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Chair of
Applied Economics

Building Up: A Satellite-Based Method for Measuring China's Vertical Urban Development

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Outline

1. Introduction
2. Method and Data
3. Results
4. Comparing to Night Light Data
5. Outlook

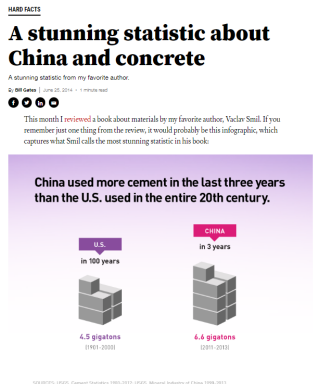
Outline

Core Idea

For the first time the urban-industrial transformation takes place while an armada of satellites watches from space

Urbanisation and China

- Mao's China (1976) idealized the farmer and the rural lifestyle
- Deng Xiaoping's Reforms (1981-1987) integrate China liberalized markets and unleashes urbanisation on massive scale
- China's Urbanisation Rate (World Bank)
  - 1980: 19%
  - 2000: 36%
  - 2021: 63%
- There was always an intricate relationship between urbanisation and economic activities (growth)


HARD FACTS

A stunning statistic about China and concrete

A stunning statistic from my favorite author.

By Bill Gates | June 20, 2014 | 1 minute read

This month I reviewed a book about materials by my favorite author, Vaclav Smil. If you remember just one thing from the review, it would probably be this infographic, which captures what Smil calls the most stunning statistic in his book:

From Bill Gates Blog

Literature

New class of models in urban economics
e.g.[Ahlfeldt et al., 2015, Dingel and Tintelnot, 2020, Heblich et al., 2020]

- Quantitative urban-spatial equilibrium model (rent bidding models)
- Beyond the concentric city with many city blocks
- Relationship between transport network, agglomeration economics and density

There is a recent literature of 3D height estimation

- High resolution but limited scope (some expensive commercial satellite imagery) and no time dimension [Cao and Huang, 2021, Frantz et al., 2021]
- Low resolution, large scope but no time dimension
  [Wen et al., 2019, Li et al., 2020, Li et al., 2023]
- Deletion approach Shenzhen [Yu et al., 2021]

Outline

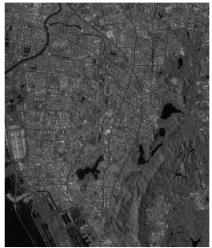
Satellite Imagery

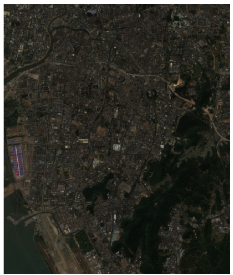
Sentinel 1

- SAR
- 2014-present
- Resolution 10m
- Frequency: 3 days

Sentinel 2

- Optical (RGB) + Infra Red
- 2017-present
- Resolution 10m
- Frequency: 20 days
- Need for mosaic (median of all images of the year)



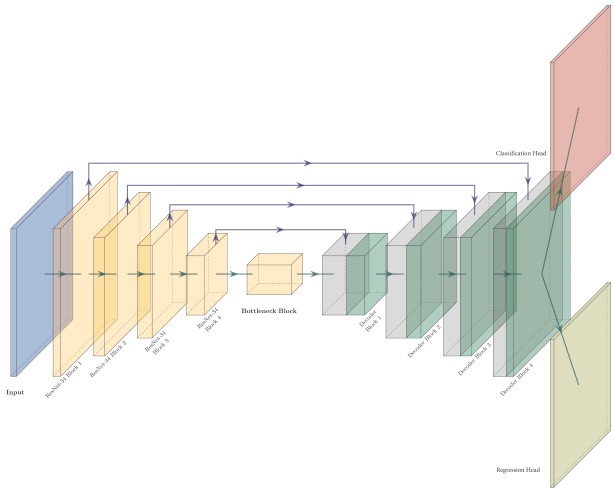


Reference Data

- Large crowd sourced/scraped Amap data set
- Widely used to predict urban structures in China
- 77 cities with partial coverage
- 40 with best coverage are chosen
- No clear date and missing/old entries
- Polygons are translated into 10m grid of Sentinel

Model Architecture

- We feed 256 × 256 grids tiles
- U-Net - ResNet-34: encoder-decoder convolutional structure with skip connections
- Multi-task learning approach
  - Segment building footprints
  - Predict building height
- This is the winner of various model architectures tested in the validation set
- All results are based on trustworthy Shenzhen reference data (the test set)



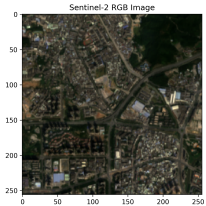
Model Architecture Graph: ResNet-34 with two precition heads

Outline

Example Cases

Footprint Identification:

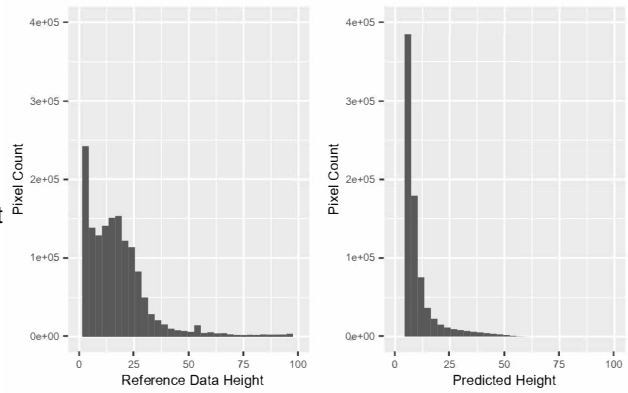
- Identification of regions covered by buildings
- Difficulty in distinguishing small, closely located buildings
- Overestimate of building footprint coverage
- Limitation of Sentinel resolution in relation to urban topology
- Discovery of buildings not documented in reference data



Height Distribution

Height estimation:

- Consistent underestimation of high-rise building heights
- Heavy overestimation of the lowest bin

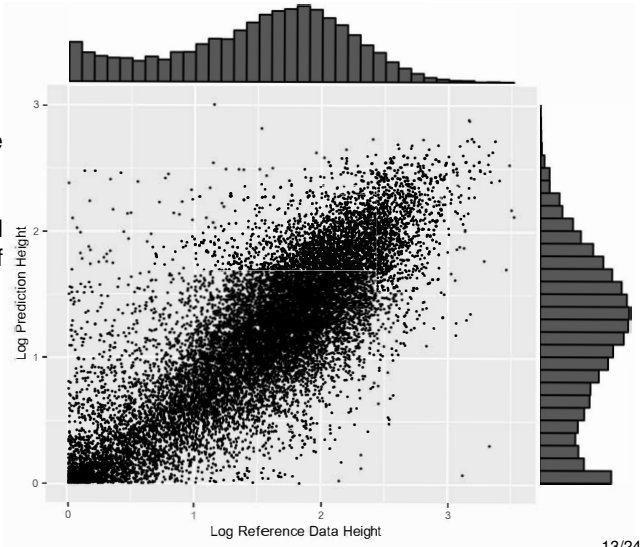


Height distribution of reference data and prediction for test set (Shenzhen)

Variation

Logarithemised height reference data to prediction

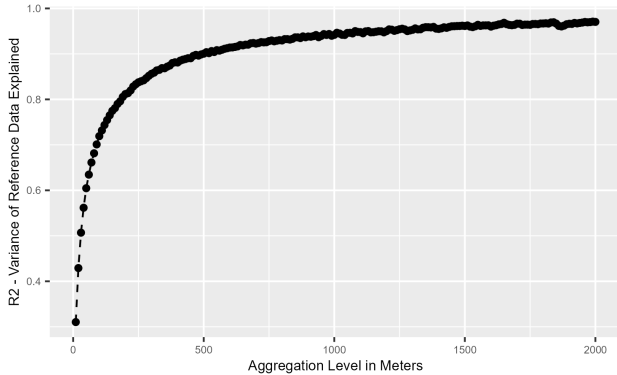
Accurate portrayal of hierarchical structure of building heights (92% of predictions)



Aggregation

Aggregation shows that our explanatory power is much better than it look at the first glance

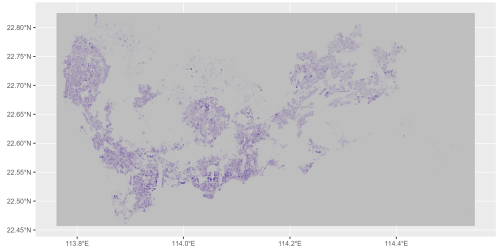
- We do not produce sharp edges of buildings
- Building height is distributed over several cells
- R2 by aggreagtion level:
  - 10x10 meter: 31%
  - 200x200 meter: 80%
  - 2000x2000 meter: 98%



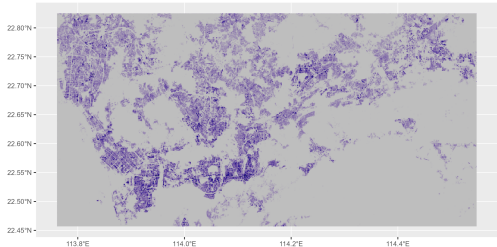
Outline

Overview

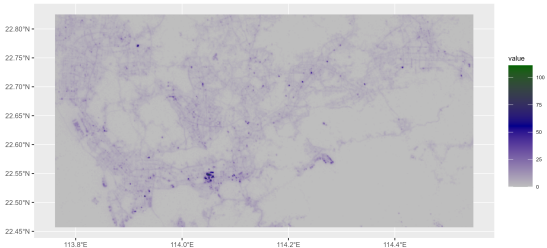
Reference Data



Prediction



Night Light Reflectance



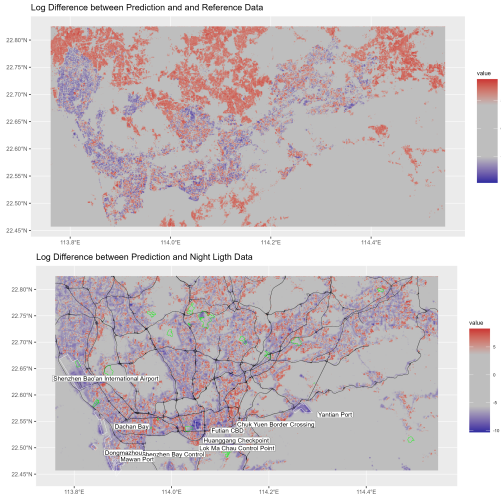
Differences

Prediction vs. Reference data

- Shows regions missing from reference data but featured in our prediction (e.g., Hong Kong, peripheral areas)

Prediction vs. Night light data

- Over-representation of large-scale infrastructures (ports, customs checks, airports, highways) and recreational facilities (golf courts)
- Underestimation of building volumes in dense urban environments



Outline

Further Steps

Technical Level

- Get height regression right (transformer, gradient loss, image augmentation)
- Extending panel beyond Sentinel constellation time frame (back to 2009, PlanetScope and RapidEye)
- Extending beyond 2009 in lower resolution with Landsat (urban land-use model)
- Extending scope to the urban areas which covers over 60% of populations in China

Urban Economics

- Hedonic housing price equation for traffic networks
- Local exposure to trade shocks and it's densification implications
- ...

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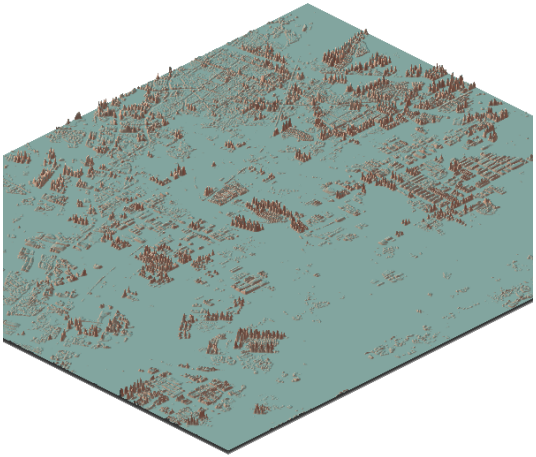
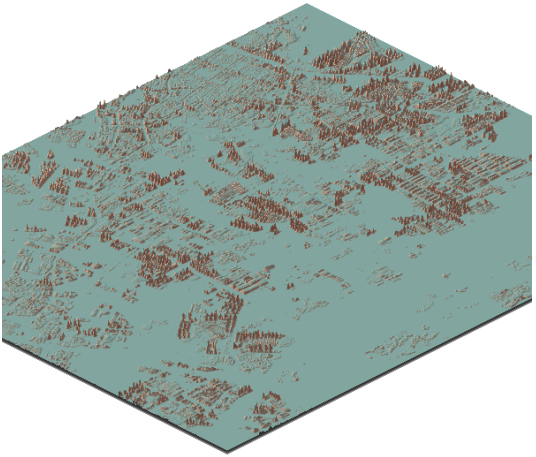
Pingshan District

Prediction for Pingshan District 2018

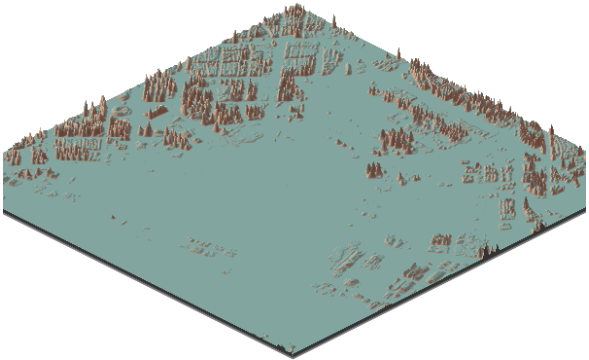


Prediction for Pingshan District 2021



Qianhai District

Prediction for Qianhai Bay 2018



Prediction for Qianhai Bay 2021