[b], Tomer Fishman[b,c], Alessio Miatto[b], Heinz Schandl[d], and Helmut Haberl[a]

[a]Institute of Social Ecology Vienna, Alpen-Adria University, A-1070 Vienna, Austria; [b]Graduate School of Environmental Studies, Nagoya University, Chikusa-ku, Nagoya 464-8601, Japan; [c]Center for Industrial Ecology, School of Forestry and Environmental Studies, Yale University, New Haven, CT 06511;

Ecological Economics 156 (2019) 121–133

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Methodological and Ideological Options

Integrating Material Stock Dynamics Into Economy-Wide Material Flow Accounting: Concepts, Modelling, and Global Application for 1900–2050

Dominik Wiedenhofer[a,*], Tomer Fishman[b], Christian Lauk[a], Willi Haas[a], Fridolin Krausmann[a]

Resources, Conservation & Recycling 163 (2020) 105076

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Full length article

Spaceship earth's odyssey to a circular economy - a century long perspective

Willi Haas*, Fridolin Krausmann, Dominik Wiedenhofer, Christian Lauk, Andreas Mayer

Global Environmental Change 71 (2021) 102410

Contents lists available at ScienceDirect

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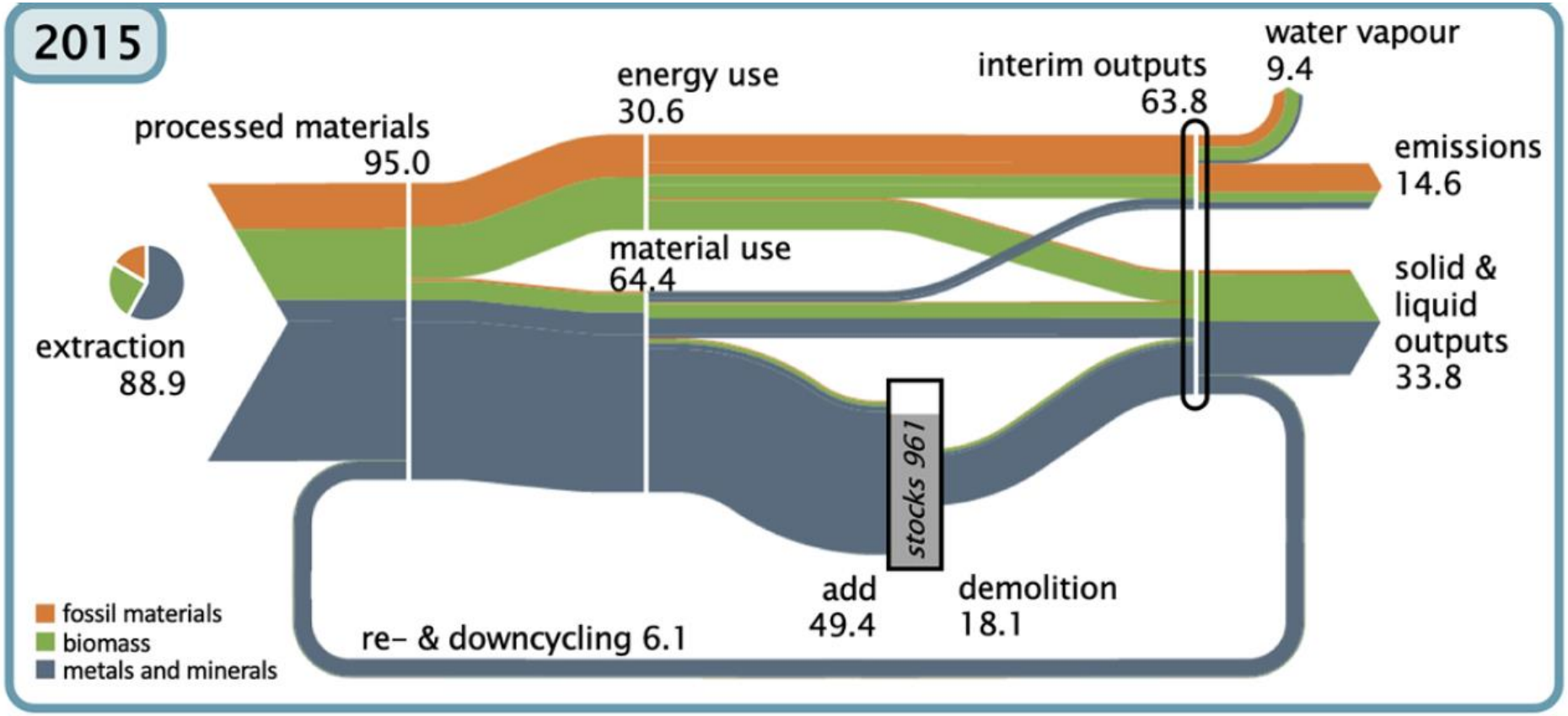
Prospects for a saturation of humanity's resource use? An analysis of material stocks and flows in nine world regions from 1900 to 2035

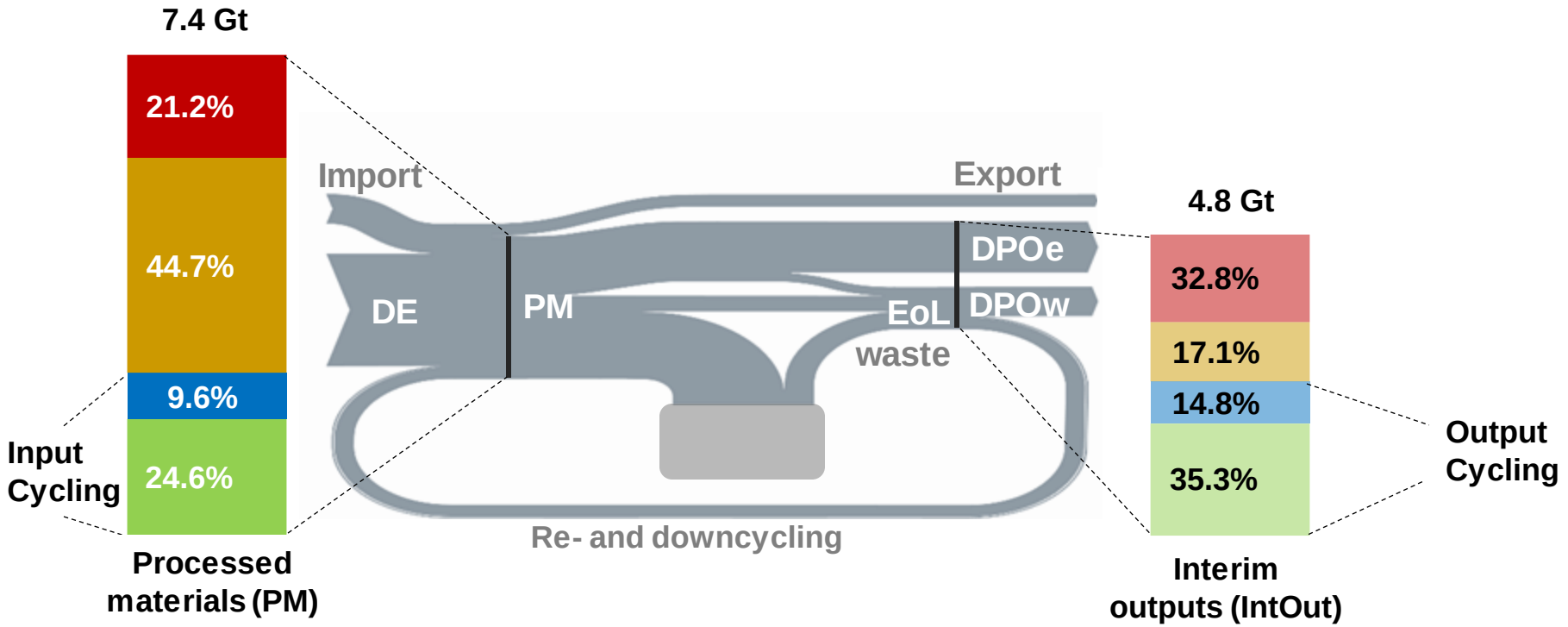
Dominik Wiedenhofer[a,*], Tomer Fishman[b], Barbara Plank[a], Alessio Miatto[c], Christian Lauk[a], Willi Haas[a], Helmut Haberl[a], Fridolin Krausmann[a]

Application 1: how circular is the global economy?



Haas, Krausmann, Wiedenhofer, Lauk, and Mayer. „Spaceship Earth's Odyssey to a Circular Economy - a Century Long Perspective". *Resources, Conservation & Recycling* (2020). https://doi.org/10.1016/j.resconrec.2020.105076.

Application 2: Policy relevant headline indicators for the EU

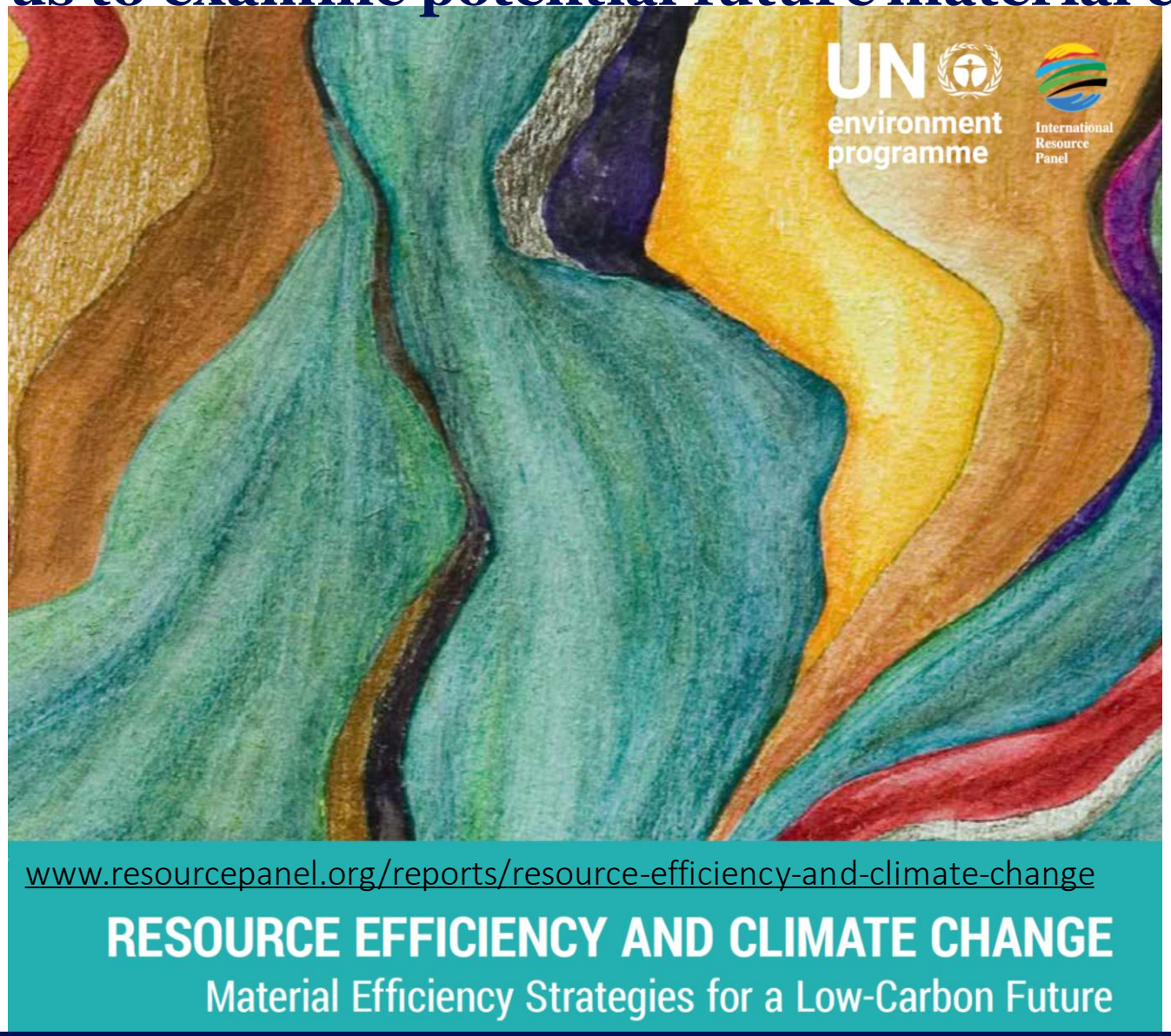


- Input non-circularity rate (INCr)
- Remaining non-renewable primary resources
- **Input socio-economic cycling rate (ISCr)**
- **Input ecological cycling rate potential (IECrp)**

- Output non-circularity rate (ONCr)
- Remaining interim outputs
- **Output socio-economic cycling rate (OSCr)**
- **Output ecological cycling rate potential (OECrp)**

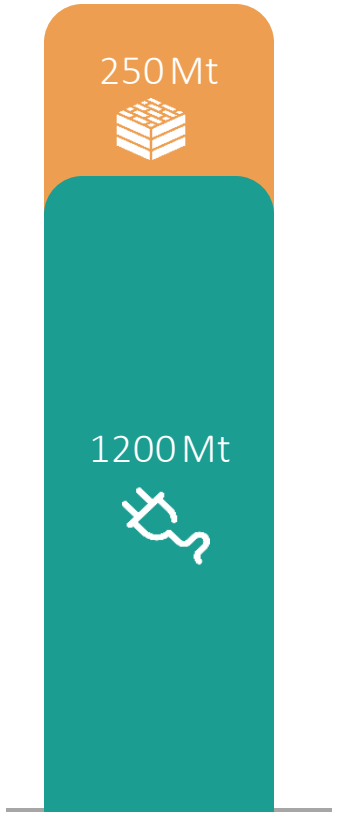
Mayer, A., Haas, W., **Wiedenhofer, D.**, Krausmann, F., Nuss, P., and Blengini, G.A. 'Measuring Progress towards a Circular Economy - a Monitoring Framework for Economy-Wide Material Loop Closing in the EU28.' *Journal of Industrial Ecology*, 2018. https://doi.org/10.1111/jiec.12809

Approach 2: Understanding material stocks of residential buildings and vehicles enables us to examine potential future material cycles



Material Efficiency Strategies can reduce **35-40%** of lifecycle emissions from **homes** in **G7 countries** in 2050

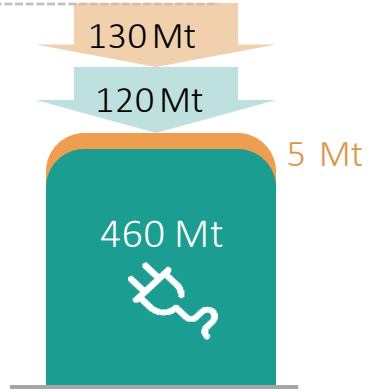
- Material cycle emissions
- Emissions from operational energy use
- Material cycle emission reductions
- Operational energy use emission reductions



2016
life-cycle emissions

35%
life-cycle emissions can be reduced through ME strategies.

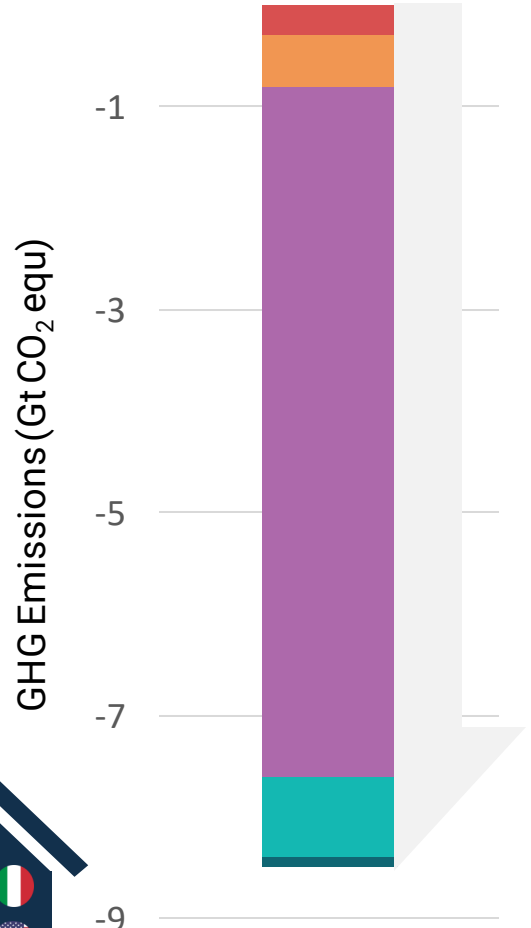
2050
life-cycle emissions
without ME strategies



2050
life-cycle emissions
with ME strategies

More intensive use and recycling are the most influential strategies

Potential GHG savings from material efficiency strategies for homes in G7 (2016-2060)



- Using less material by design
- Material substitution
- More intensive use
- Enhanced end-of-life recovery and fabrication yield improvements
- Product lifetime extension and reuse

**The reduction potentials shown here are for strategy cascades, i.e. implementing one strategy after the other, therefore having synergetic effects.*

Most of the strategies reduce predominantly material related emissions

Some affect materials and operational energy use

✓ Particularly More intensive use reduces materials and heating/cooling needs

Approach 3: stock-driven mapping, using cadaster data or remote-sensing

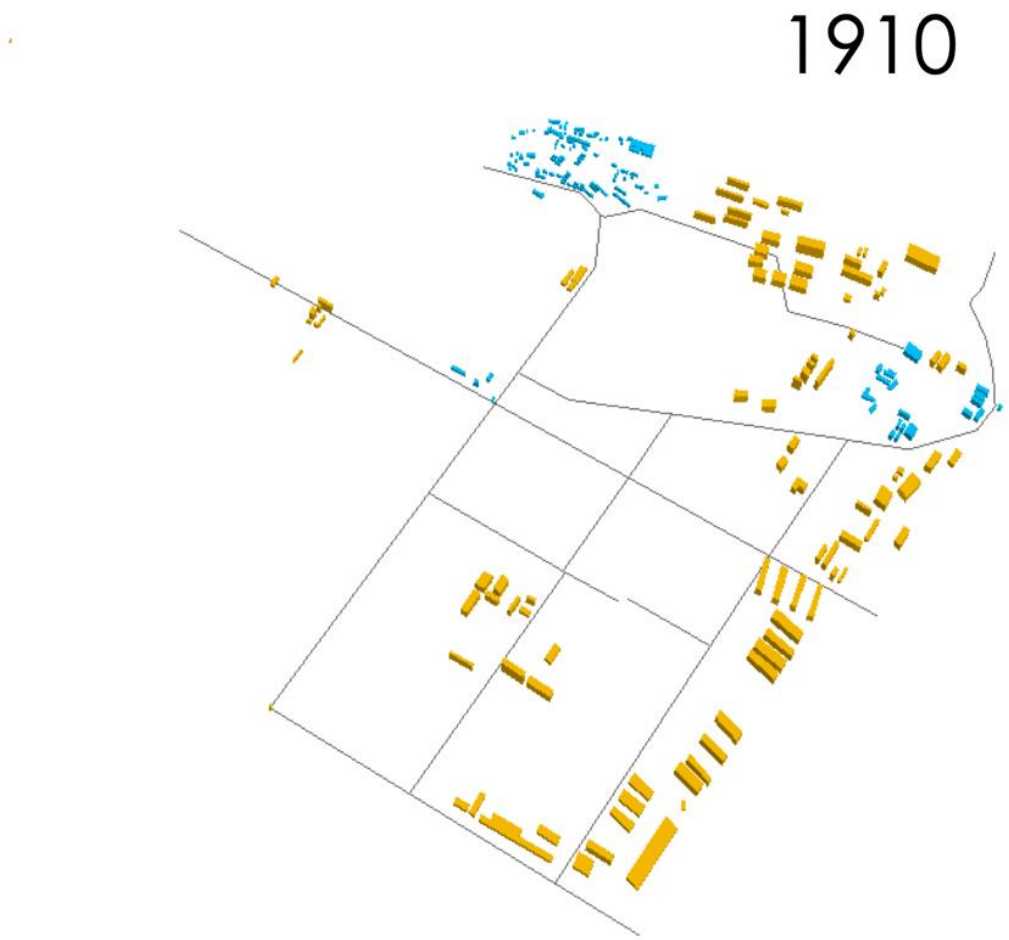
Ideally:

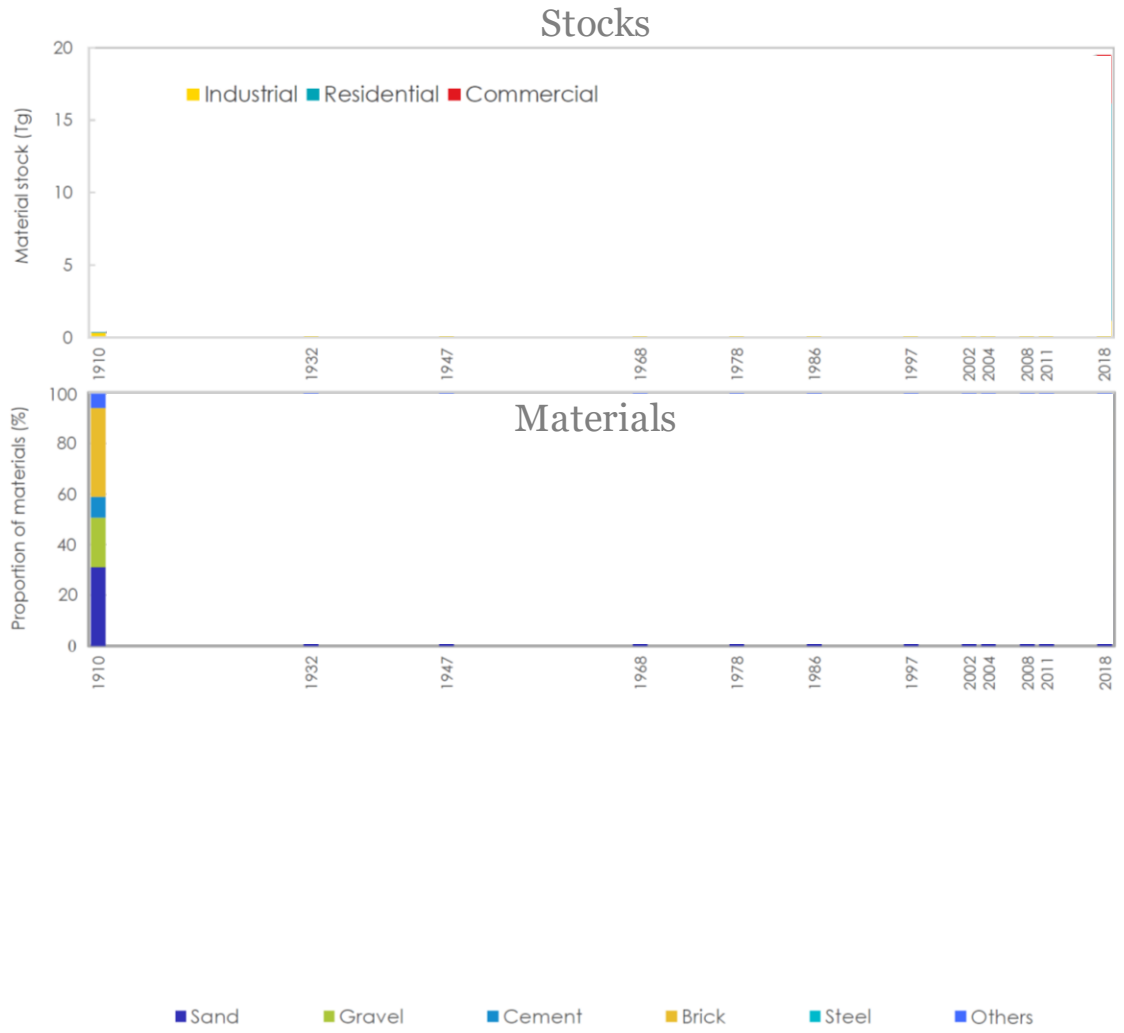
- High spatial resolution
- Time series
- Differentiation by:
  - Material
  - End-use
  - Age
  - Etc.

Challenges:

- Few or no data sources
- Uncertainties
- Time-consuming and resource-consuming
- High variabilities across:
  - Locations
  - Time
  - Use & function
  - Construction styles
  - Etc.

A century of construction material flows and stocks in Tiexi, China





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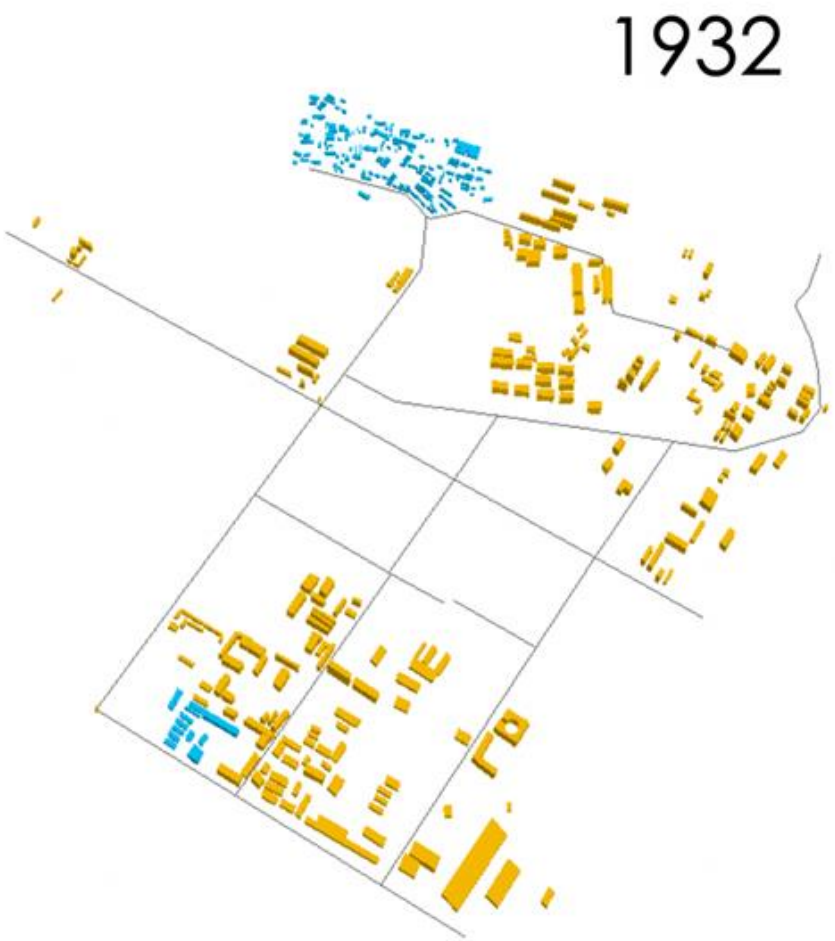

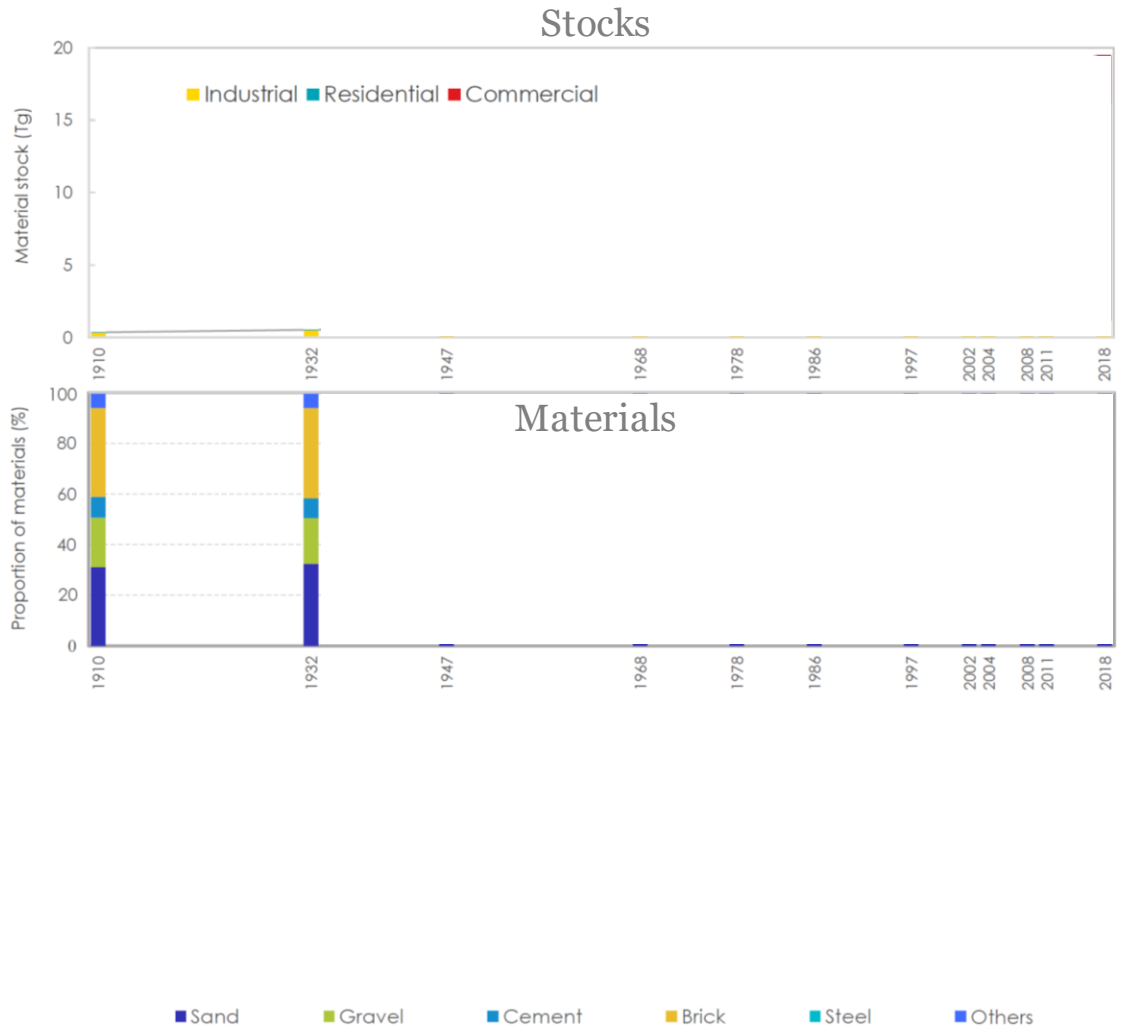

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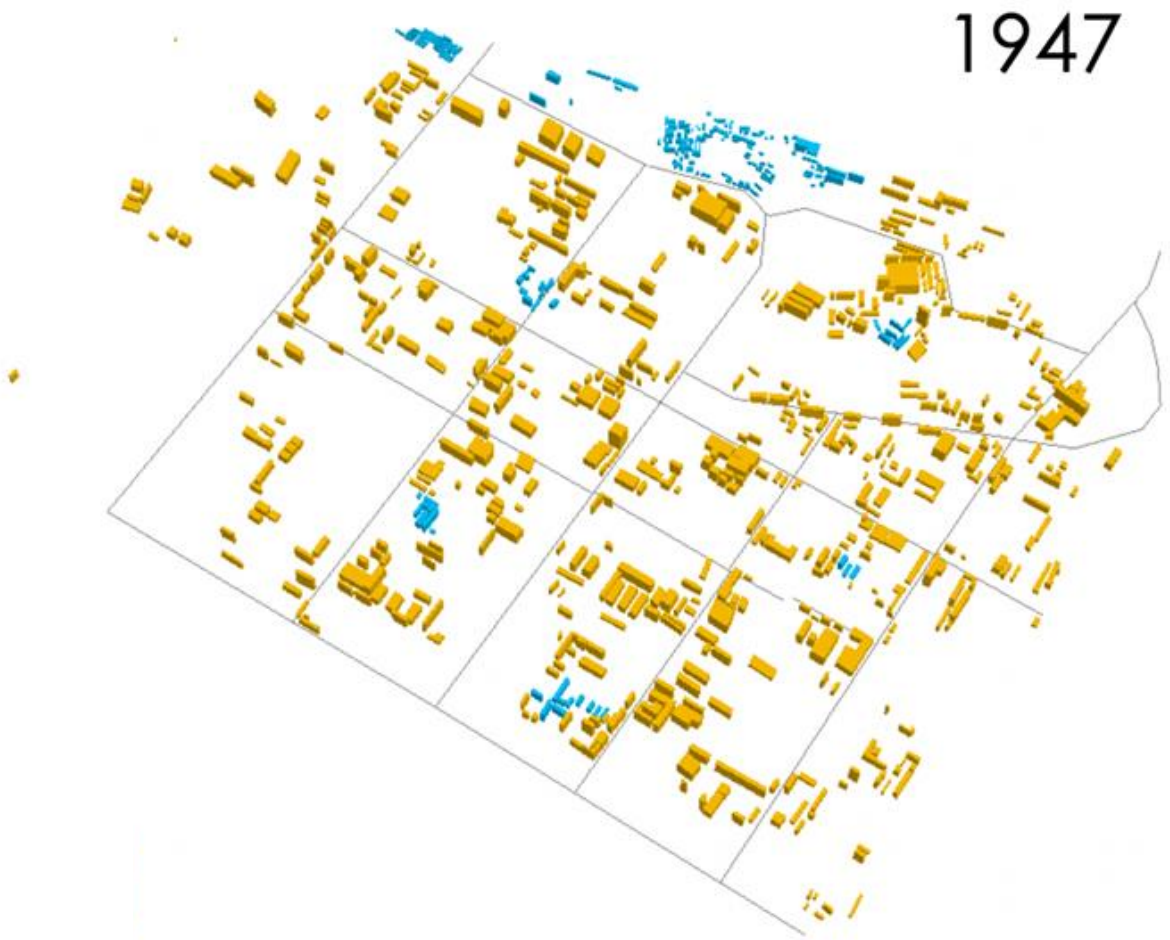

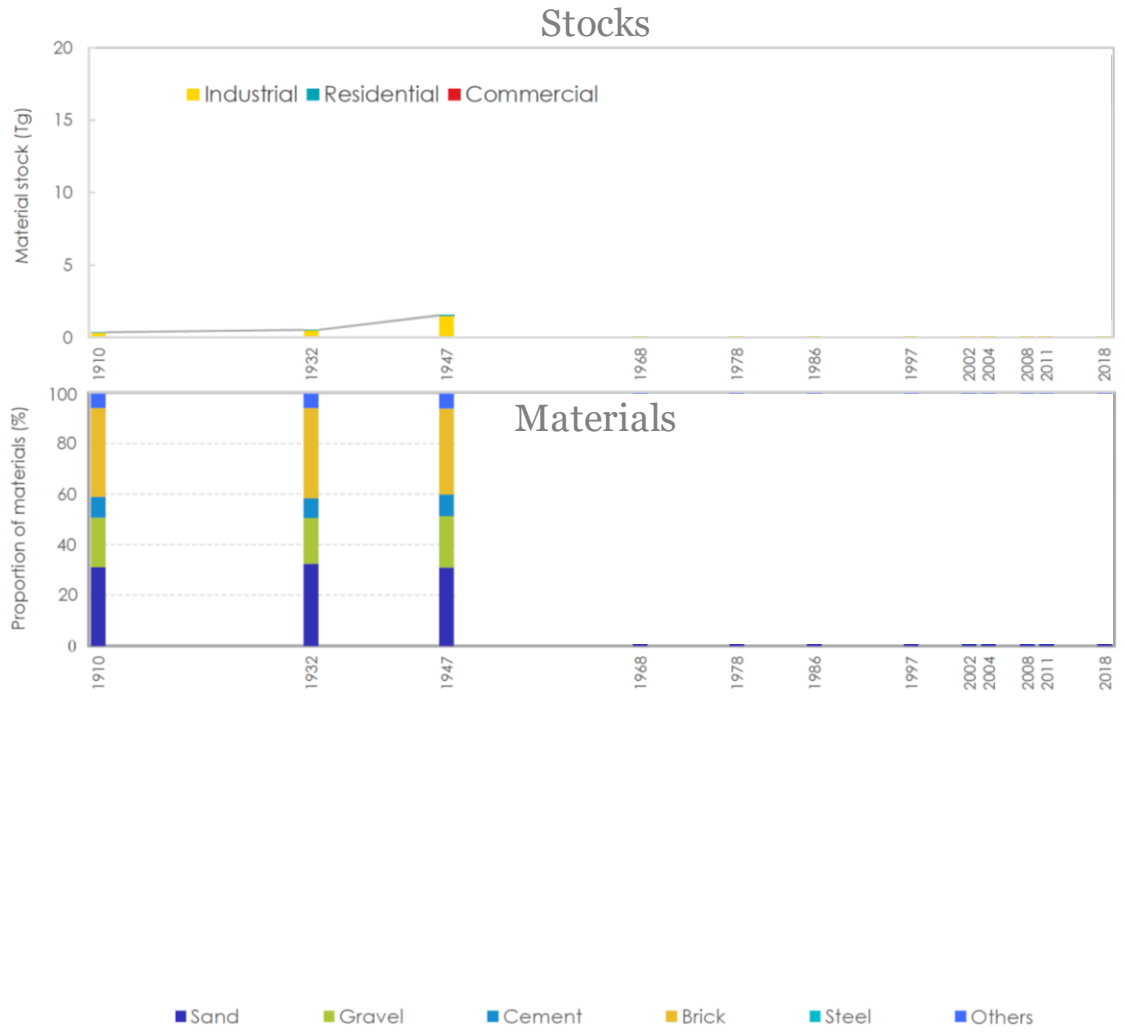

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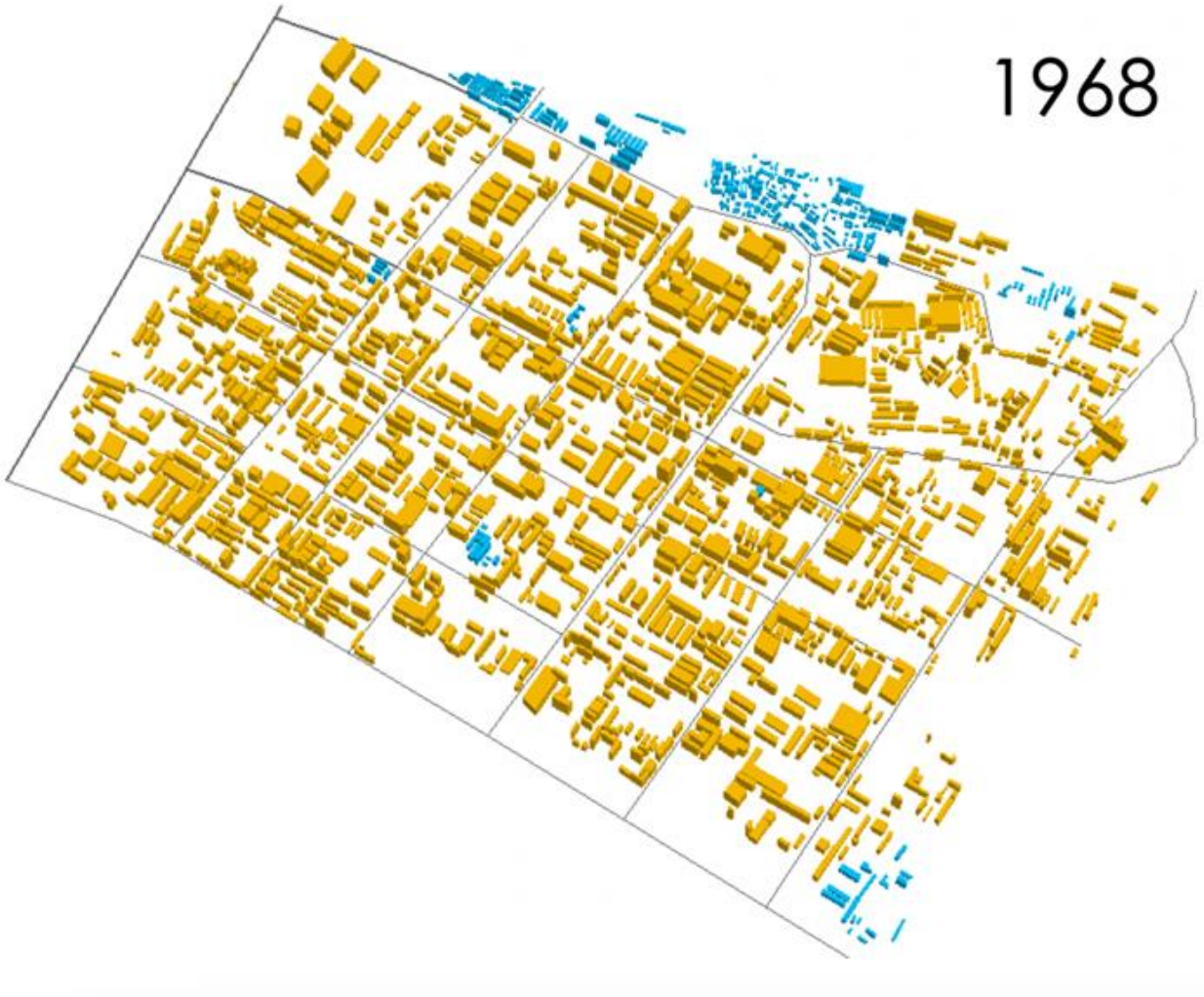

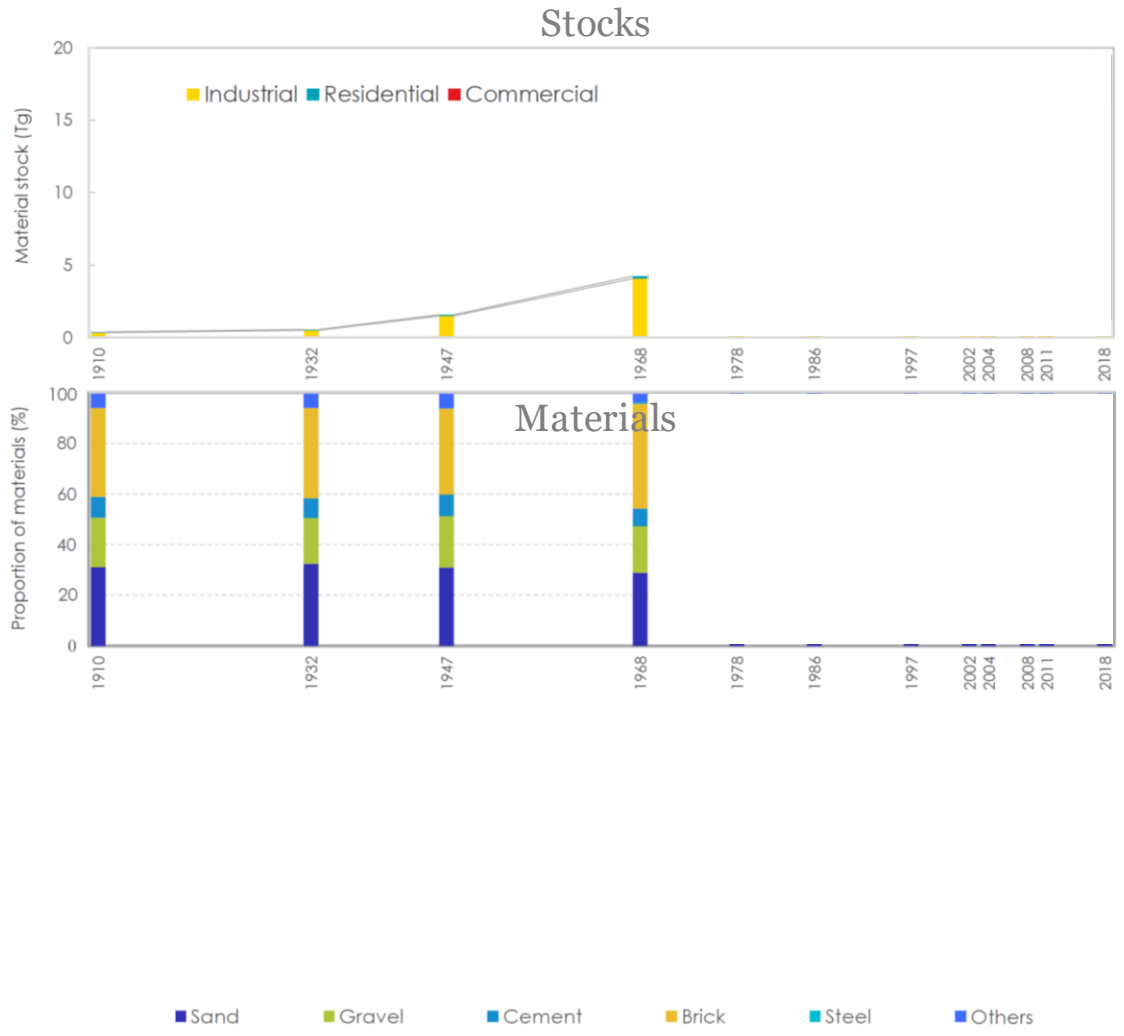

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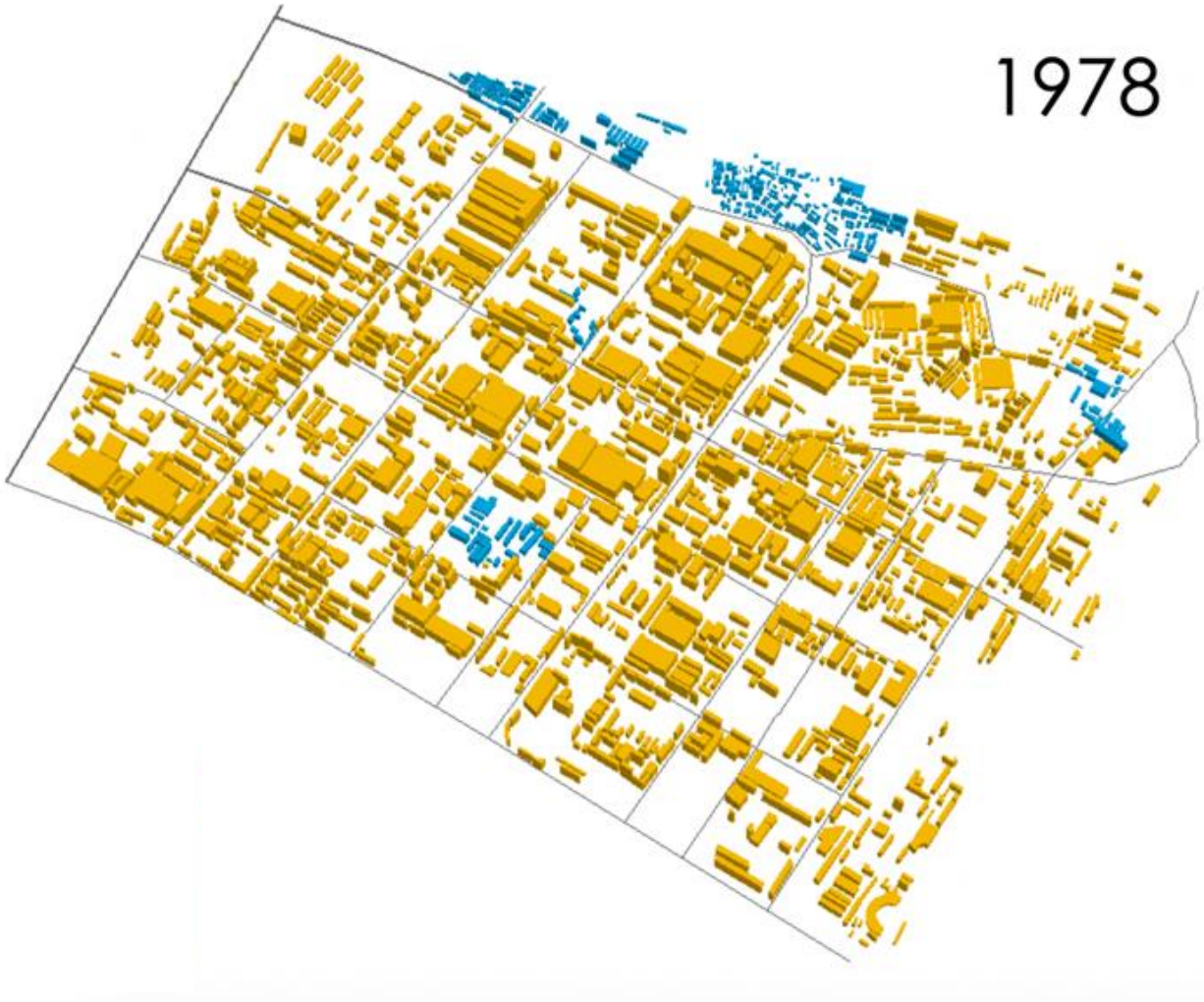

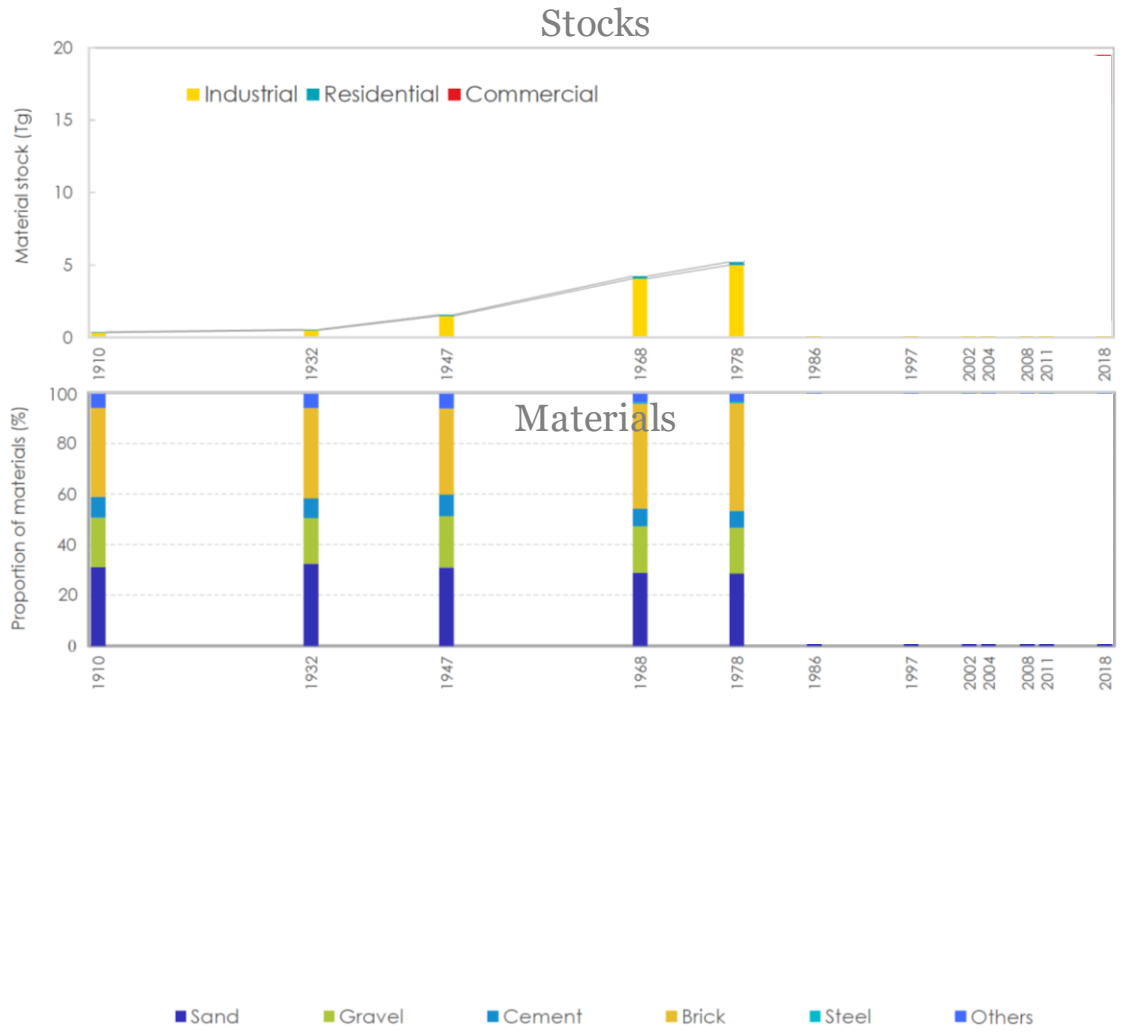

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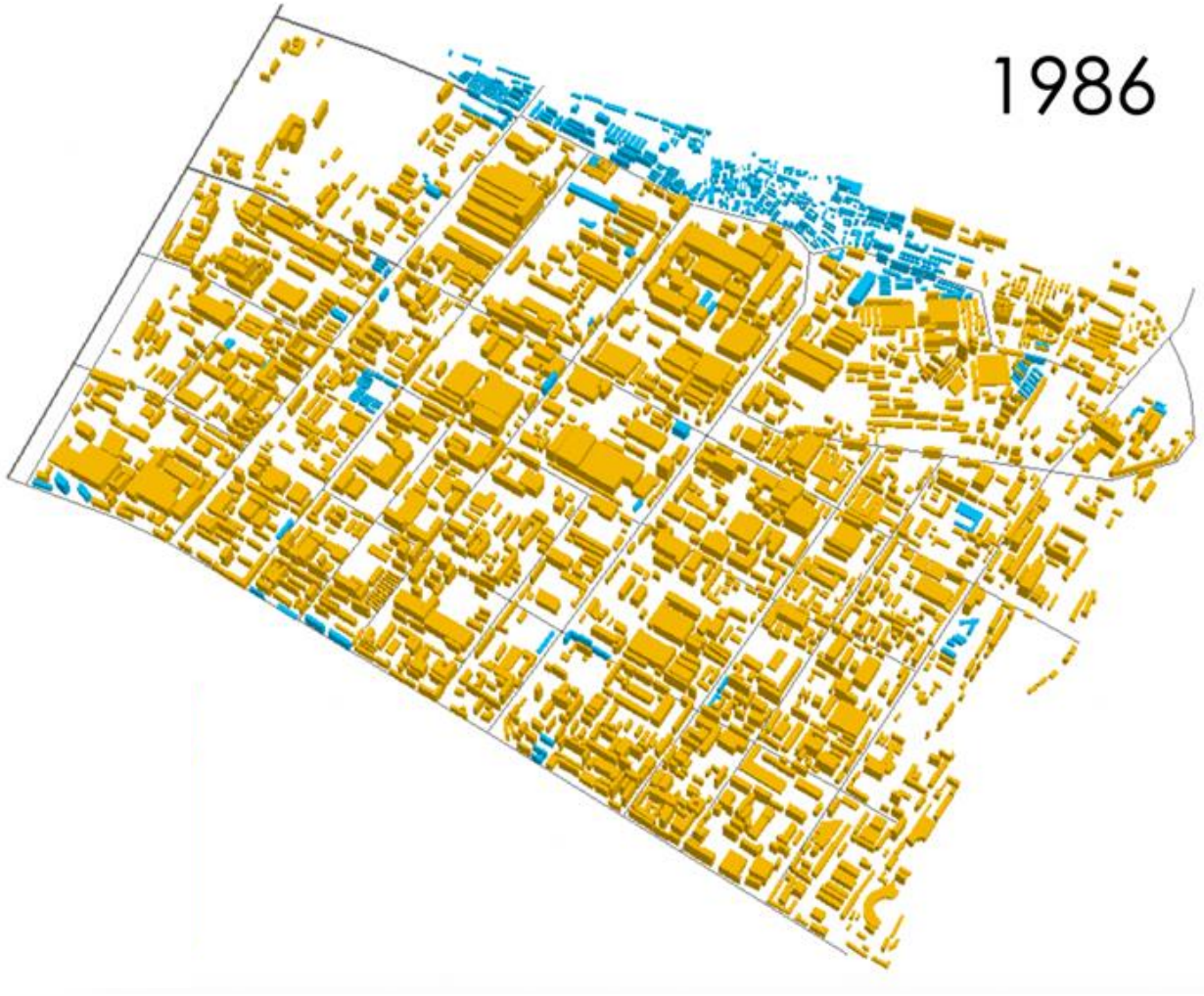

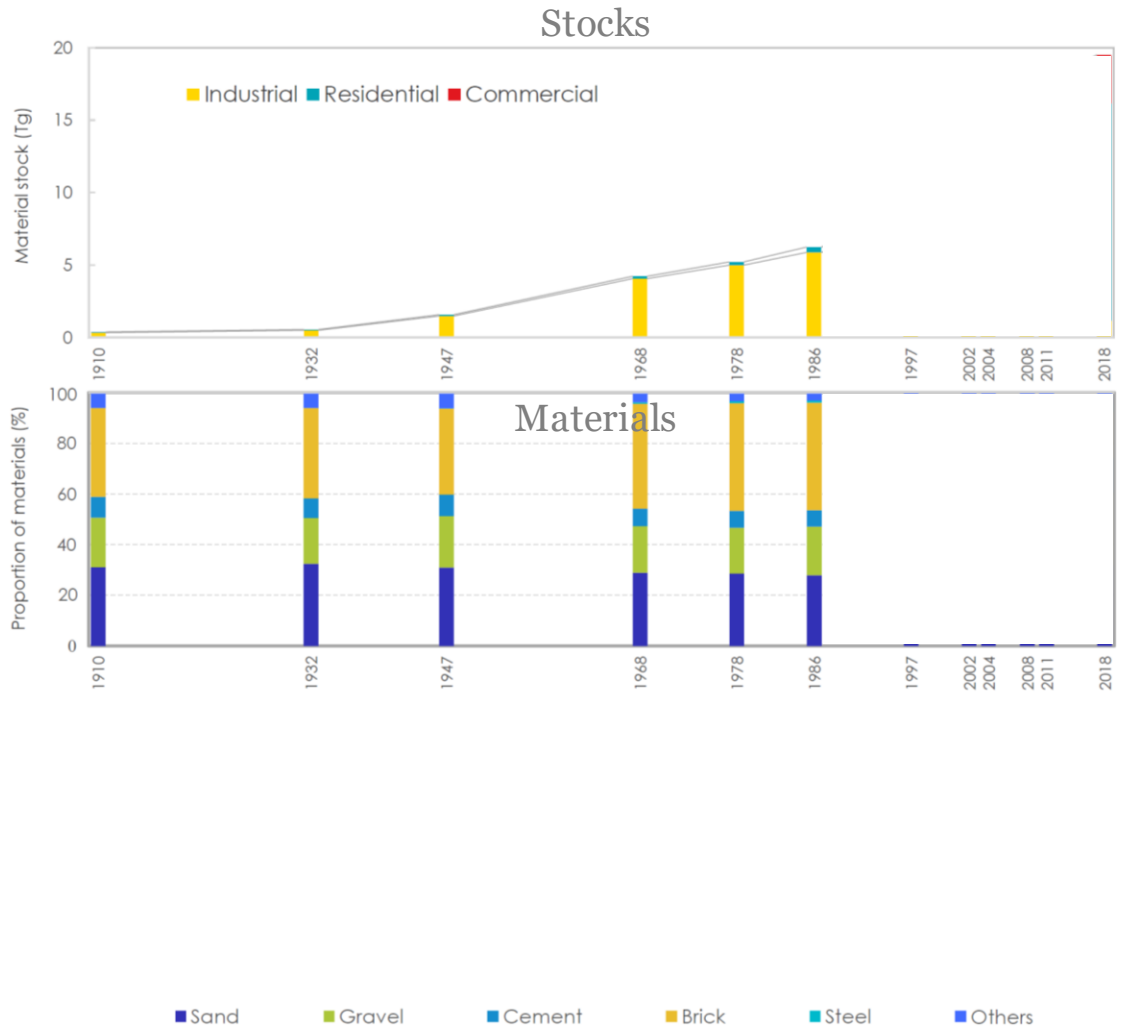

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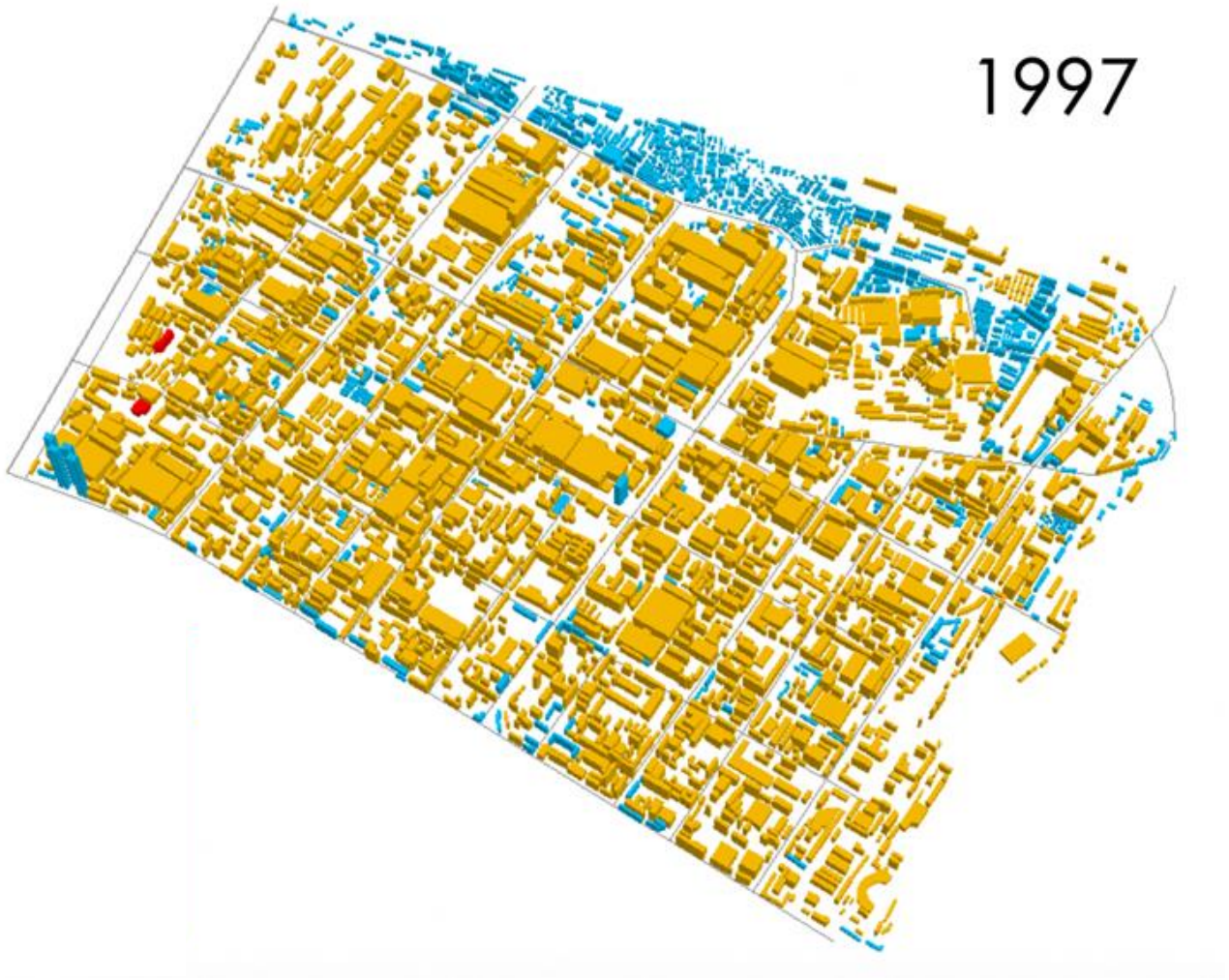

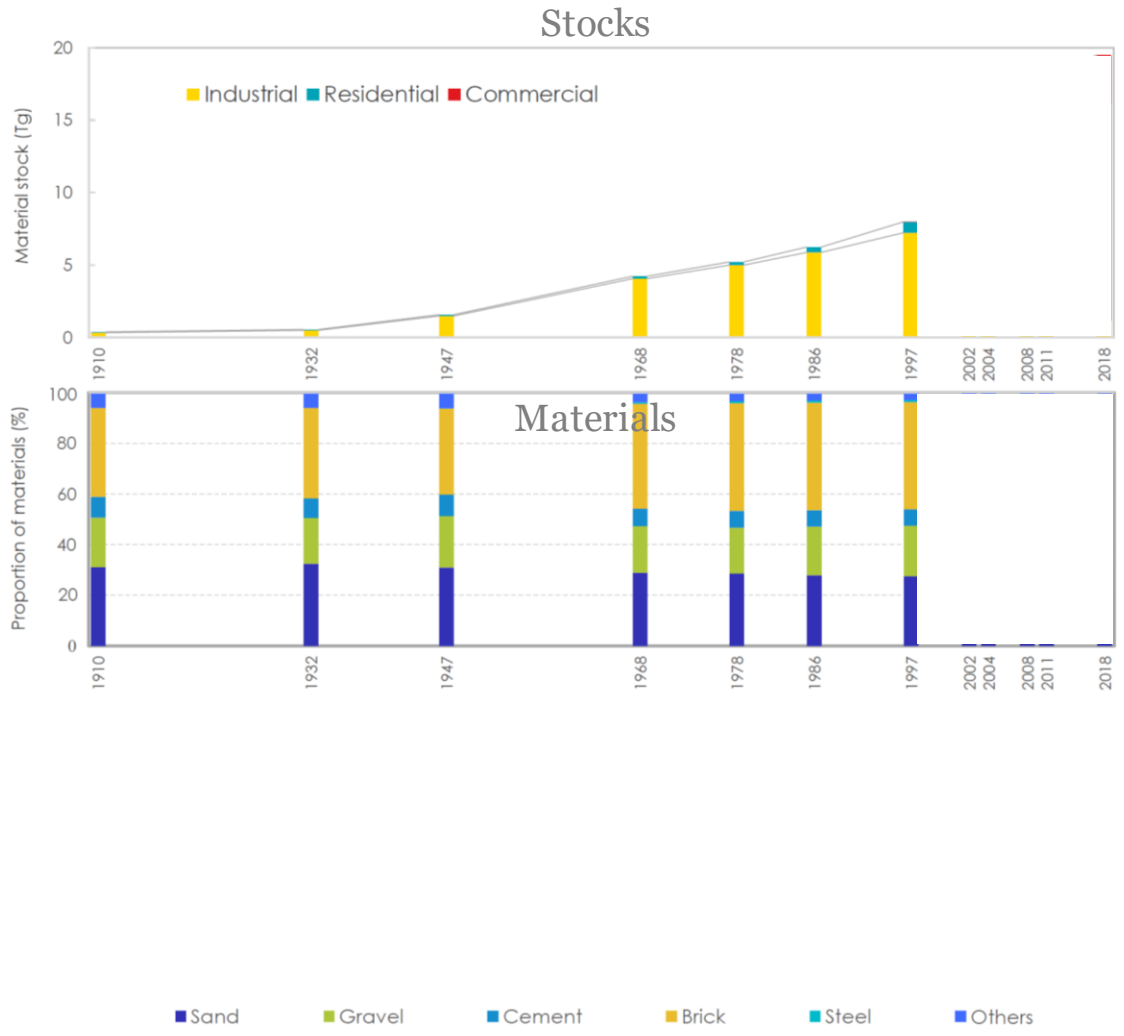

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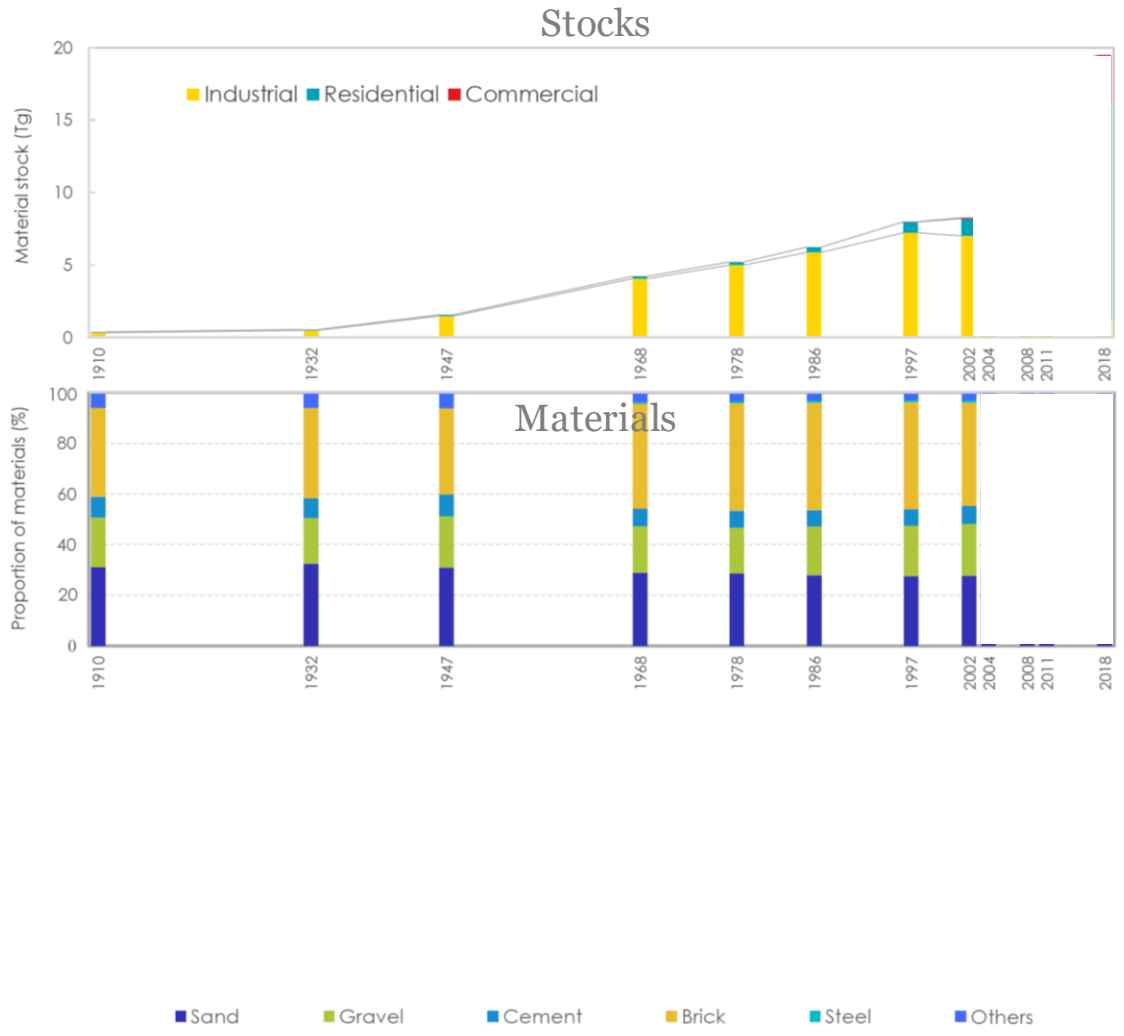

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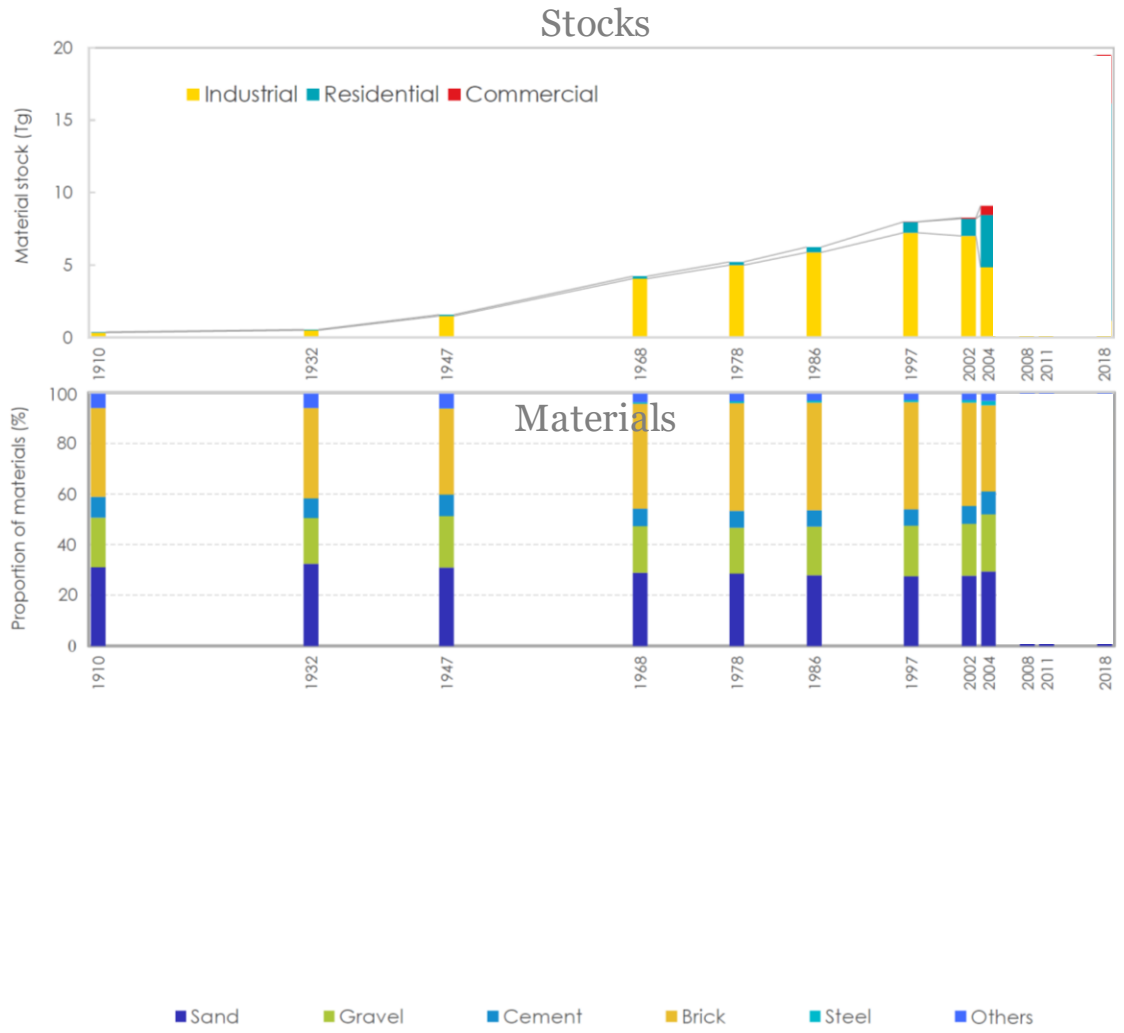

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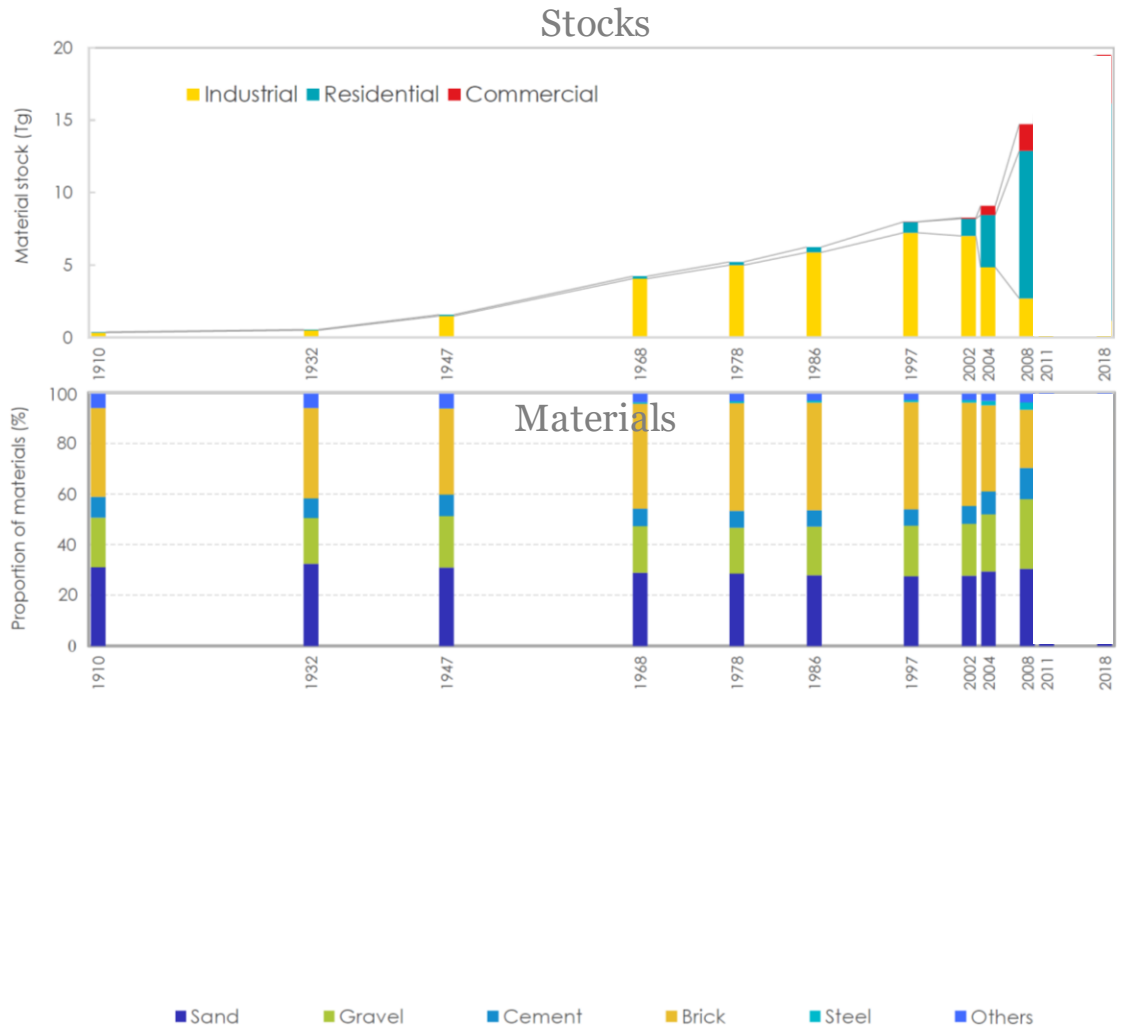

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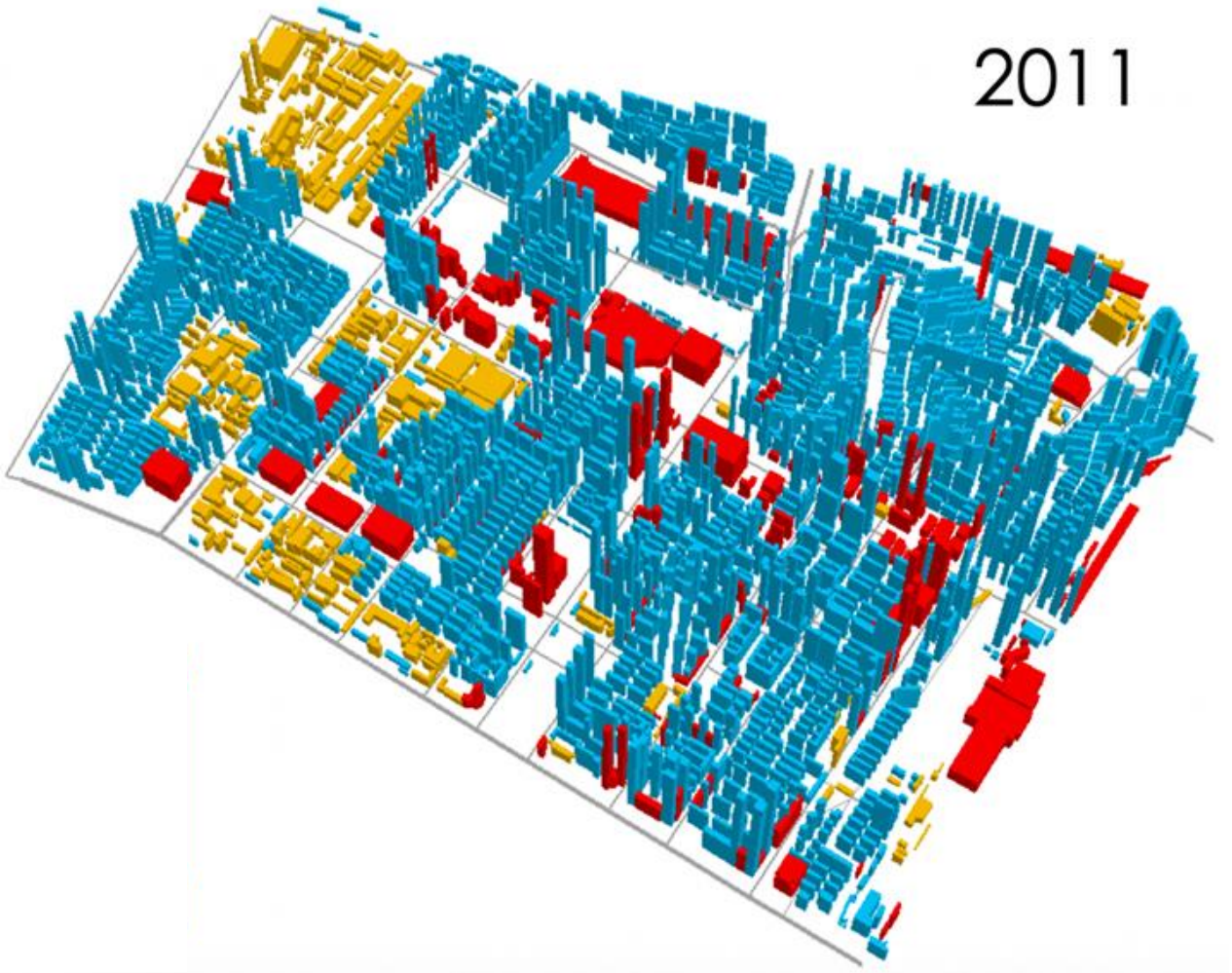

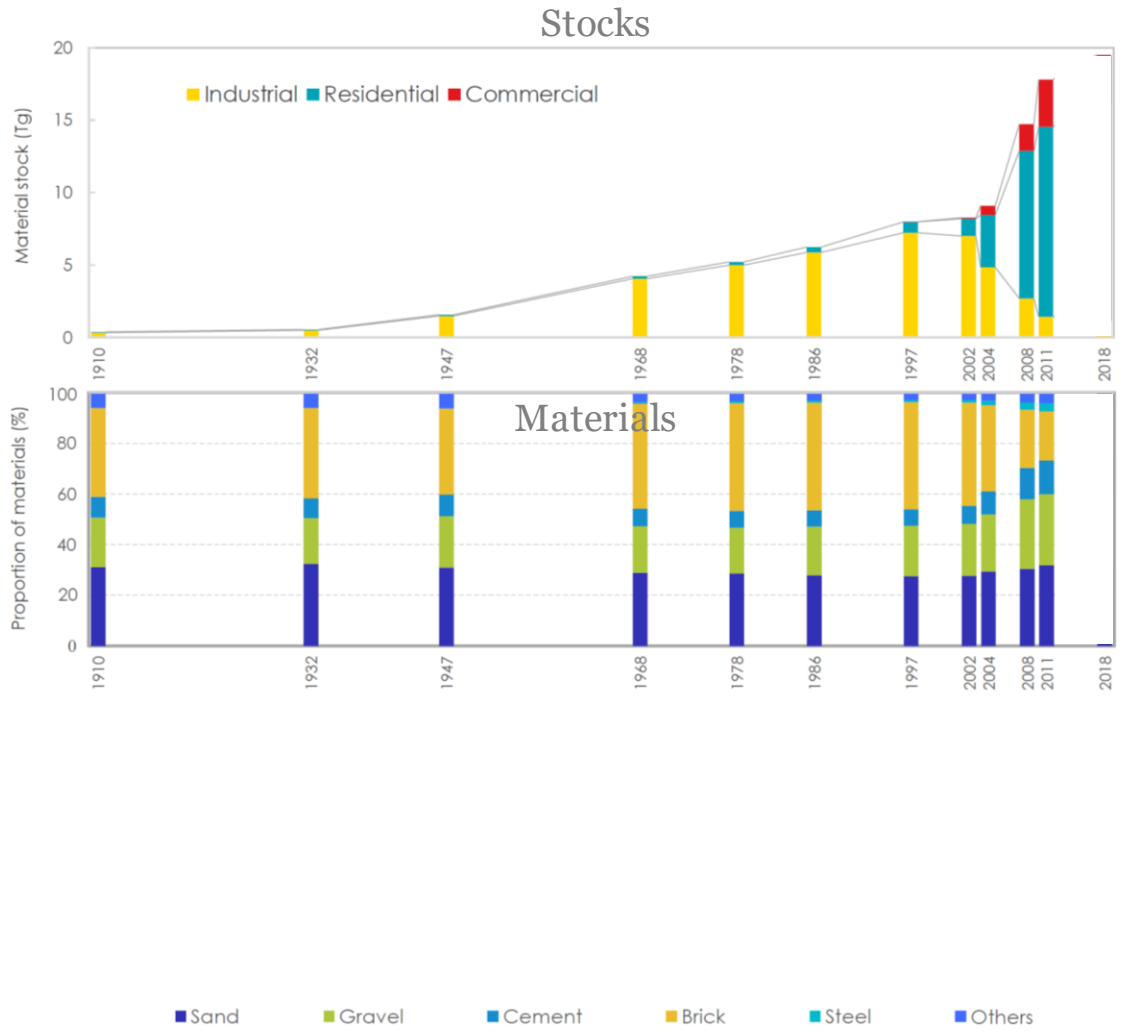

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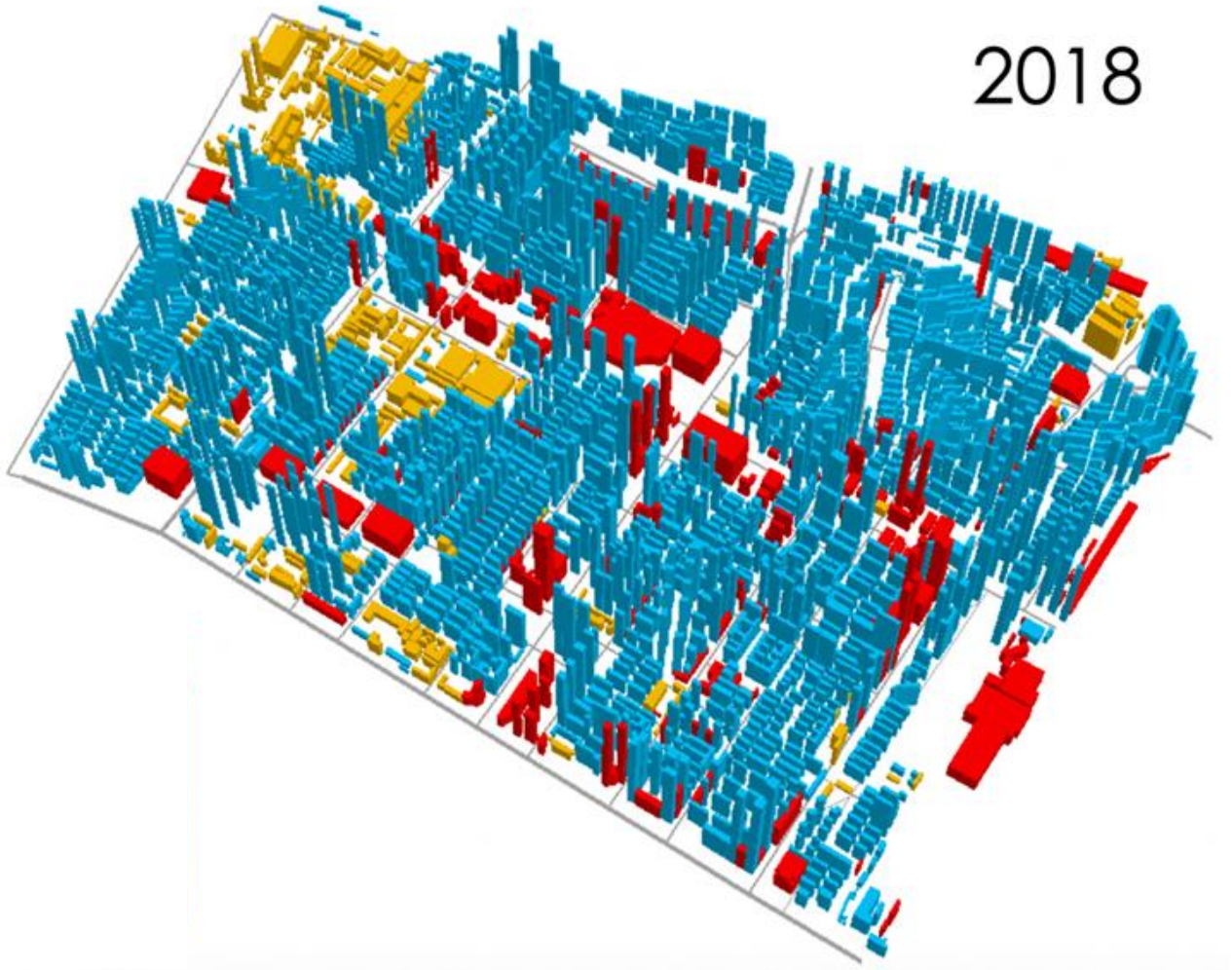

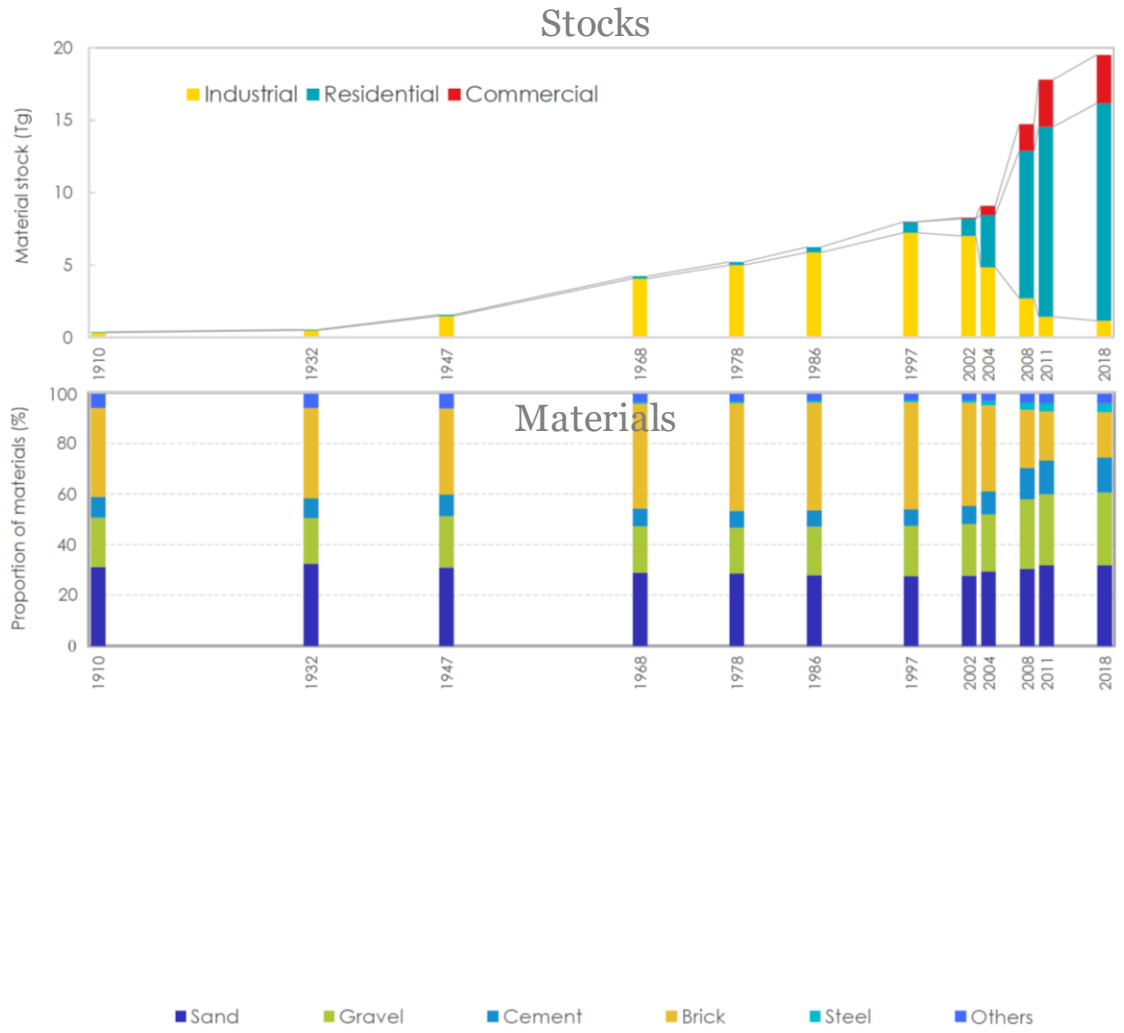

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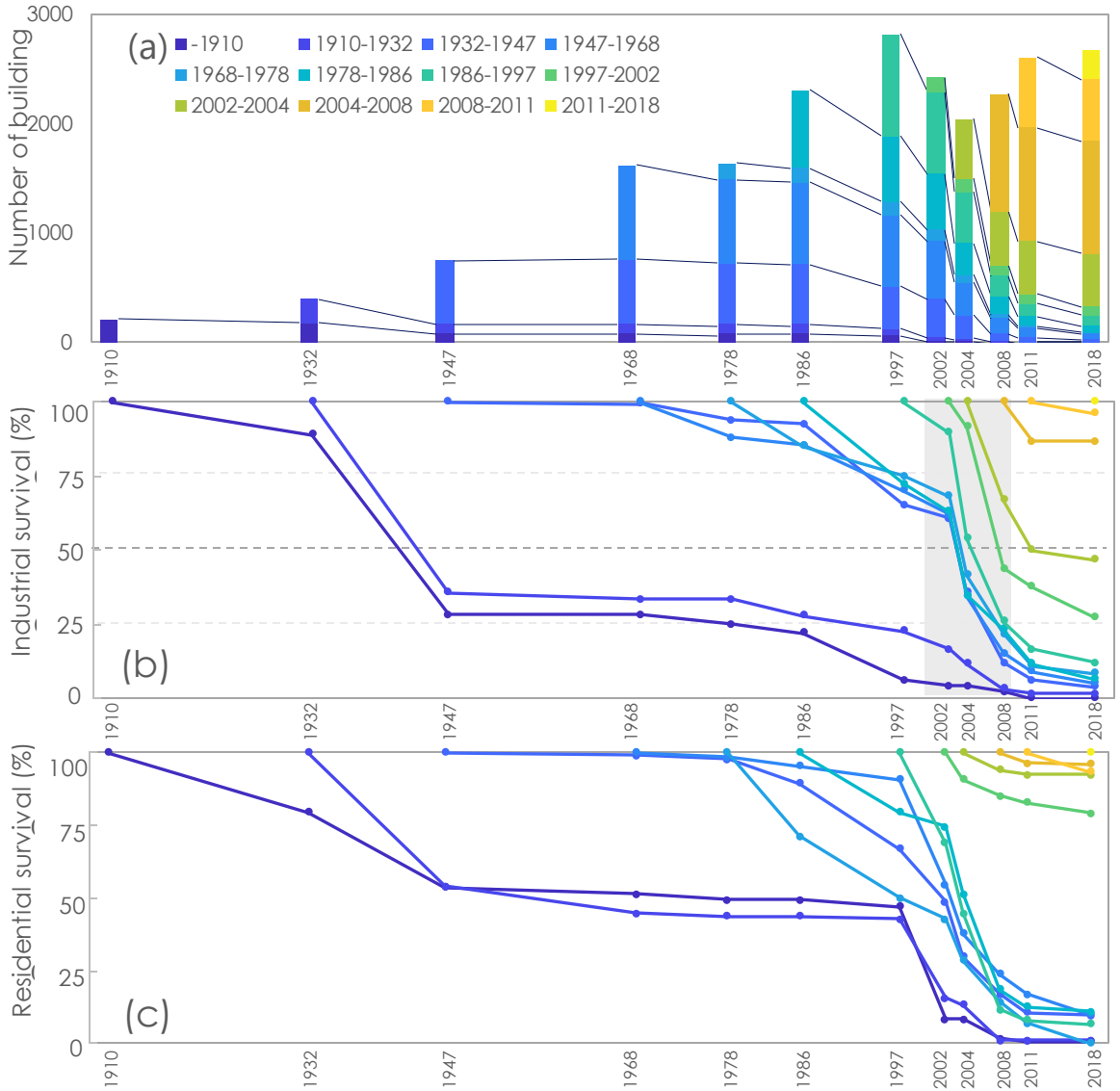
Deriving building survival curves and lifespans



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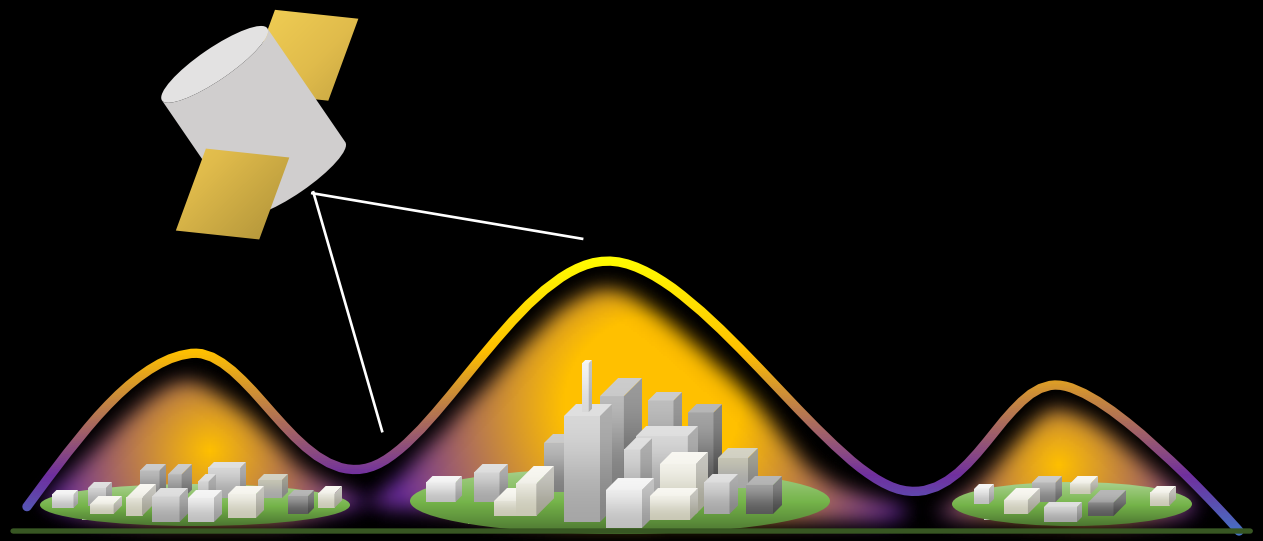
Spatially explicit material stock data is still sporadic

Country level data

Spatially explicit data

Approach 4: Remote sensing of material stocks



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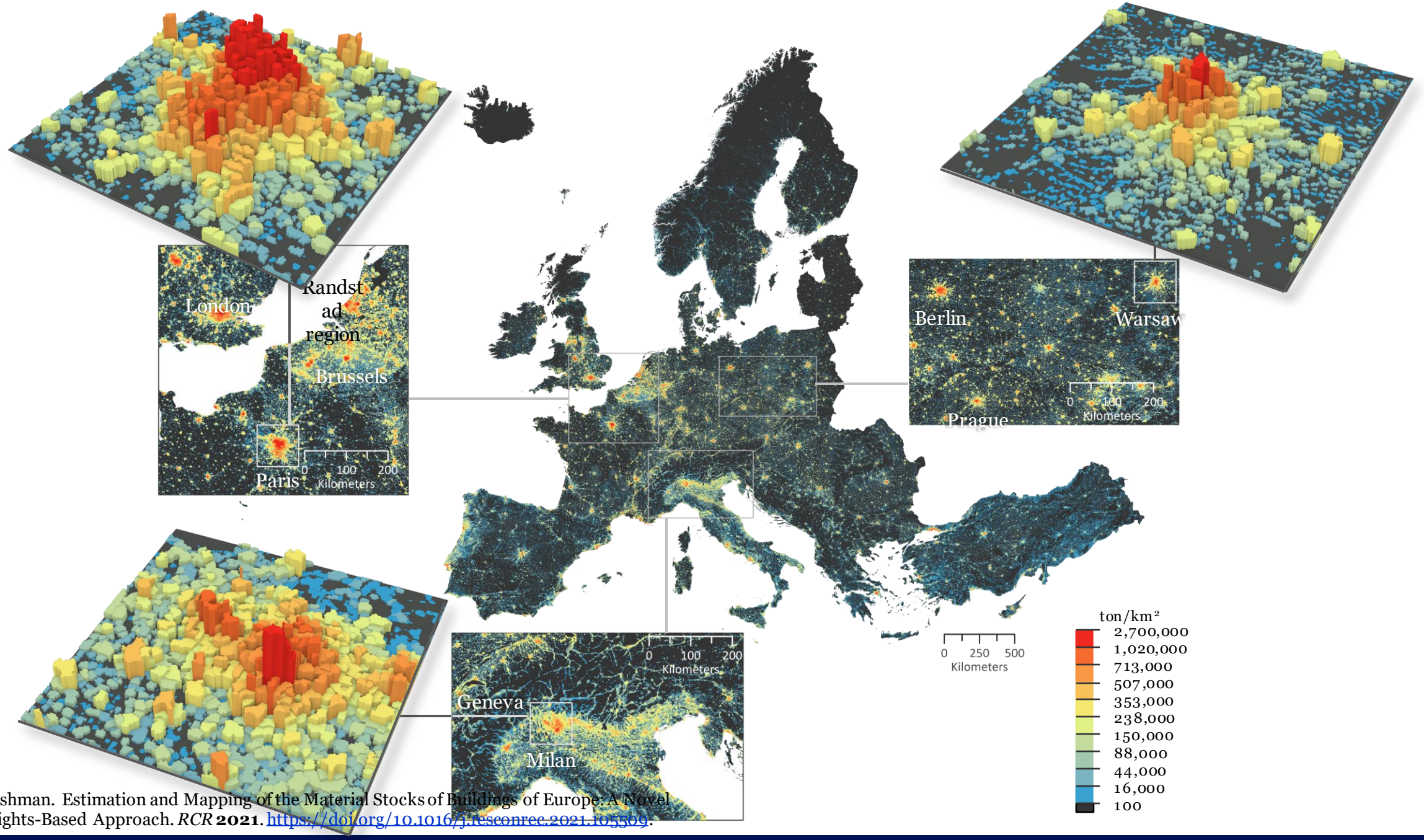

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Conclusions on progress & next steps

- Rapid evolution of the field of stock-flow socio-metabolic research in last 10 years, for both inflow- & stock-driven modelling, as well as in mapping via remote sensing and cadaster-based methods
- However, lots of inconsistencies between results, due to lack of harmonized data and differing system boundaries.
- EW-MEFA compatible stock-flow methods developed, country-level data currently in preparation (MAT_STOCKS project*)
- Ongoing work to conceptually and quantitatively link material stocks and flows to their societal roles/services, as well as their life-cycle environmental impacts.
- Links to economic models, integrated assessment models, and other models of nature and society in their infancy
- Two new Horizon Europe projects started this year, addressing these challenges over the next years, CircEUlar (Wiedenhofer, www.circeular.org) & CIRCOMOD (Fishman, http://circomod.eu/)