MSc Geomatics Thesis
P5 Presentation

04 November 2021
Denis Giannelli

Commission

Giorgio Agugiaro	1st supervisor
Camilo León-Sánchez	2nd supervisor
Peter Koorstra	delegate of the board of examiners
Olindo Isabella	co-reader

TU Delft

Solar Analysis on Buildings of Favelas in São Paulo to Estimate PV Potential

Introduction → Theory & Literature → Method → Experiments → Results → Conclusions

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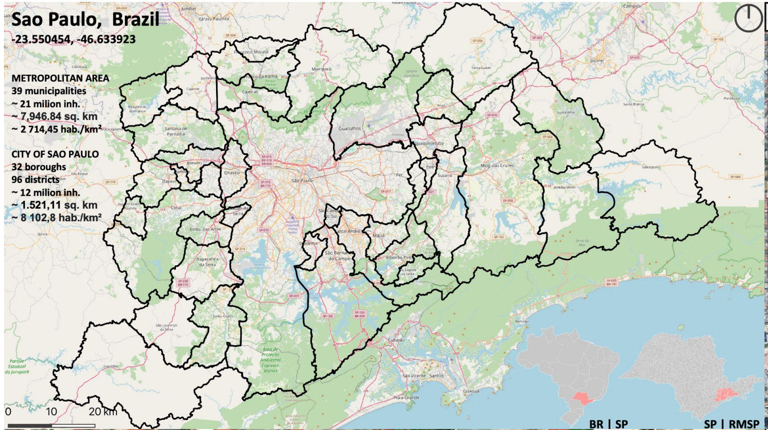
Context



The ‘formal city’ and the ‘informal city’ in São Paulo, Brazil.

Context

Introduction
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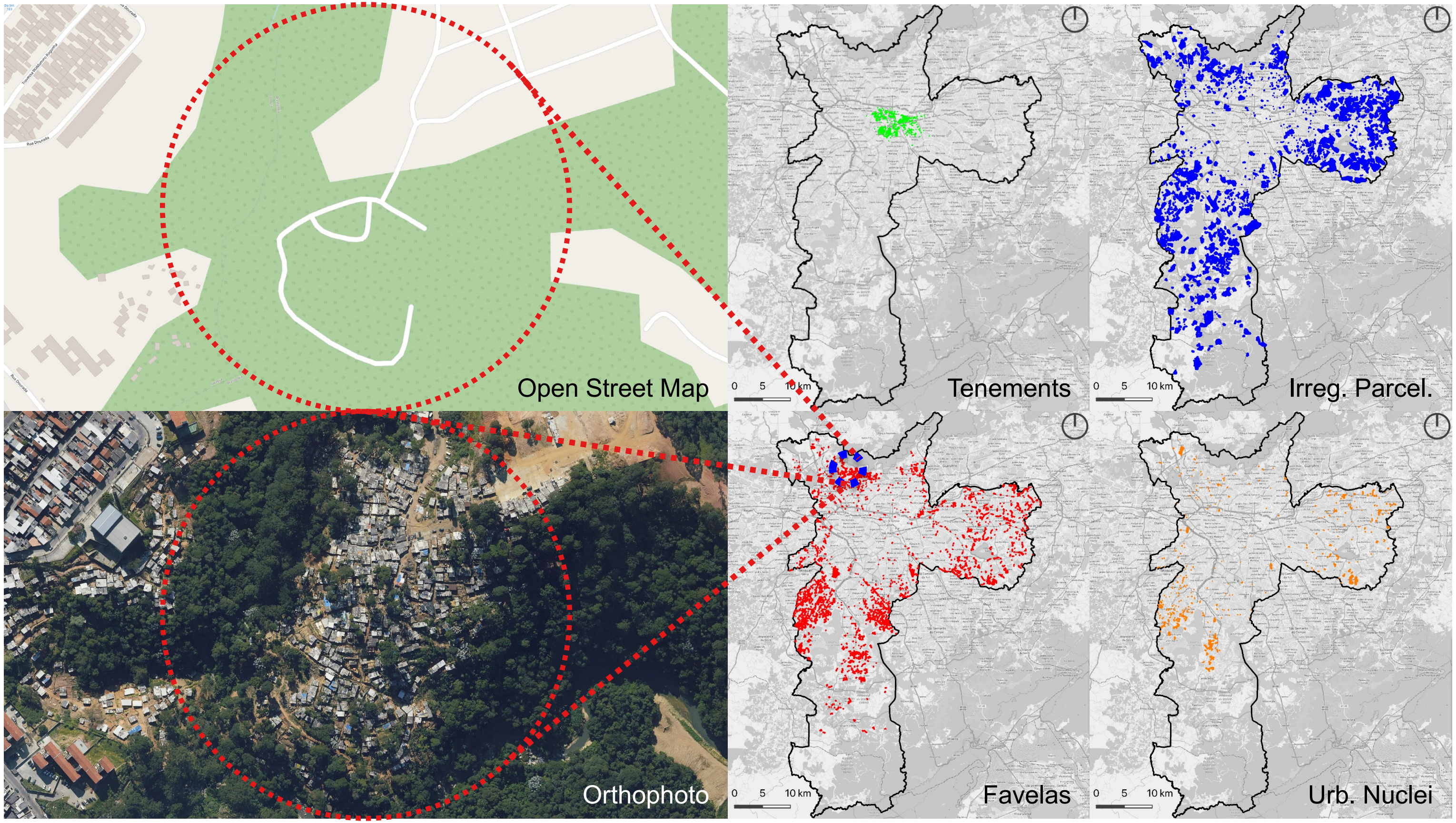

The geo-information segregation and the *terra incognita*.

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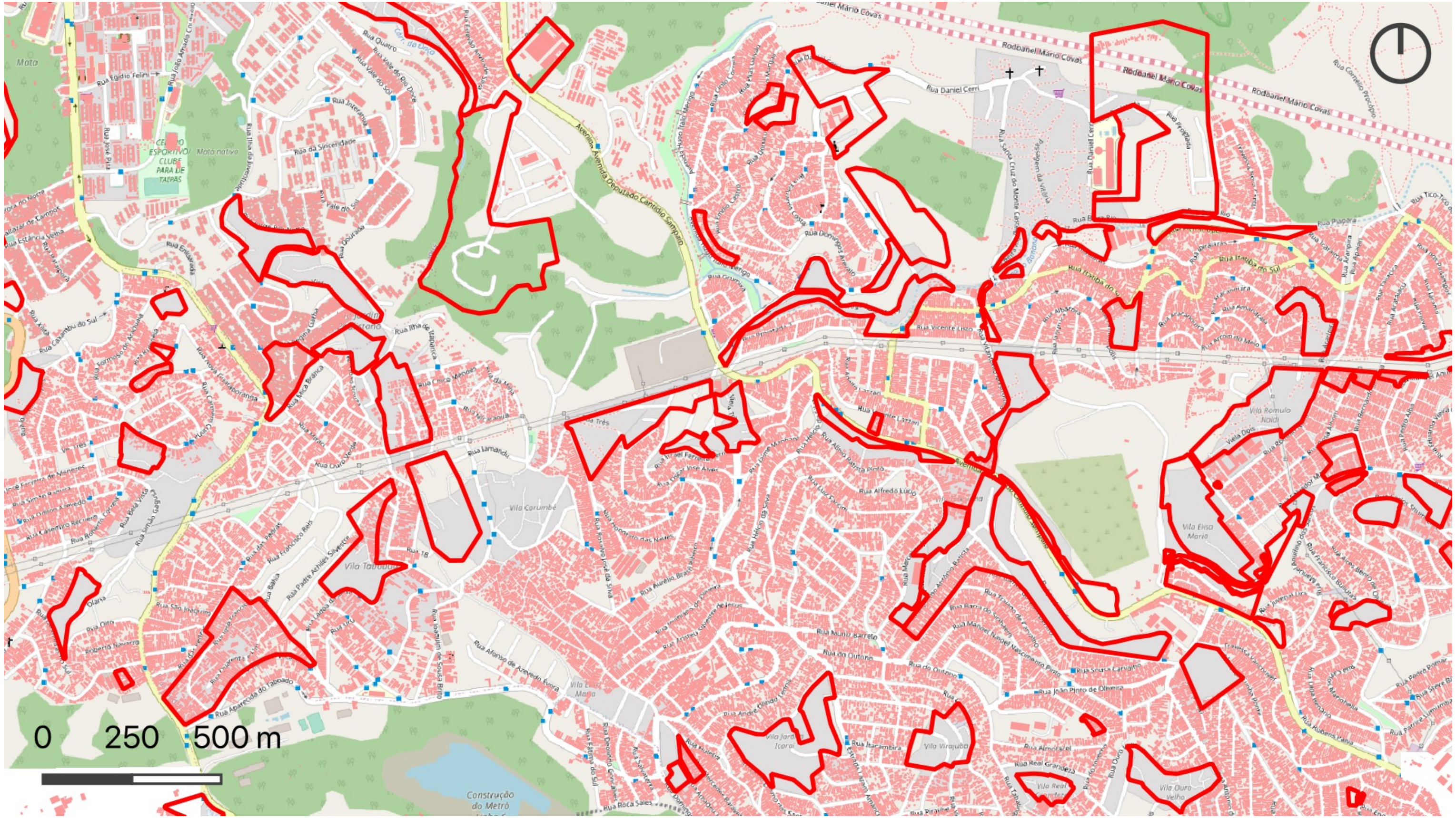


Favelas (red edge) and the scarcity of cadastral data (pink fill).

Problem Statement

Providing the informal city with infrastructure: multiple urban domains.

Without mapping, the provision of urban infrastructure is jeopardized.

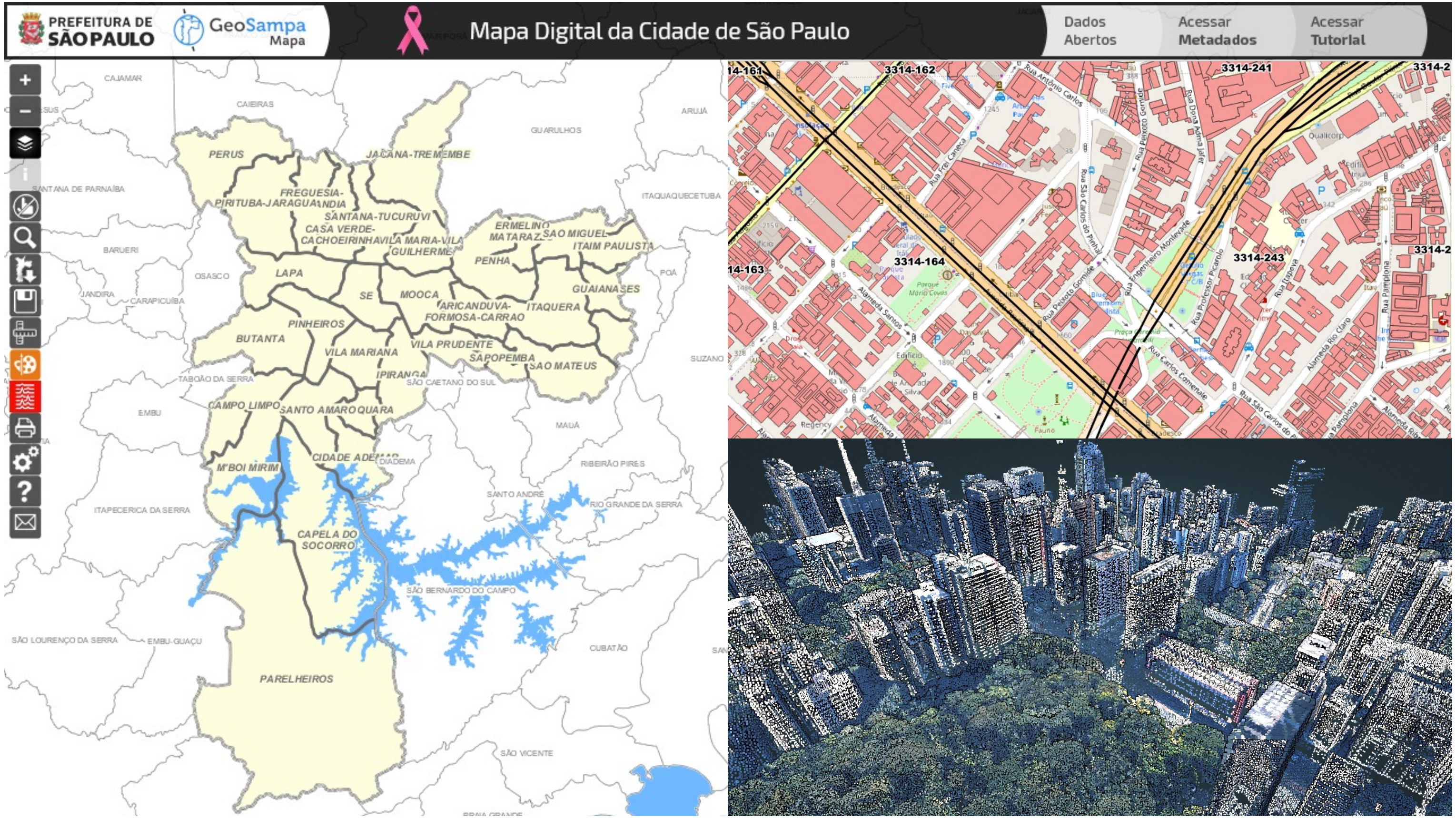
In particular: **ENERGY**

- Expensive energy fees in Brazil,
- Volatility of energy fees,
- Energy losses in favelas,
- Socioeconomic vulnerability,
- ***ENERGY POVERTY !***

Problem Statement

Solar energy in favelas: intentional exclusion from official solar map, but favelas DO exist!

Problem Statement



In São Paulo: favelas similarly lack infrastructure; SDI allows a broader investigation.

Research Questions

"How far is it possible to perform solar analysis on buildings of favelas in São Paulo, with the goal of estimating PV Potential?"

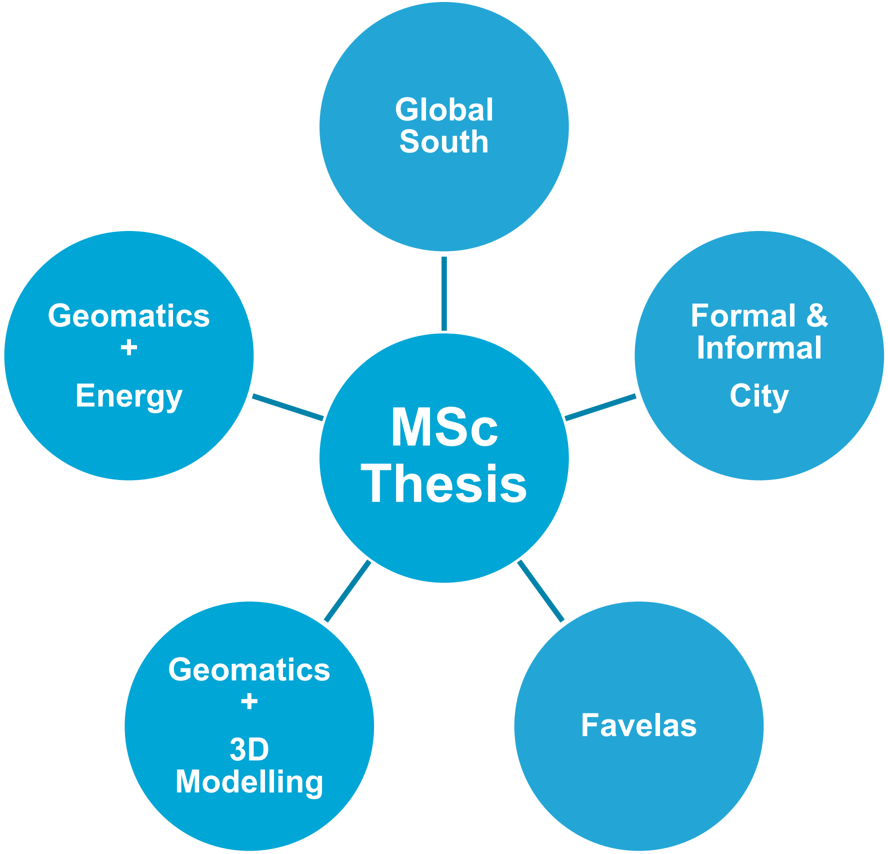
Solar Irradiation Modules

- Minimum data requirements
- Automatization / Complexity
- Self-contained or package
- Running time
- Assessable feature types
- Simulation flexibility
- Time granularity / Output data model
- Level of accuracy (ground truth)

Roof Mapping

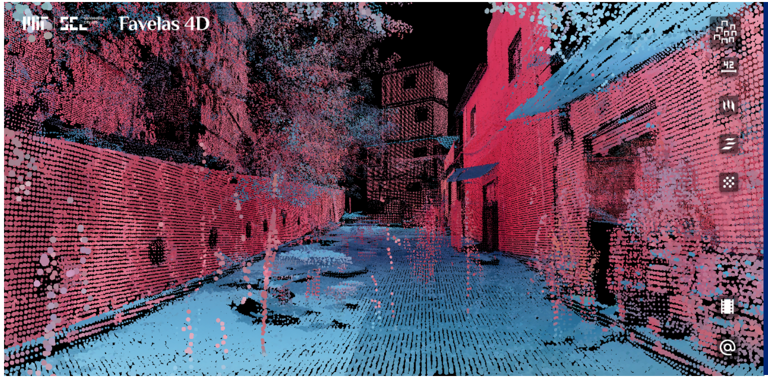
- Minimum geodata to map roofs
- Algorithmic steps
- Existing algorithms suitable for favelas
- Specific methodology for favelas

Cross Domain Research

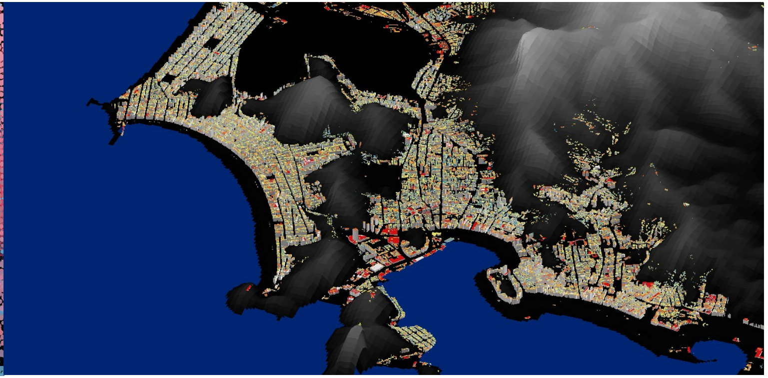


Urbanism, Geomatics & Building Physics.

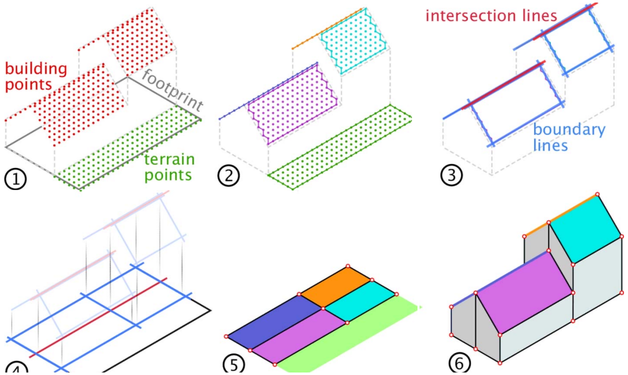
Related Work



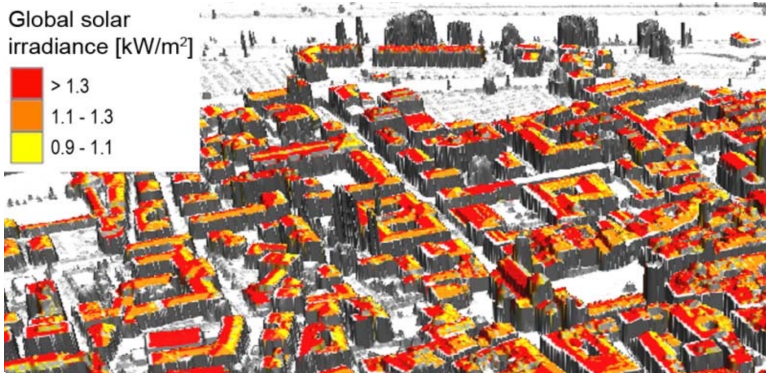
Salazar Miranda et al. (2021)



Lange (2015)



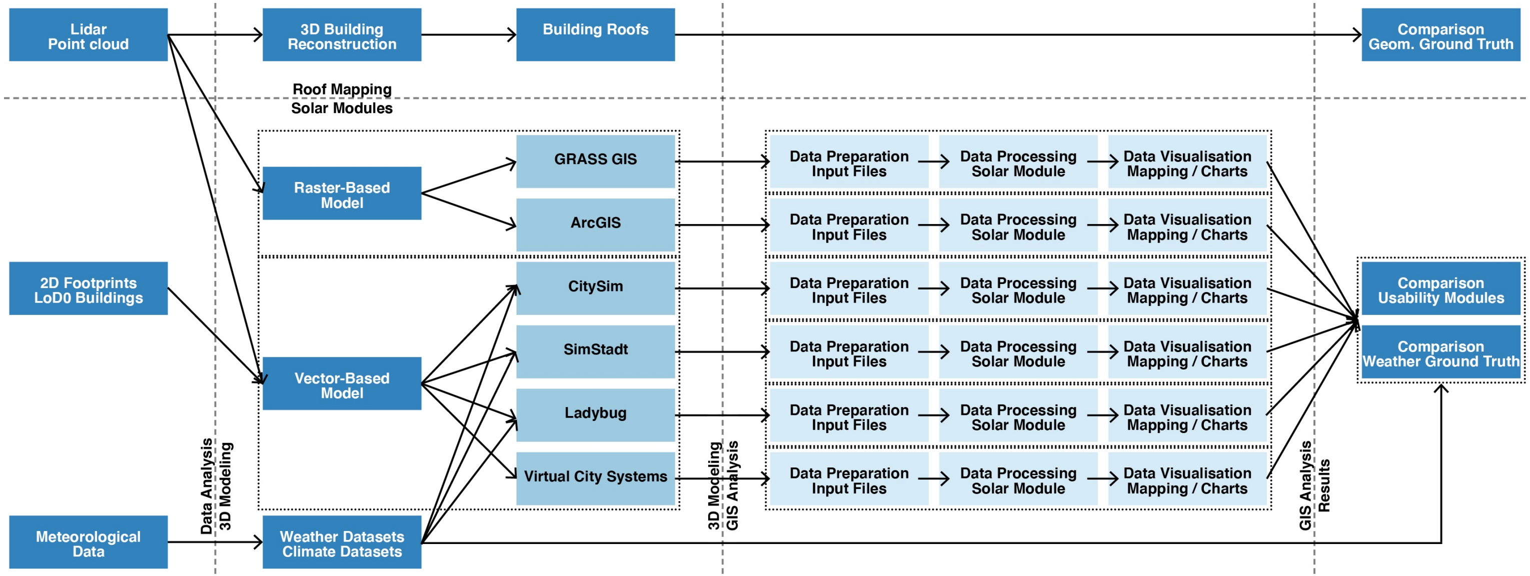
Ohori et. al. (2021)



Agugiaro et al. (2012)

Reference literature for building reconstruction and solar irradiation analysis.

General Pipeline



Two topics: Solar irradiation modules | Roof mapping.

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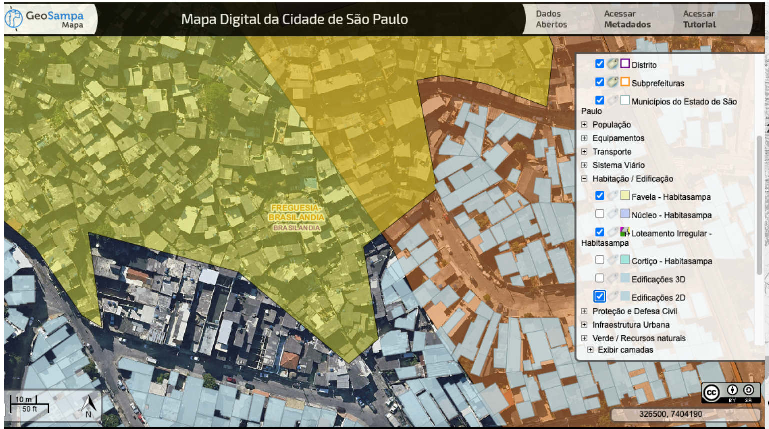
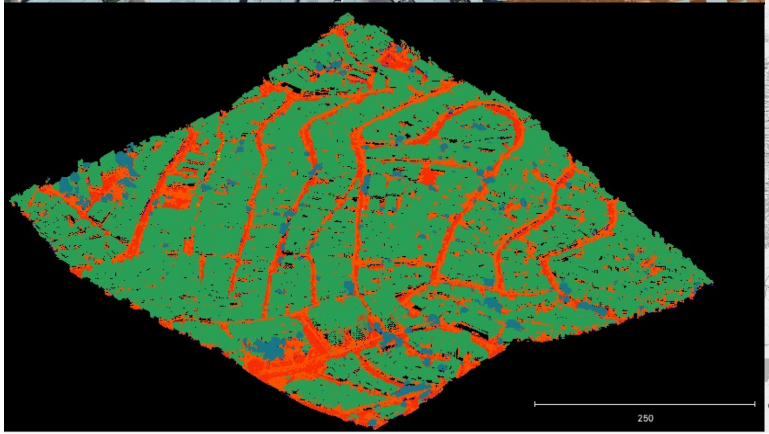
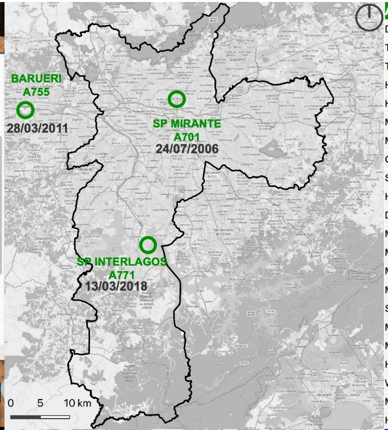
The Spatial Data Infrastructure

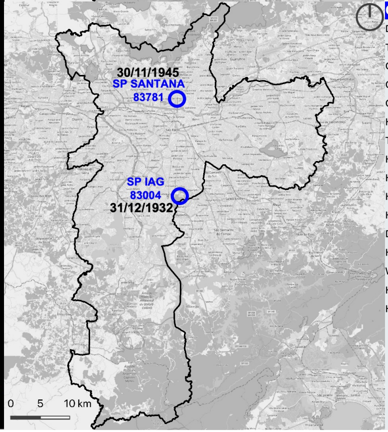






AUTOMATIC METEOROLOGICAL STATIONS - DATA

DATE (DD-MM-YYYY)
TIME UTC
TOTAL HOURLY PRECIPITATION (mm)
HOURLY ATMOSPHERIC PRESSURE AT STATION LEVEL (mB)
HOURLY ATMOSPHERIC PRESSURE AT SEA LEVEL AUT(mB)
MAXIMAL ATMOSPHERIC PRESSURE OF THE PREVIOUS HOUR (AUT)(mB)
MINIMAL ATMOSPHERIC PRESSURE OF THE PREVIOUS HOUR (AUT)(mB);
GLOBAL RADIATION (KJ/m²);
STATION CPU TEMPERATURE (ºC)
HOURLY DRY-BULB TEMPERATURE (ºC)
DEW POINT TEMPERATURE (ºC)
MAXIMUM AIR TEMPERATURE OF THE PREVIOUS HOUR (AUT)(ºC)
MINIMUM AIR TEMPERATURE OF THE PREVIOUS HOUR (AUT)(ºC)
MAXIMUM DEW POINT TEMPERATURE OF THE PREVIOUS HOUR (AUT)(ºC)
MINIMUM DEW POINT TEMPERATURE OF THE PREVIOUS HOUR (AUT)(ºC)
STATION'S BATTERY VOLTAGE (V)
MAXIMUM RELATIVE HUMIDITY OF THE PREVIOUS HOUR. (AUT)(%)
MINIMUM RELATIVE HUMIDITY OF THE PREVIOUS HOUR. (AUT)(%)
HOURLY RELATIVE HUMIDITY (%)
WIND DIRECTION (AZIMUTH º)
MAXIMUM WIND BLOW (m/s)
HOURLY WIND SPEED (m/s)



CONVENTIONAL METEOROLOGICAL STATIONS - DATA

DATE (DD-MM-YYYY)
TIME UTC
CH – HIGH CLOUDS (code)
CL – LOW CLOUDS (code)
CM – MEDIUM CLOUDS (code)
HOURLY NEBULOSITY (decimal)
TOTAL HOURLY PRECIPITATION (mm)
HOURLY ATMOSPHERIC PRESSURE AT STATION LEVEL (mB)
HOURLY ATMOSPHERIC PRESSURE AT SEA LEVEL AUT (mB)
HOURLY DRY-BULB TEMPERATURE (ºC)
HOURLY HUMID-BULB TEMPERATURE (ºC)
DEW POINT TEMPERATURE (ºC)
HOURLY RELATIVE HUMIDITY (%)
WIND DIRECTION (code)
HOURLY WIND SPEED (m/s)
HOURLY VISIBILITY (code)

Main data sources: Geosampa and INMET.

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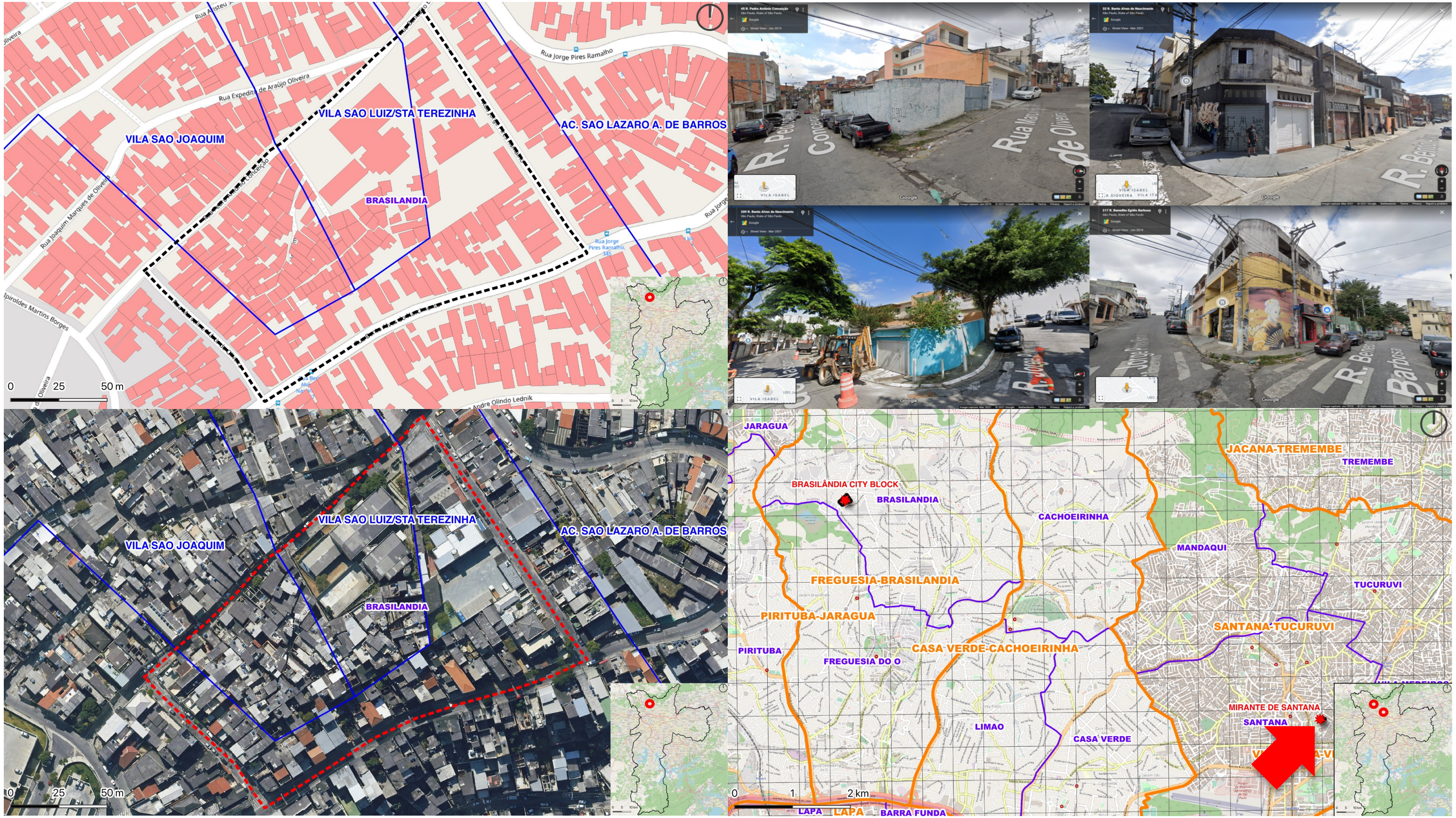
Scenario Brasilândia and Scenario Santana



Urban morphology of a favela; footprints available; close by the **meteorological station.**

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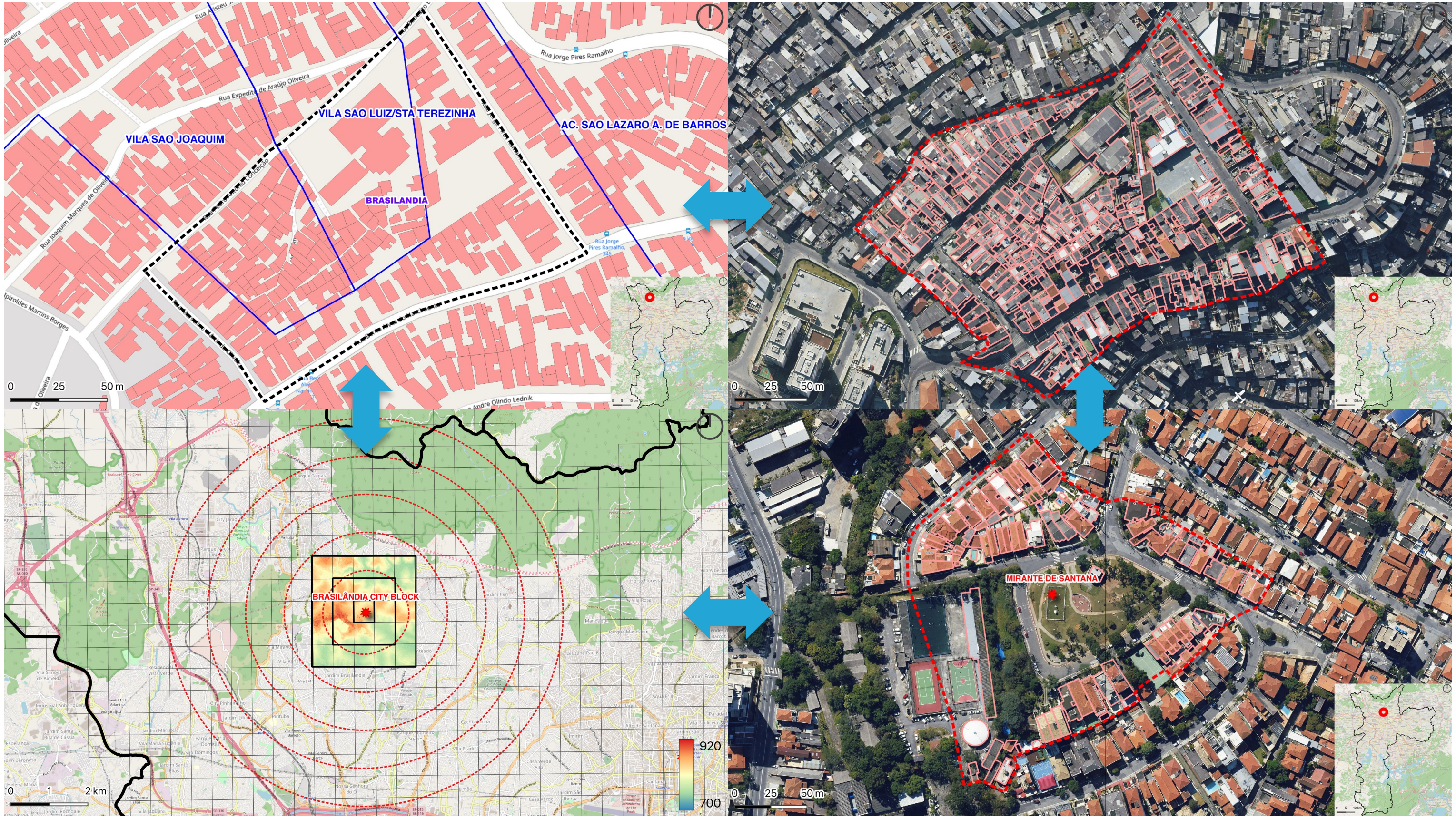
Extended Scenarios Brasilândia & Santana



An interactive process: geographical extent, model complexity and irradiation accuracy.

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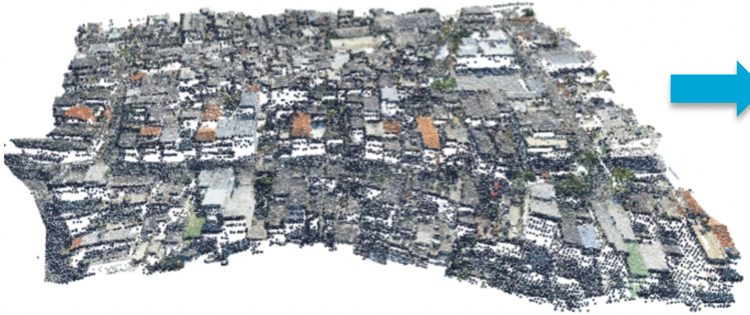
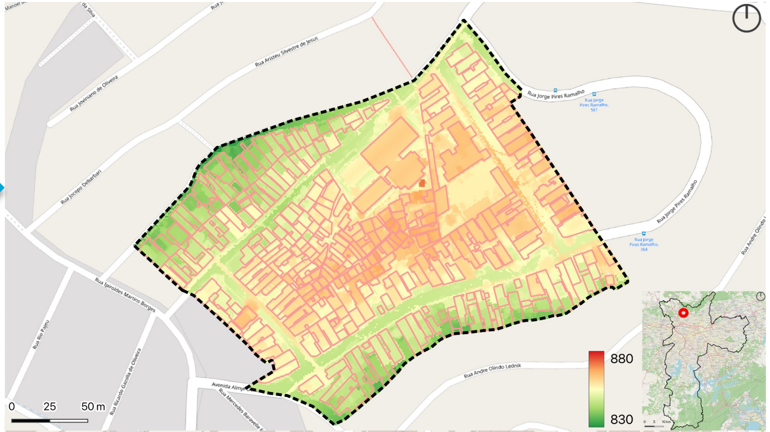
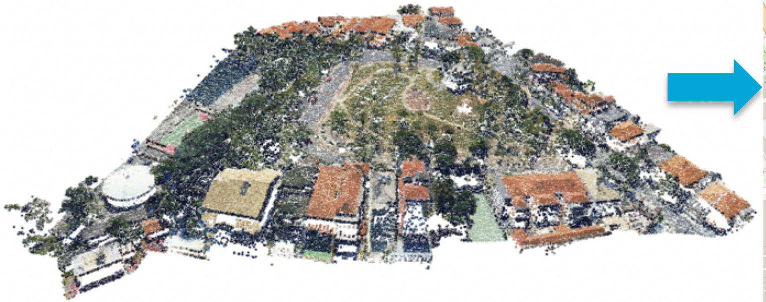
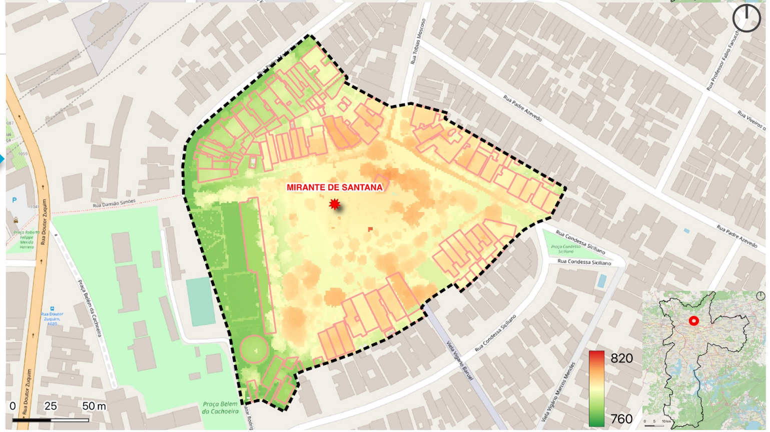
Raster-Based Models



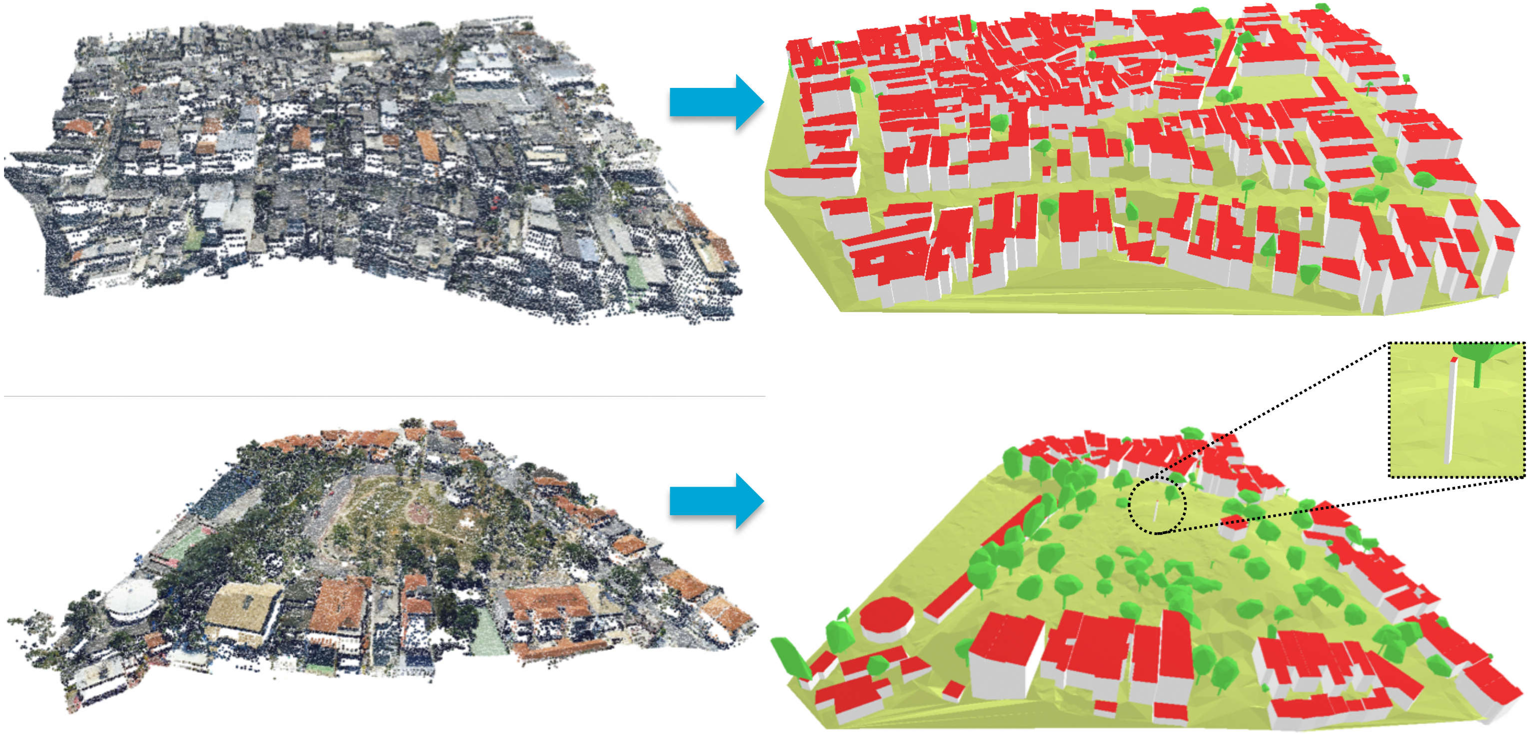






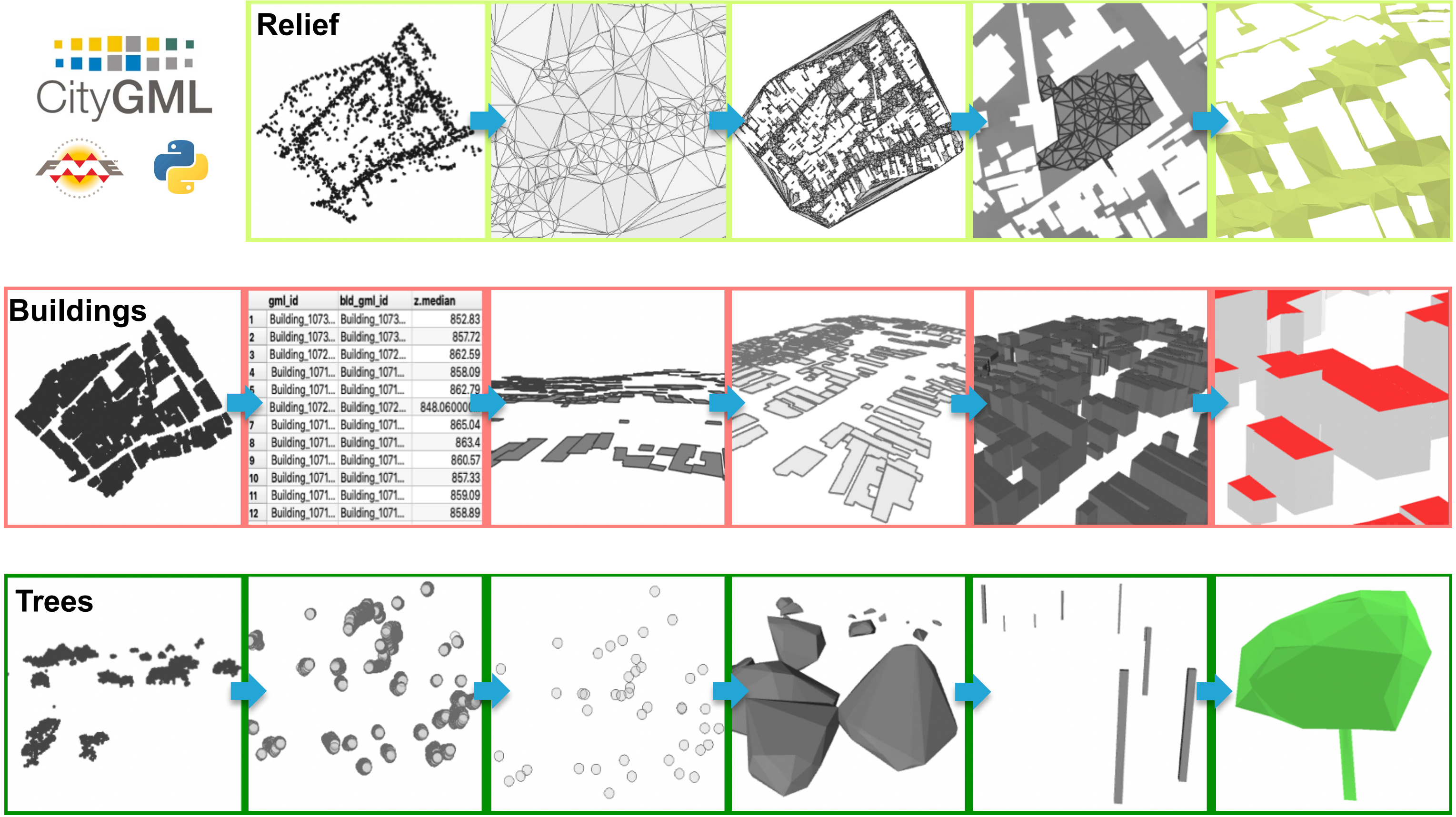
Raster models are necessary for the simulations in GRASS GIS and ArcGIS.

Vector-Based Models



Vector models are necessary for the simulations in CitySim, SimStadt, Ladybug and VCS.

Vector-Based Models



Relief, buildings and trees are responsible for most of the shading effect in the model.

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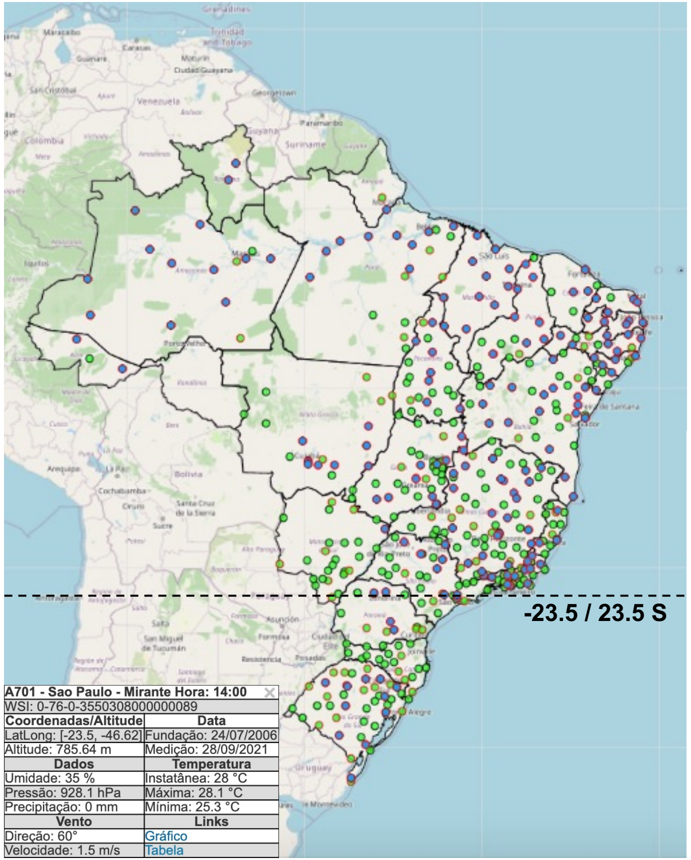
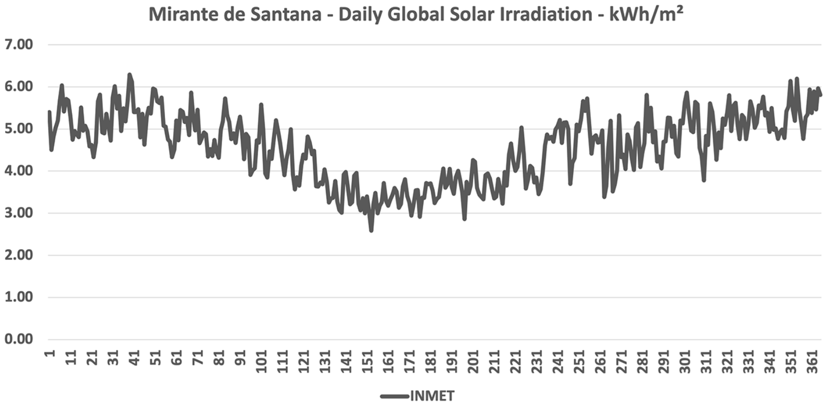
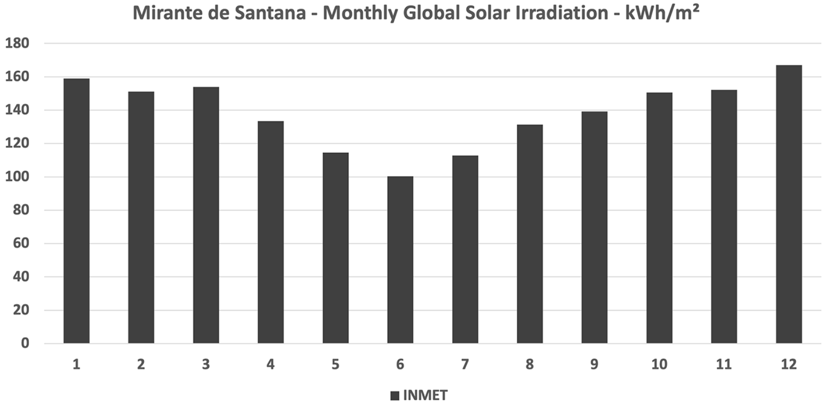
Weather Station Data

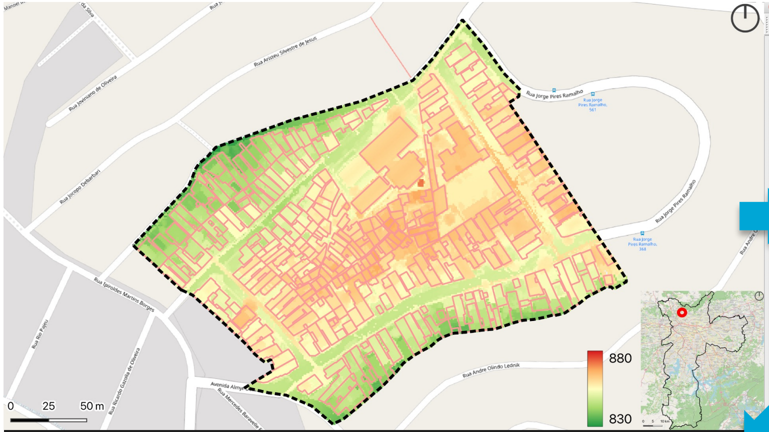


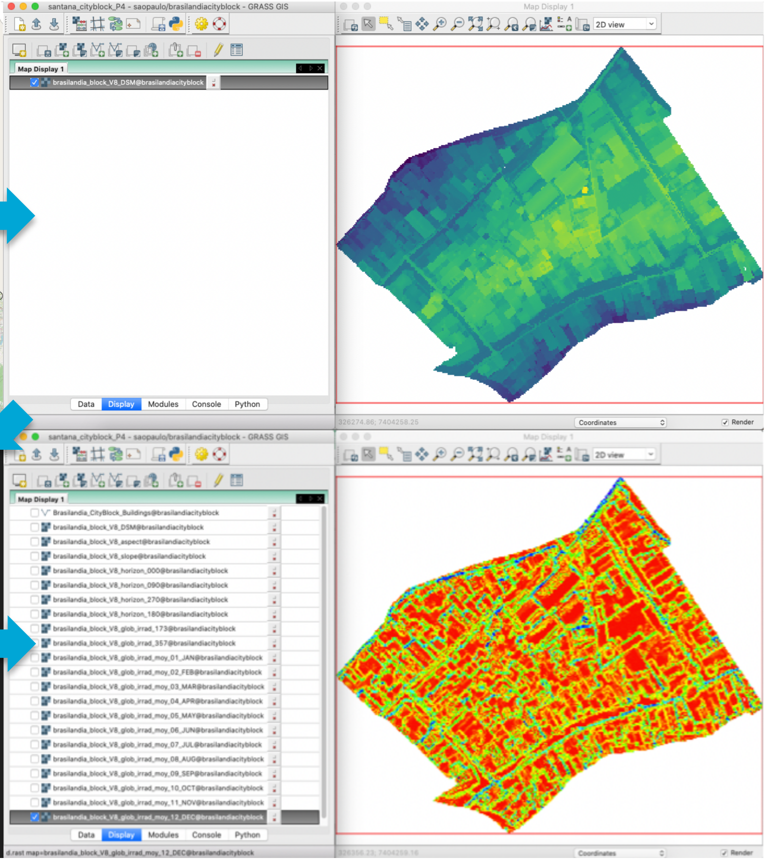




Weather data from 24/06/06 to 12/07/21 averaged into typical hourly values.

GRASS GIS






```
def compute_r_sun(i):
    day_value = str(i).zfill(3)
    glob_rad_value = 'brasilandia_block_V8_glob_irrad_' + day_value
    gscript.run_command('r.sun',
                        overwrite=True,
                        elevation='brasilandia_block_V8_DSM',
                        aspect='brasilandia_block_V8_aspect',
                        slope='brasilandia_block_V8_slope',
                        horizon_basename='brasilandia_block_V8_horizon',
                        horizon_step=3,
                        glob_rad=glob_rad_value,
                        day=i,
                        step=0.5)
if __name__ == '__main__':
    for i in range(1,366):
        compute_r_sun(i)
```

Raster-based solar module; Weather data handled by the software.

ArcGIS

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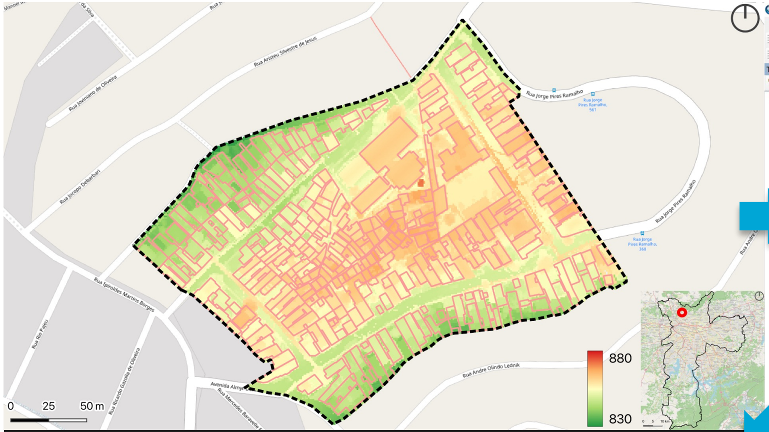

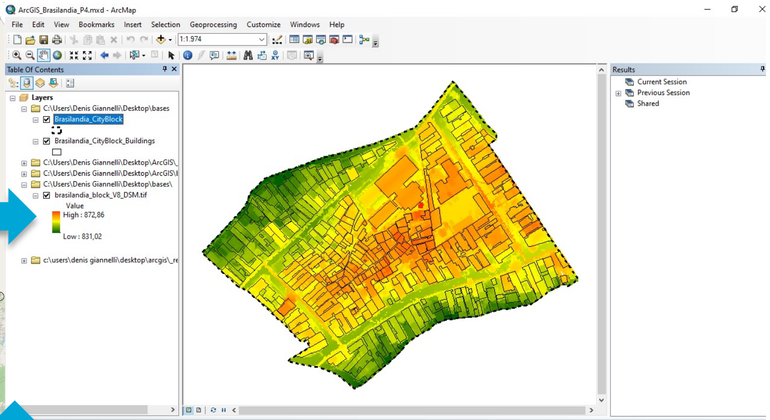

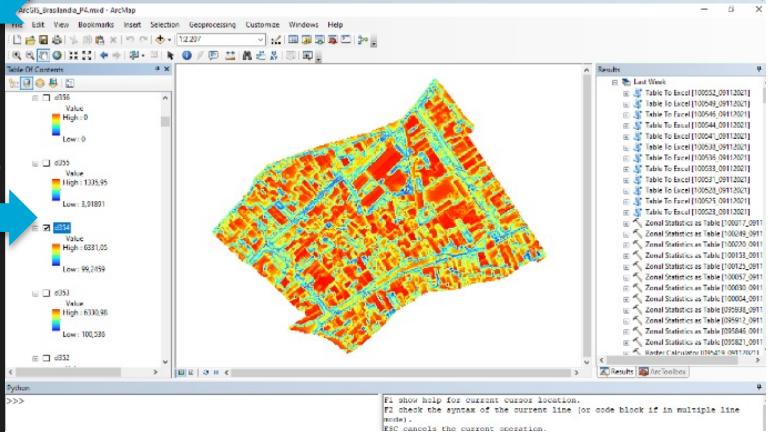


```
for i in range(1,365):
    dsm     = "(…)/brasilandia_block_V8_DSM.tif"
    fout    = "(…)/d"+str(i).zfill(3)
    multi   = "MultiDays   2021      "+str(i)+"     "+str(i+1)
    arcpy.gp.AreaSolarRadiation_sa(dsm, fout, "-23,4973947988913", "200", multi,
"1", "0,5", "INTERVAL", "1", "FROM_DEM", "32", "8", "8", "UNIFORM_SKY", "0,3",
"0,5", "", "", "")

dsm       = "(…)/brasilandia_block_V8_DSM.tif"
fout_365     = "(..)/d"+str(365).zfill(3)
multi_365    = "MultiDays   2021      "+str(365)+"     "+str(1)
arcpy.gp.AreaSolarRadiation_sa(dsm, fout_365, "-23,4973947988913", "200",
multi_365, "1", "0,5", "INTERVAL", "1", "FROM_DEM", "32", "8", "8",
"UNIFORM_SKY", "0,3", "0,5", "", "", "")
```

Raster-based solar module; Weather data handled by the software.

CitySim

- Introduction
- Theory & Literature
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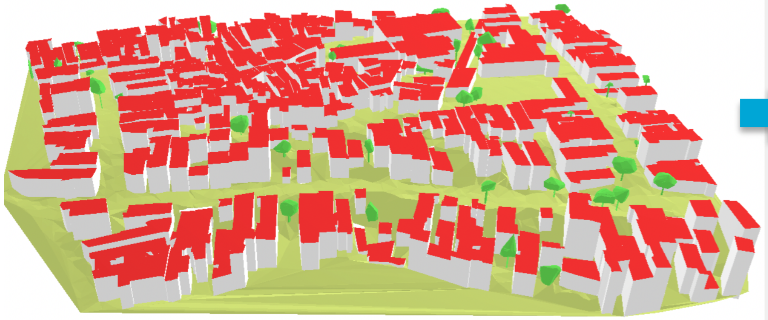
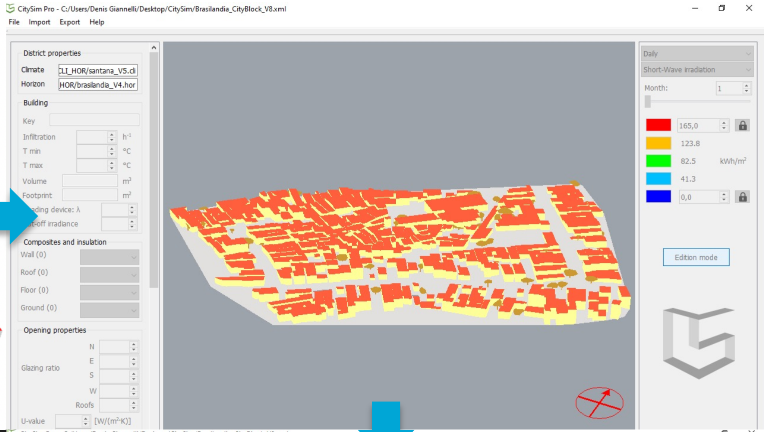
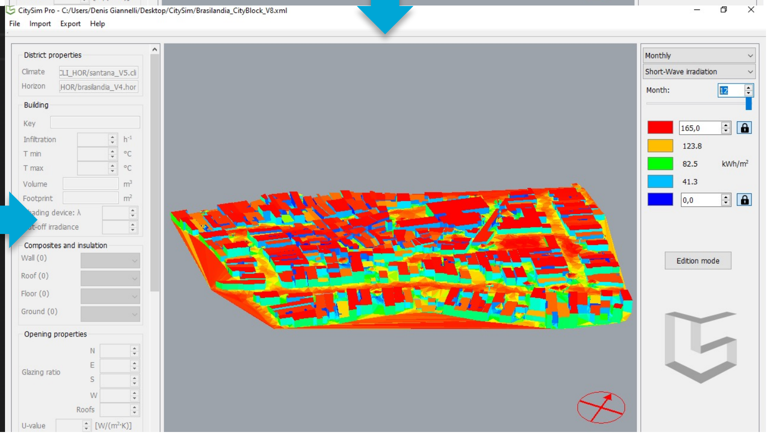
- Conclusion



```
Sao Paulo - Mirante de Santana
-23.49629154,-46.62009244,802.78,-3

dm  m   h   G_h Ta   Ts   FF   DD   RH   RR   N
1   1   0   0.0 21.9      21.9      0.5 73   78   0.0 6
1   1   1   0.0 21.8      21.8      0.6 45   79   0.0 6
1   1   2   0.0 21.5      21.5      0.3 64   81   0.1 6
1   1   3   0.0 21.4      21.4      0.5 101 81   0.1 6
1   1   4   0.0 21.2      21.2      0.5 81   81   0.0 6
1   1   5   0.0 21.1      21.1      0.2 96   82   0.1 6
1   1   6   20.1      21.5      21.5      0.6 78   79   0.0 6
1   1   7   136.8     22.3      22.3      0.4 116 76   0.0 6
1   1   8   316.8     23.2      23.2      1.3 117 73   0.1 6
1   1   9   502.1     24.2      24.2      1.3 117 70   0.0 6
1   1   10  611.7     25.0      25.0      1.8 138 66   0.2 6
1   1   11  638.7     26.2      26.2      1.8 134 63   0.6 6
```





Vector-based solar module; Weather data from CLI file.

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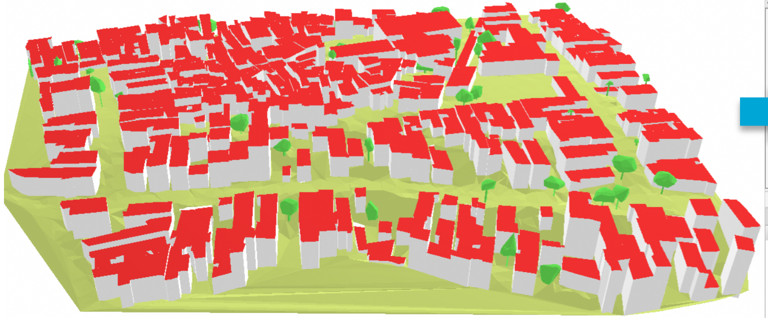
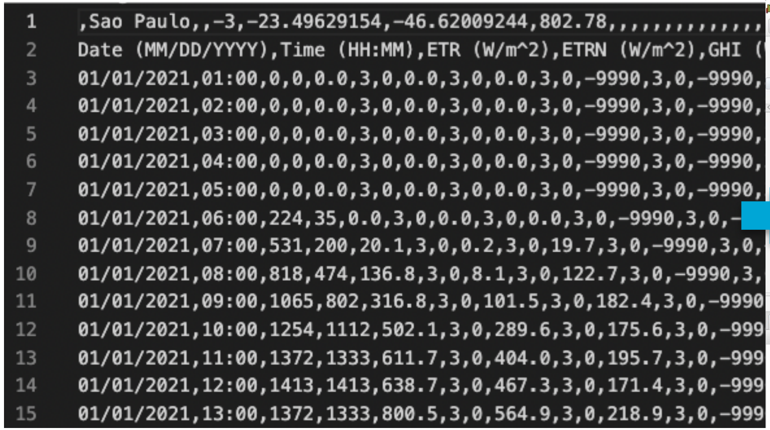
SimStadt





```
,Sao Paulo,,-3,-23.49629154,-46.62009244,802.78,,,,,,,,,,,,,,
Date (MM/DD/YYYY),Time (HH:MM),ETR (W/m^2),ETRN (W/m^2),GHI (
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01/01/2021,02:00,0,0,0.0,3,0,0.0,3,0,0.0,3,0,-9990,3,0,-9990,
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01/01/2021,09:00,1065,802,316.8,3,0,101.5,3,0,182.4,3,0,-9990
01/01/2021,10:00,1254,1112,502.1,3,0,289.6,3,0,175.6,3,0,-999
01/01/2021,11:00,1372,1333,611.7,3,0,404.0,3,0,195.7,3,0,-999
01/01/2021,12:00,1413,1413,638.7,3,0,467.3,3,0,171.4,3,0,-999
01/01/2021,13:00,1372,1333,800.5,3,0,564.9,3,0,218.9,3,0,-999
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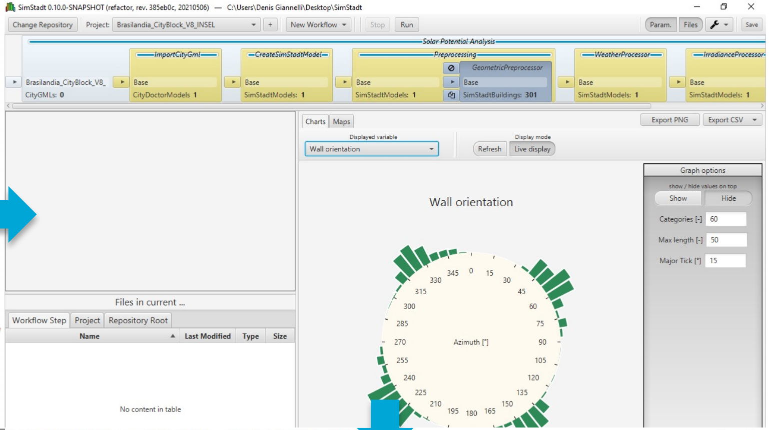
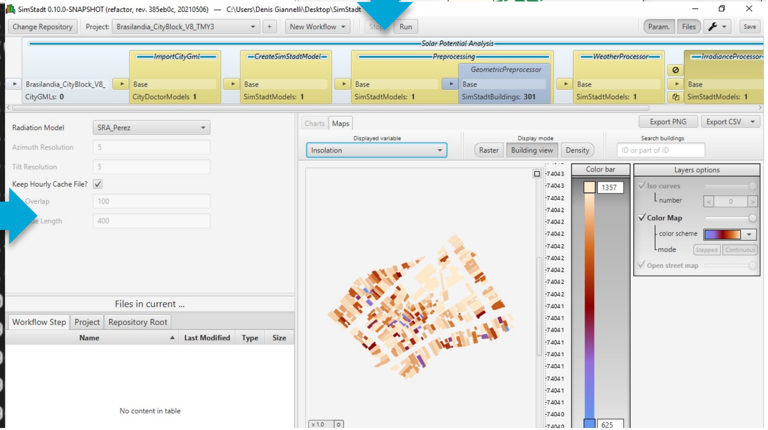
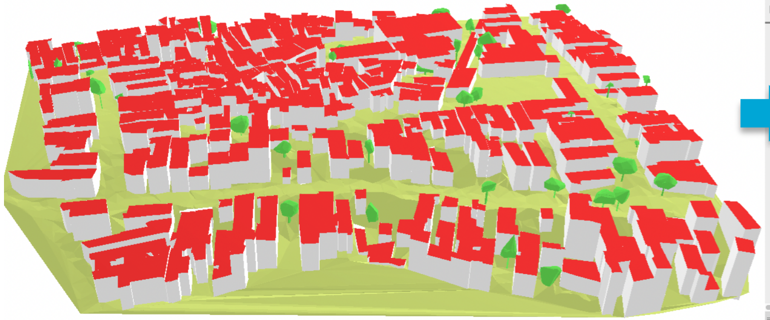




Vector-based solar module; Weather data from TMY3 file; Derived direct and diffuse irrad

Ladybug



```
LOCATION,Sao Paulo,SP,BRA,,,-23.49629154,-46.62009244,-3,802.78
DESIGN CONDITIONS,1,2017 ASHRAE Handbook -- Fundamentals - Chapter 14 Climatic Design In
TYPICAL/EXTREME PERIODS,6,Summer - Week Nearest Max Temperature For Period,Extreme,2/10,
GROUND TEMPERATURES,3,.5,,,,22.10,21.61,20.68,19.80,18.15,17.29,17.06,17.51,18.54,19.82,
HOLIDAYS/DAYLIGHT SAVINGS,No,0,0,0
COMMENTS 1,""
COMMENTS 2,""
DATA PERIODS,1,1,Data,Sunday, 1/ 1,12/31
2021,1,1,1,0,?9?9?9?9E0?9?9?9*9*9?9?9?9?9?9?9?9?9?9?9?9?9C9?9?9,21.9,17.8,78,92400,0,0,38
2021,1,1,2,0,?9?9?9?9E0?9?9?9*9*9?9?9?9?9?9?9?9?9?9?9?9?9C9?9?9,21.8,17.8,79,92300,0,0
2021,1,1,3,0,?9?9?9?9E0?9?9?9*9*9?9?9?9?9?9?9?9?9?9?9?9?9C9?9?9,21.5,17.9,81,92300,0,0
2021,1,1,4,0,?9?9?9?9E0?9?9?9*9*9?9?9?9?9?9?9?9?9?9?9?9?9C9?9?9,21.4,17.8,81,92300,0,0,38
2021,1,1,5,0,?9?9?9?9E0?9?9?9*9*9?9?9?9?9?9?9?9?9?9?9?9?9C9?9?9,21.2,17.8,81,92300,0,0,38
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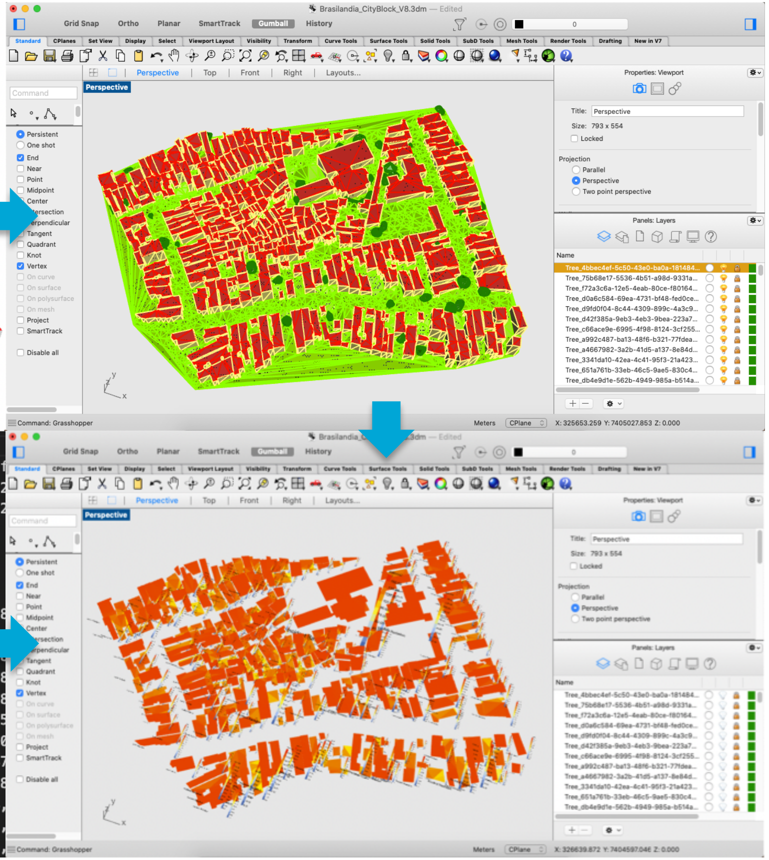
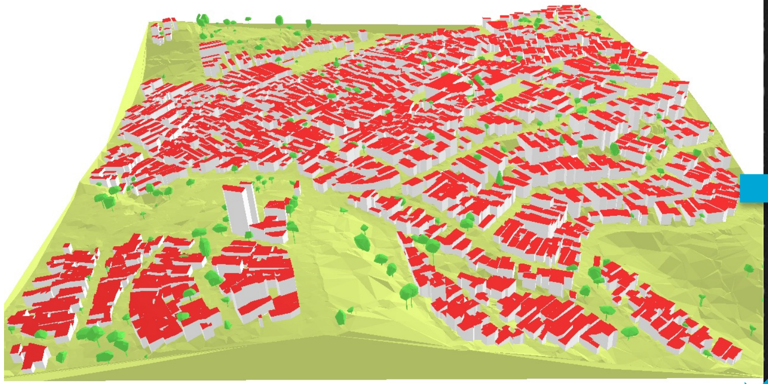


Vector-based solar module; Weather data from EPW file; Derived direct and diffuse irrad.

Virtual City Systems - 3D Solar Analysis

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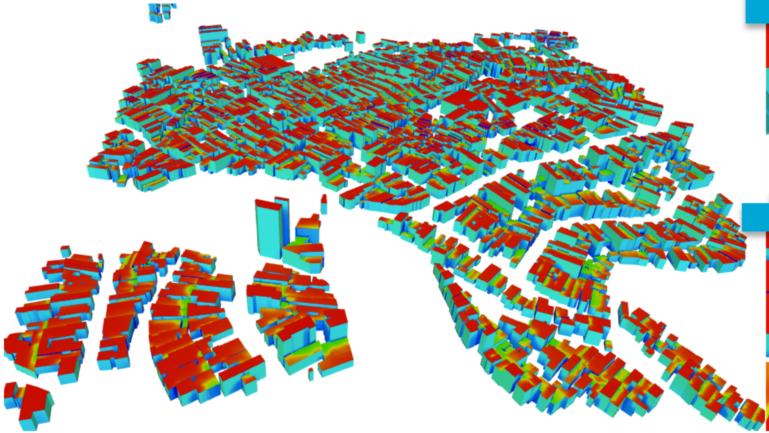

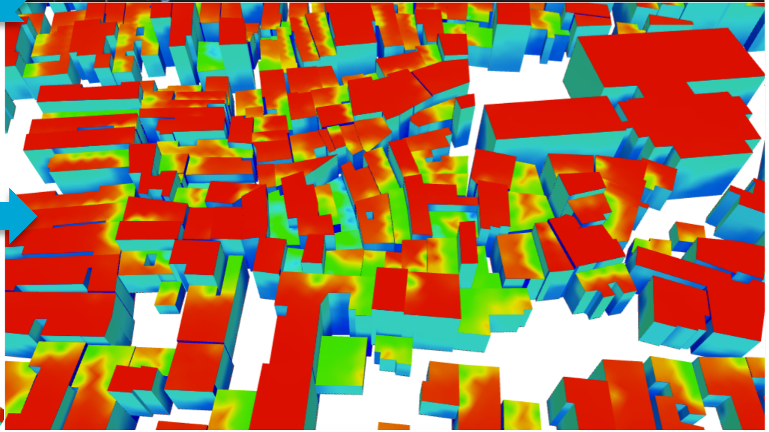

Vector-based solar module; Weather data handled by VCS; Textured models with results.

Qualitative Comparison

example

	GRASS	ArcGIS	CitySim	SimStadt	Ladybug	VCS Solar
Minimum data requirements	Raster DSM	Raster DSM	CityGML + CLI + (Opt. HOR)	CityGML (Opt. TMY3)	B-rep/ Mesh + EPW	CityGML
Automatization Complexity	Multiple steps	One-click basis	One-click basis	One-click basis	Multiple steps	Info. not available
Self-contained or package	Self-contained	Self-contained	Package of Solutions	Self-contained	Self-contained	Info. not available
Running time	HH:MM:SS 00:19:01	HH:MM:SS 04:43:41	BRA ±3 hr SAN ±7.5 hr	HH:MM:SS 00:08:06	HH:MM:SS 01:04:00	Info. not available
Assessable feature types	All features accepted	All features accepted	Buildings + Trees + Relief	Only buildings	All features accepted	Only buildings
Simulation flexibility	No flexibility	Minimal flexibility	No Flexibility	No Flexibility	Full flexibility	No Flexibility
Time granularity	Daily	Daily	Hourly	Hourly	Hourly	Monthly
Output data	Raster file	Raster file	TSV file	OUT file	Data tree	Enriched CityGML

Each solar modules offers potentialities but also limitations: no straightforward choice.

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Quantitative Comparison - Santana

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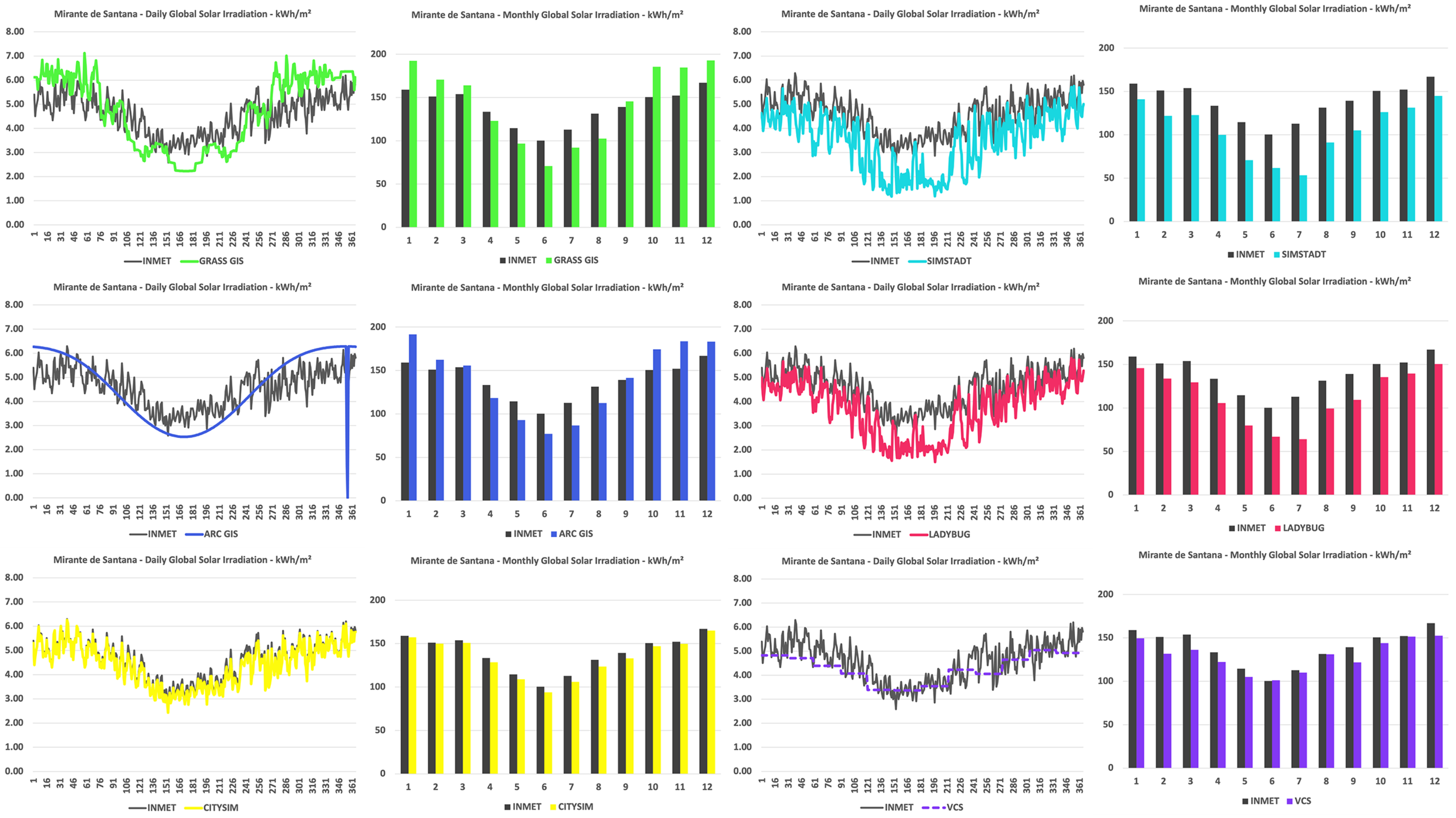
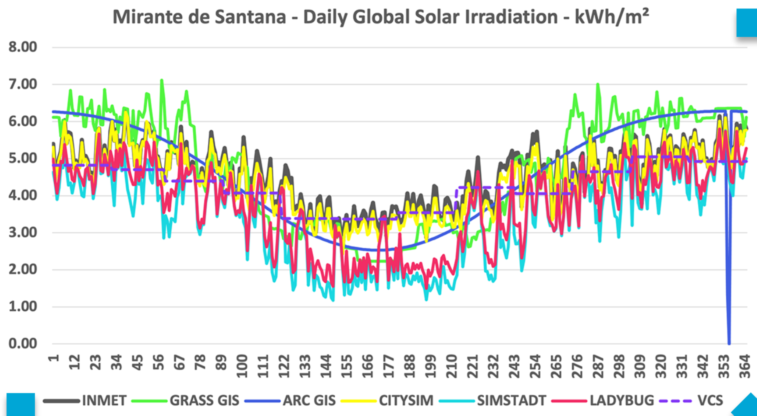
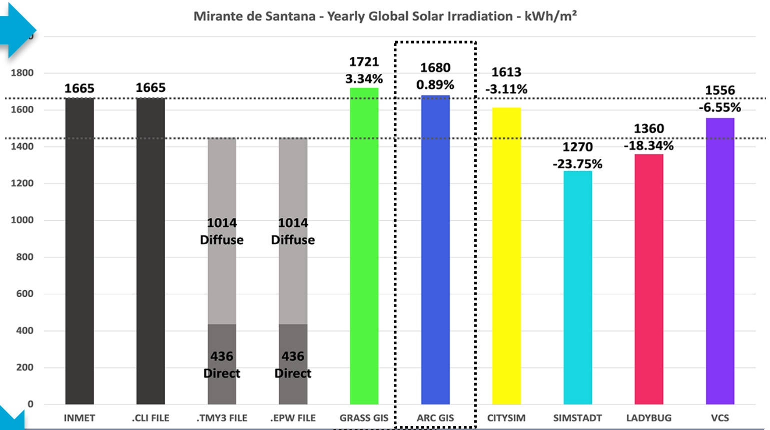


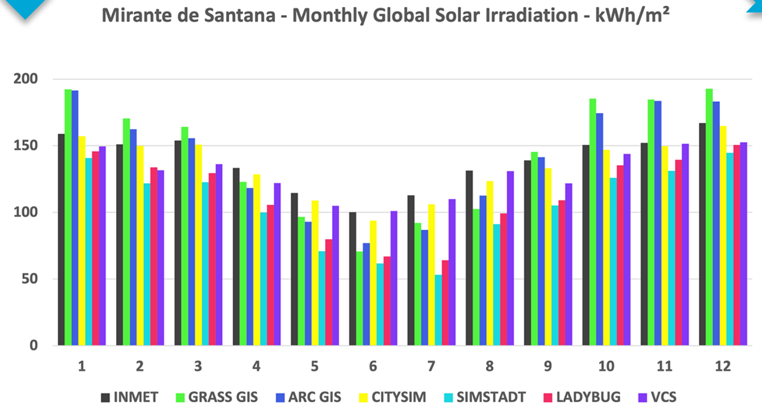
Simulated values for Santana are confronted with ground truth data (INMET).

TU Delft

Quantitative Comparison - Santana







RMSE	GRASS GIS	ARC GIS	CITYSIM	SIMSTADT	LADYBUG	VCS
1	1.19	1.15	0.07	0.72	0.52	0.54
2	0.92	0.60	0.05	1.20	0.70	0.85
3	0.83	0.46	0.11	1.18	0.90	0.70
4	0.85	0.71	0.18	1.35	1.11	0.65
5	0.87	0.80	0.20	1.68	1.32	0.60
6	1.08	0.85	0.22	1.46	1.26	0.29
7	0.80	0.92	0.23	2.00	1.63	0.32
8	1.08	0.76	0.26	1.53	1.21	0.55
9	0.86	0.82	0.23	1.39	1.19	0.88
10	1.36	0.91	0.13	0.98	0.60	0.55
11	1.24	1.17	0.09	0.84	0.50	0.48
12	0.94	1.54	0.08	0.86	0.63	0.62

	GRASS GIS	ARC GIS	CITYSIM	SIMSTADT	LADYBUG	VCS
YEAR	1.00	0.92	0.17	1.30	1.02	0.60

Two analyses: sum of total energy per year; RMSE between timeseries.

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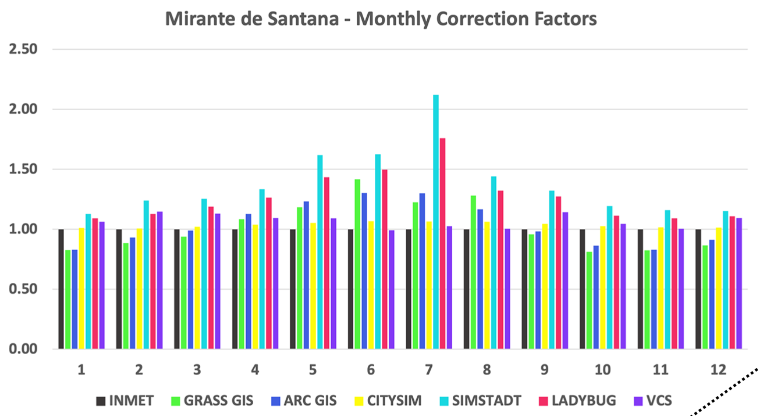
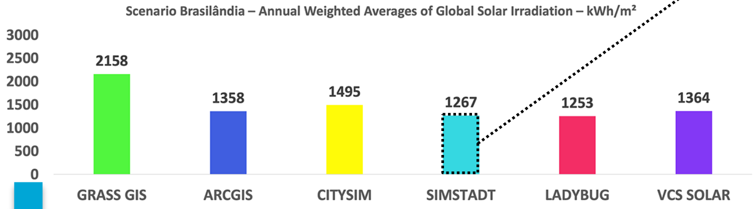
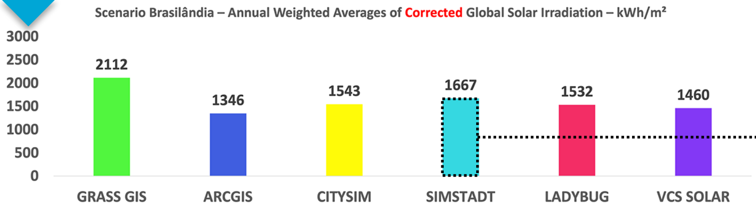
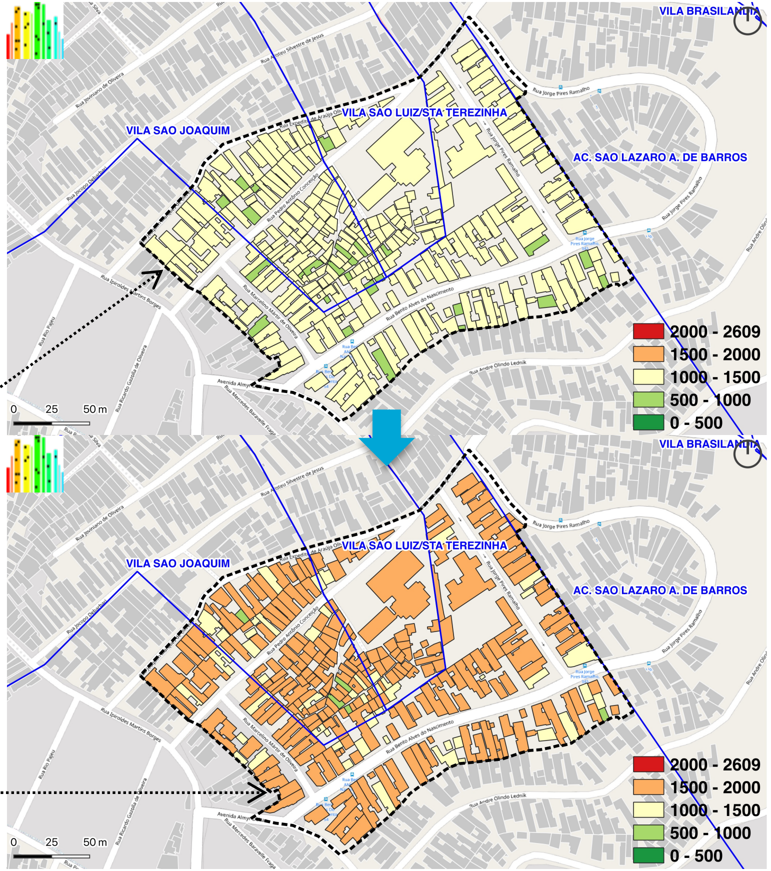


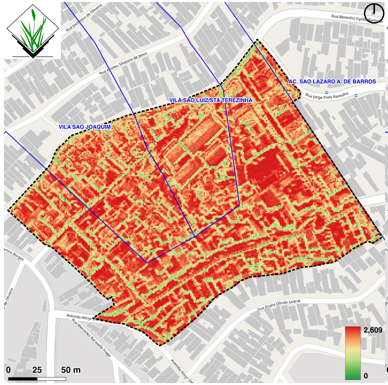




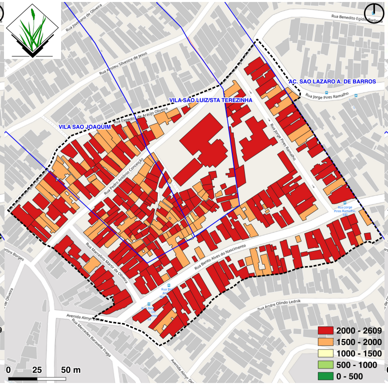


Monthly correction factors from Santana applied to 301 buildings in Brasilândia.

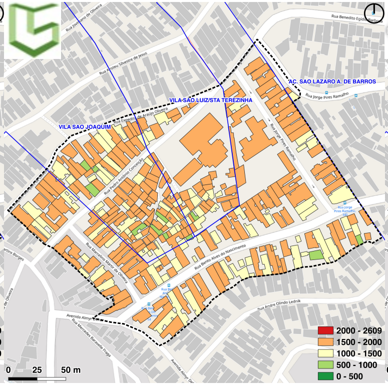
Quantitative Comparison - Brasilândia



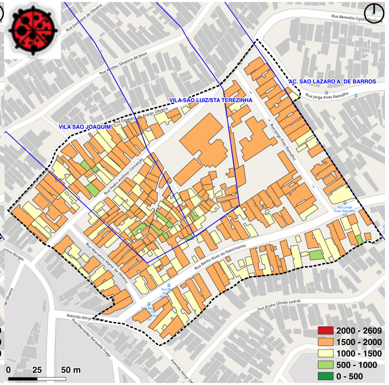
GRASS GIS - Corrected Annual



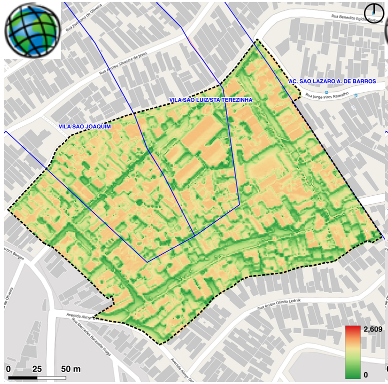
GRASS GIS - Corrected Annual



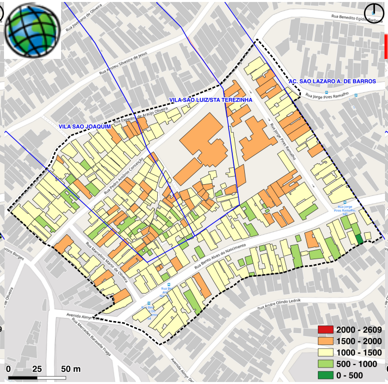
CitySim - Corrected Annual



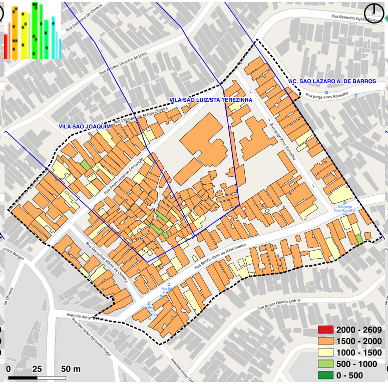
Ladybug - Corrected Annual



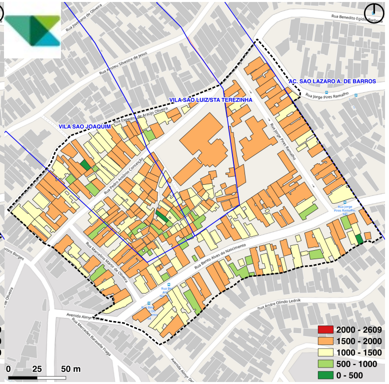
ArcGIS - Corrected Annual



ArcGIS - Corrected Annual



SimStadt - Corrected Annual



VCS Solar - Corrected Annual

General annual analysis: GRASS GIS with higher values, others with similar values.

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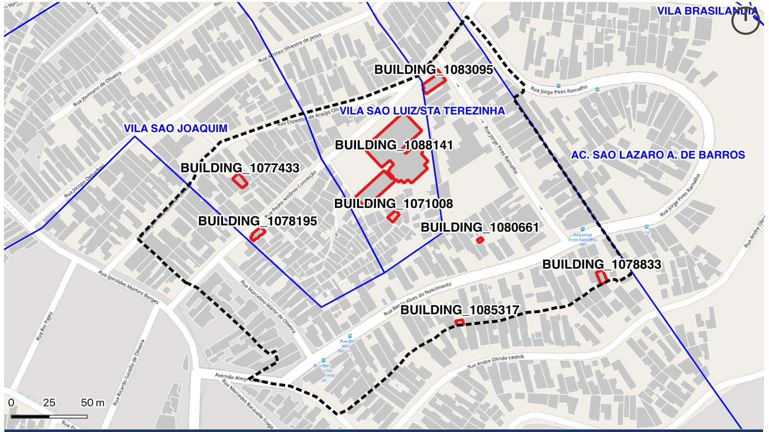
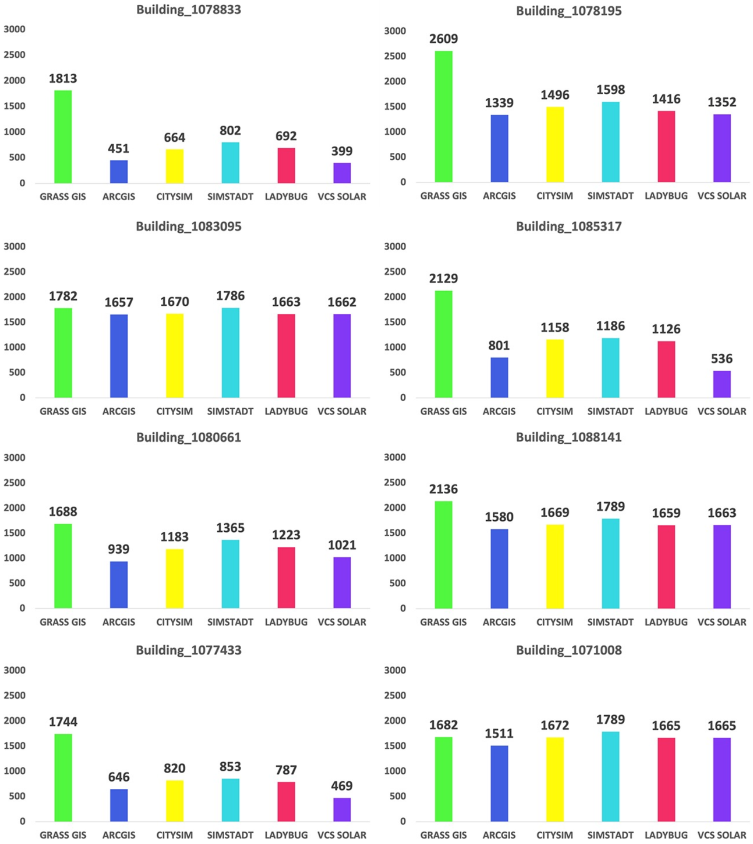
Quantitative Comparison - Brasilândia



	BUILDING GML ID	ROOF ALTITUDE (m)	FOOTPRINT AREA (m²)	MIN (kWh/m²)	MAX (kWh/m²)	(MAX-MIN) DIFF. (kWh/m²)
LOWEST ANNUAL GLOBAL IRRADIATION	Building_1078833	844.99	39.44	399	1813	1414.22
HIGHEST ANNUAL GLOBAL IRRADIATION	Building_1078195	848.76	40.59	1339	2609	1269.85
SMALLEST ABSOLUTE IRRAD. DIFFERENCE	Building_1083095	858.82	106.47	1657	1786	129.70
LARGEST ABSOLUTE IRRAD. DIFFERENCE	Building_1085317	840.05	14.86	536	2129	1593.44
SMALLEST FOOTPRINT AREA	Building_1080661	858.76	7.52	939	1688	749.46
LARGEST FOOTPRINT AREA	Building_1088141	861.68	1308.1	1580	2136	555.45
LOWEST BUILDING ROOF	Building_1077433	839.22	46.61	469	1744	1275.12
HIGHEST BUILDING ROOF	Building_1071008	867.41	28.95	1511	1789	277.57



Detailed annual analysis: GRASS often higher; ArcGIS~VCS;CitySim~SimStadt~Ladybug

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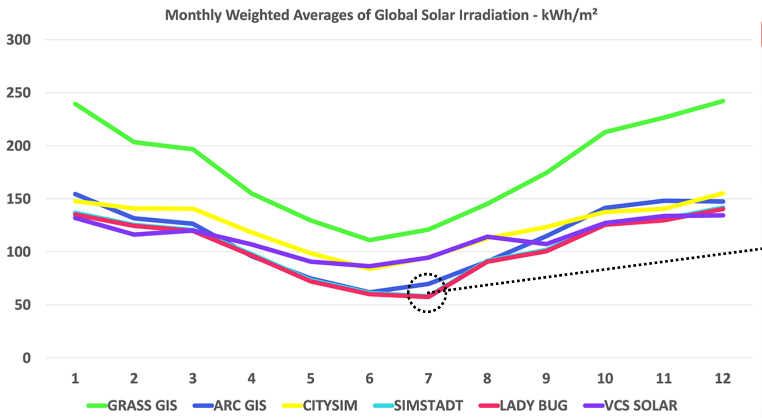
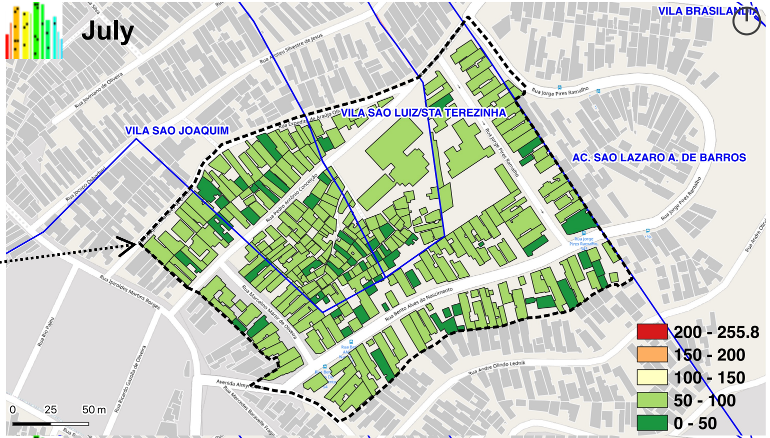
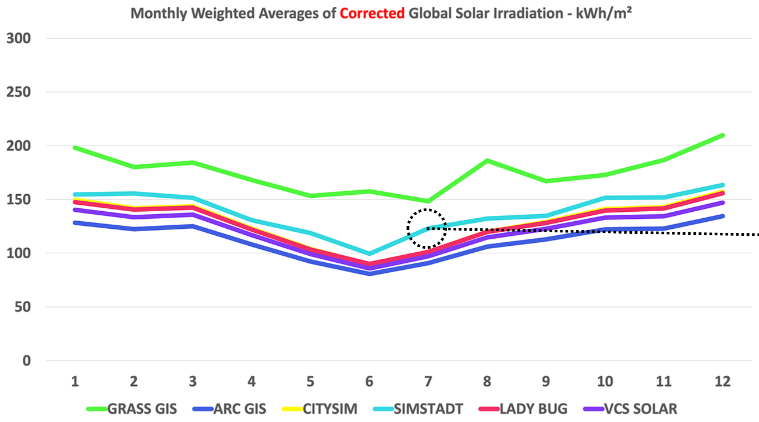
Quantitative Comparison - Brasilândia



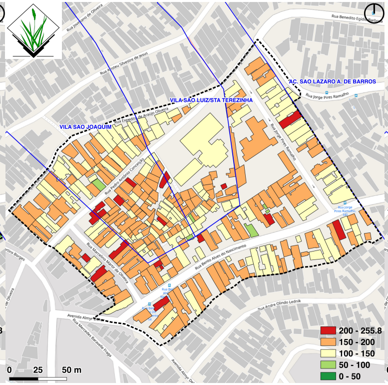




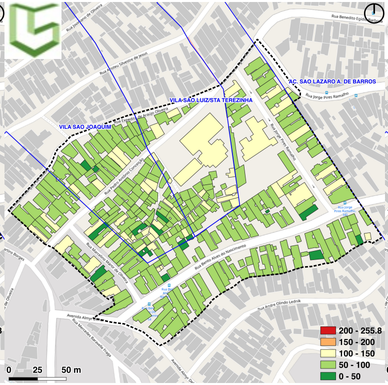
General monthly analysis: After correction, curves are offset, except for GRASS GIS.

Quantitative Comparison - Brasilândia

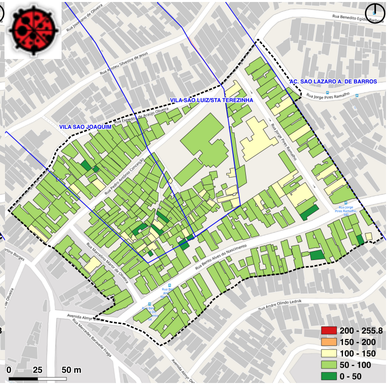
GRASS GIS - Corrected June



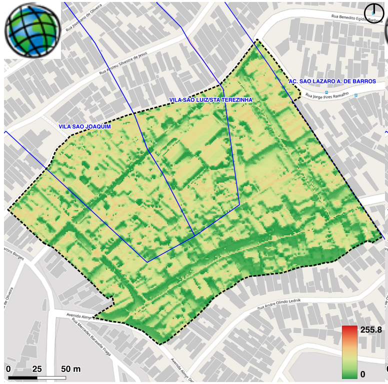
GRASS GIS - Corrected June



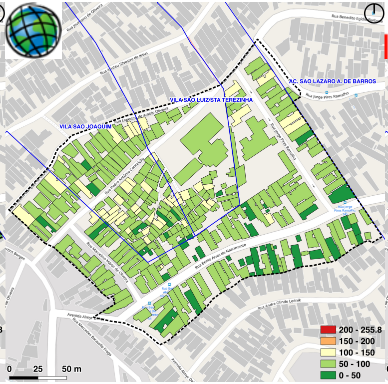
CitySim - Corrected June



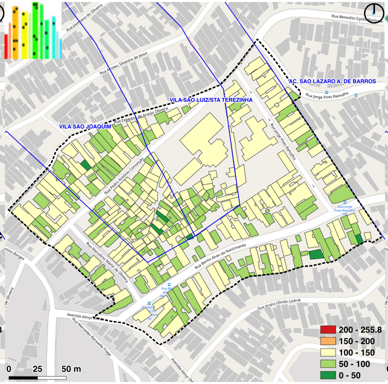
Ladybug - Corrected June



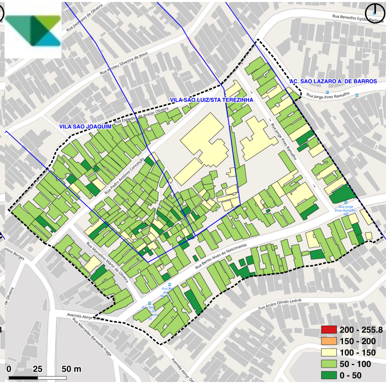
ArcGIS - Corrected June



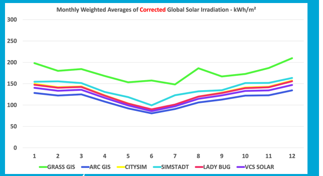
ArcGIS - Corrected June



SimStadt - Corrected June



VCS Solar - Corrected June



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General monthly analysis: In winter, curves get the closest to each other, except GRASS.

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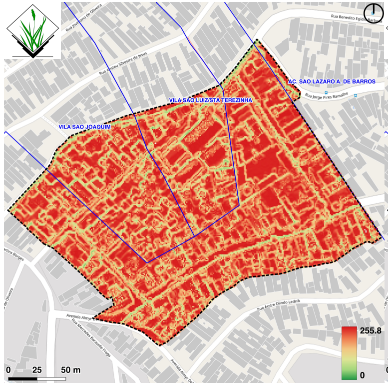
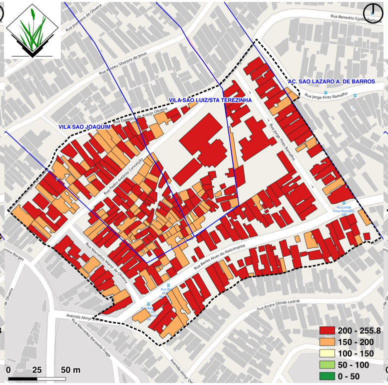
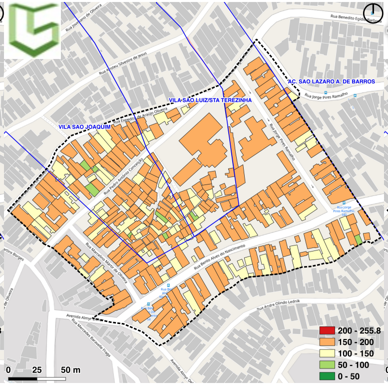


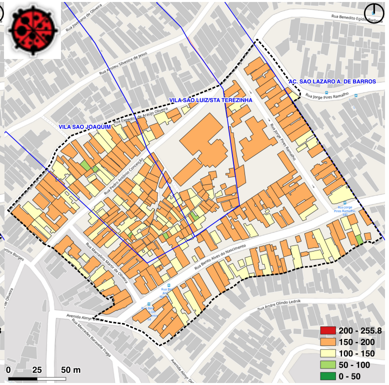
GRASS GIS - Corrected Dec.



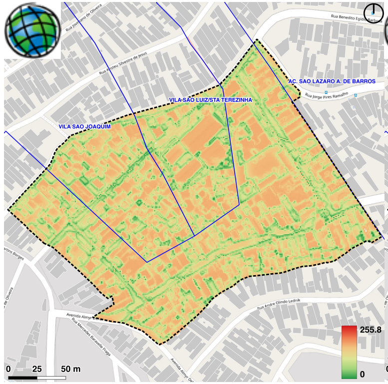
GRASS GIS - Corrected Dec.



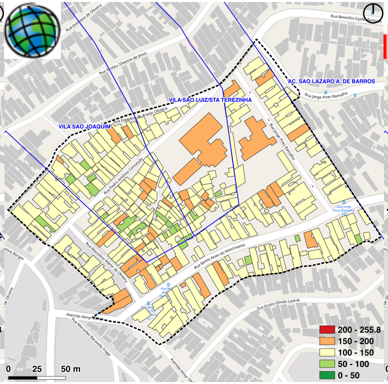
CitySim - Corrected Dec.



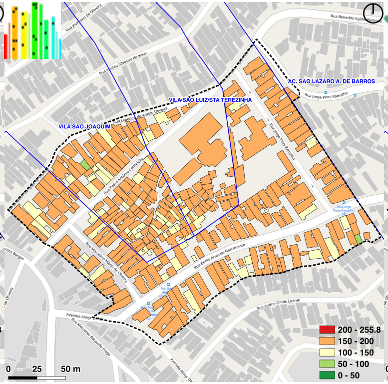
Ladybug - Corrected Dec.



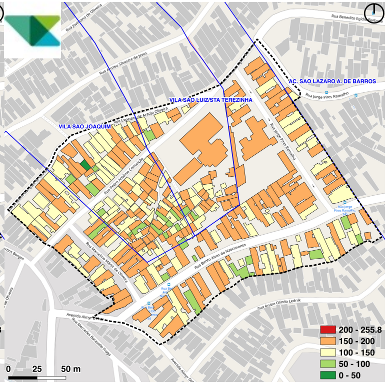
ArcGIS - Corrected Dec.



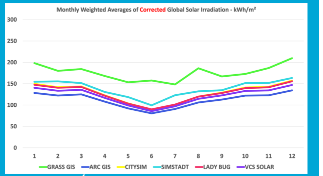
ArcGIS - Corrected Dec.



SimStadt - Corrected Dec.



VCS Solar - Corrected Dec.



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General monthly analysis: In summer, larger offsets; GRASS still presents higher values.

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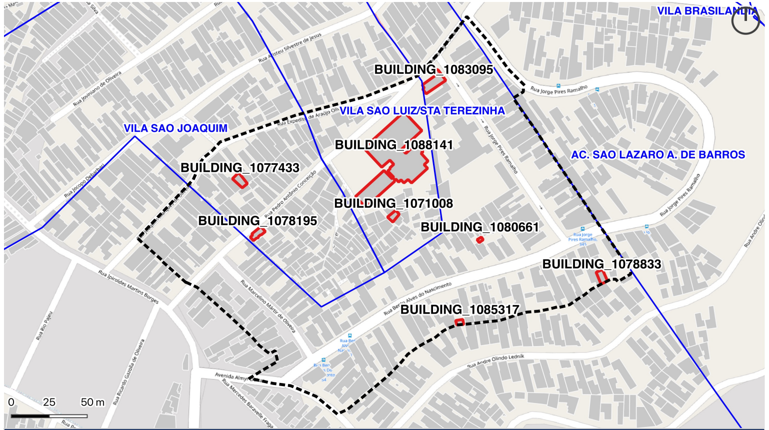
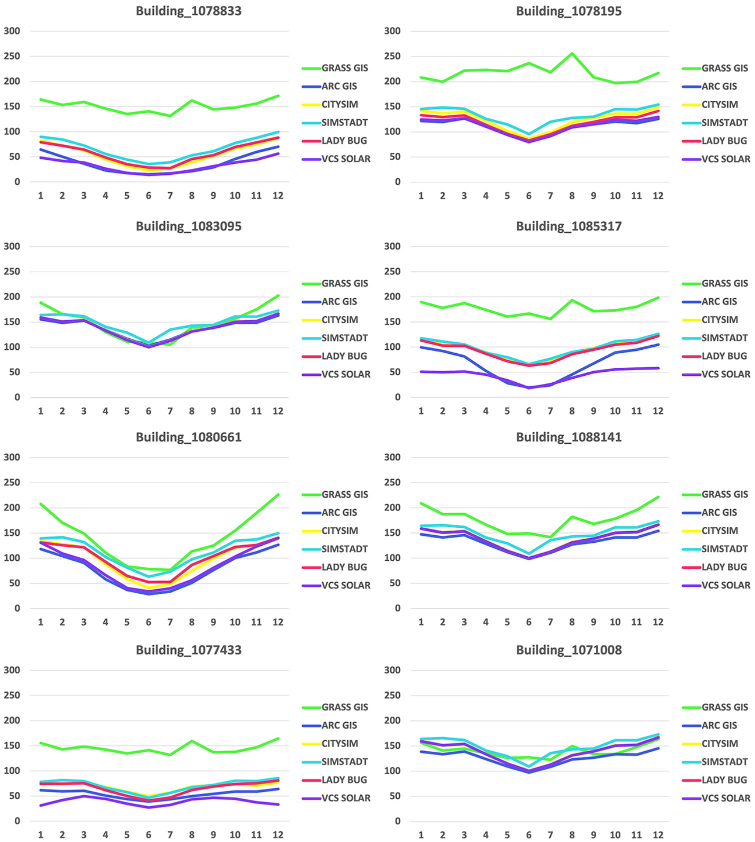


JUNE - WINTER	BUILDING GML ID	GRASS GIS (kWh/m²)	ARCGIS (kWh/m²)	CITYSIM (kWh/m²)	SIMSTADT (kWh/m²)	LADYBUG (kWh/m²)	VCS SOLAR (kWh/m²)
LOWEST ANNUAL GLOBAL IRRADIATION	Building_1078833	140.84	15.27	22.91	35.74	28.84	14.38
HIGHEST ANNUAL GLOBAL IRRADIATION	Building_1078195	236.87	82.05	86.89	95.65	83.02	79.82
SMALLEST ABSOLUTE IRRAD. DIFFERENCE	Building_1083095	109.72	102.63	100.63	108.82	100.12	100.16
LARGEST ABSOLUTE IRRAD. DIFFERENCE	Building_1085317	166.64	19.66	63.86	66.16	62.90	18.25
SMALLEST FOOTPRINT AREA	Building_1080661	78.68	28.83	41.19	63.43	52.44	34.11
LARGEST FOOTPRINT AREA	Building_1088141	149.39	98.74	100.47	109.06	99.83	100.17
LOWEST BUILDING ROOF	Building_1077433	141.29	39.33	49.92	46.56	41.25	27.40
HIGHEST BUILDING ROOF	Building_1071008	127.28	97.17	100.72	100.72	108.94	100.31
DECEMBER - SUMMER	BUILDING GML ID	GRASS GIS (kWh/m²)	ARCGIS (kWh/m²)	CITYSIM (kWh/m²)	SIMSTADT (kWh/m²)	LADYBUG (kWh/m²)	VCS SOLAR (kWh/m²)
LOWEST ANNUAL GLOBAL IRRADIATION	Building_1078833	171.46	70.17	87.46	99.62	88.27	56.61
HIGHEST ANNUAL GLOBAL IRRADIATION	Building_1078195	217.19	126.07	148.51	154.47	141.59	129.71
SMALLEST ABSOLUTE IRRAD. DIFFERENCE	Building_1083095	202.85	162.99	167.33	172.97	166.70	166.50
LARGEST ABSOLUTE IRRAD. DIFFERENCE	Building_1085317	198.32	105.02	124.90	126.59	122.36	57.88
SMALLEST FOOTPRINT AREA	Building_1080661	226.48	126.78	141.10	149.70	140.81	54.00
LARGEST FOOTPRINT AREA	Building_1088141	221.76	154.20	167.32	173.17	166.42	166.52
LOWEST BUILDING ROOF	Building_1077433	164.62	64.36	77.30	85.72	81.07	33.25
HIGHEST BUILDING ROOF	Building_1071008	163.85	145.07	167.59	173.02	167.00	166.86



Detailed monthly analysis: Often similarities except for GRASS – in magnitude and trend.

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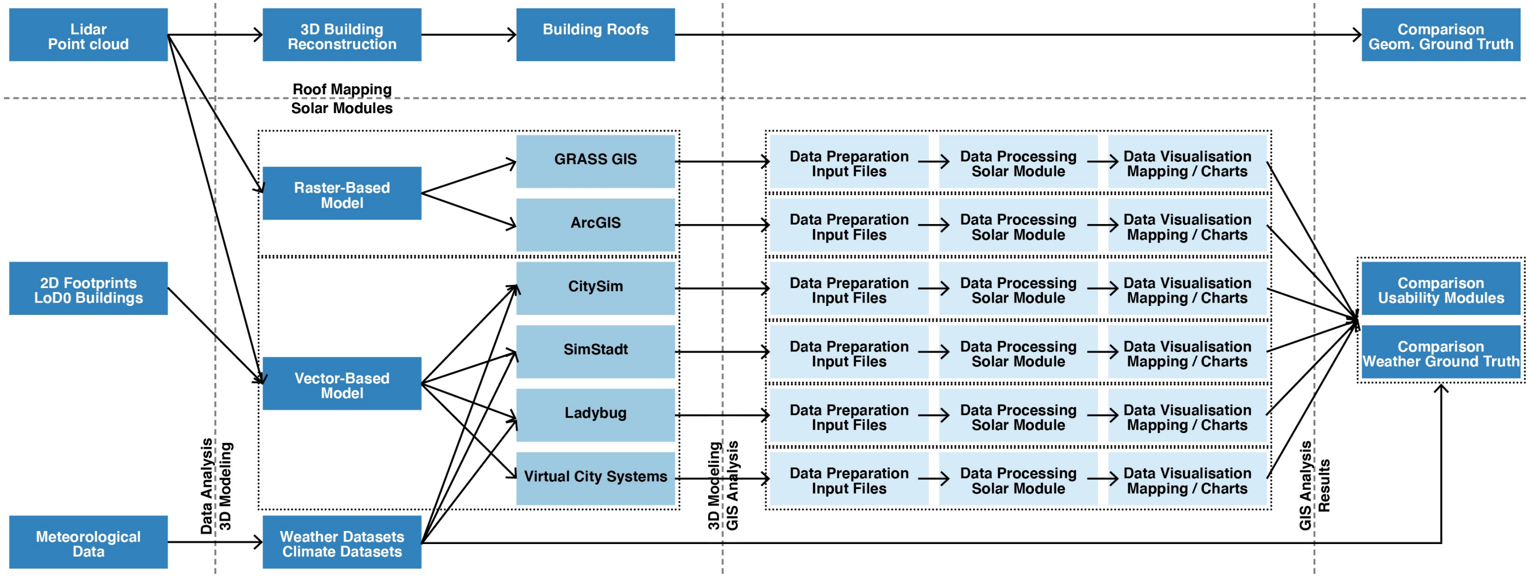
General Pipeline



Two topics: Solar irradiation modules | Roof mapping.

3D Building Reconstruction

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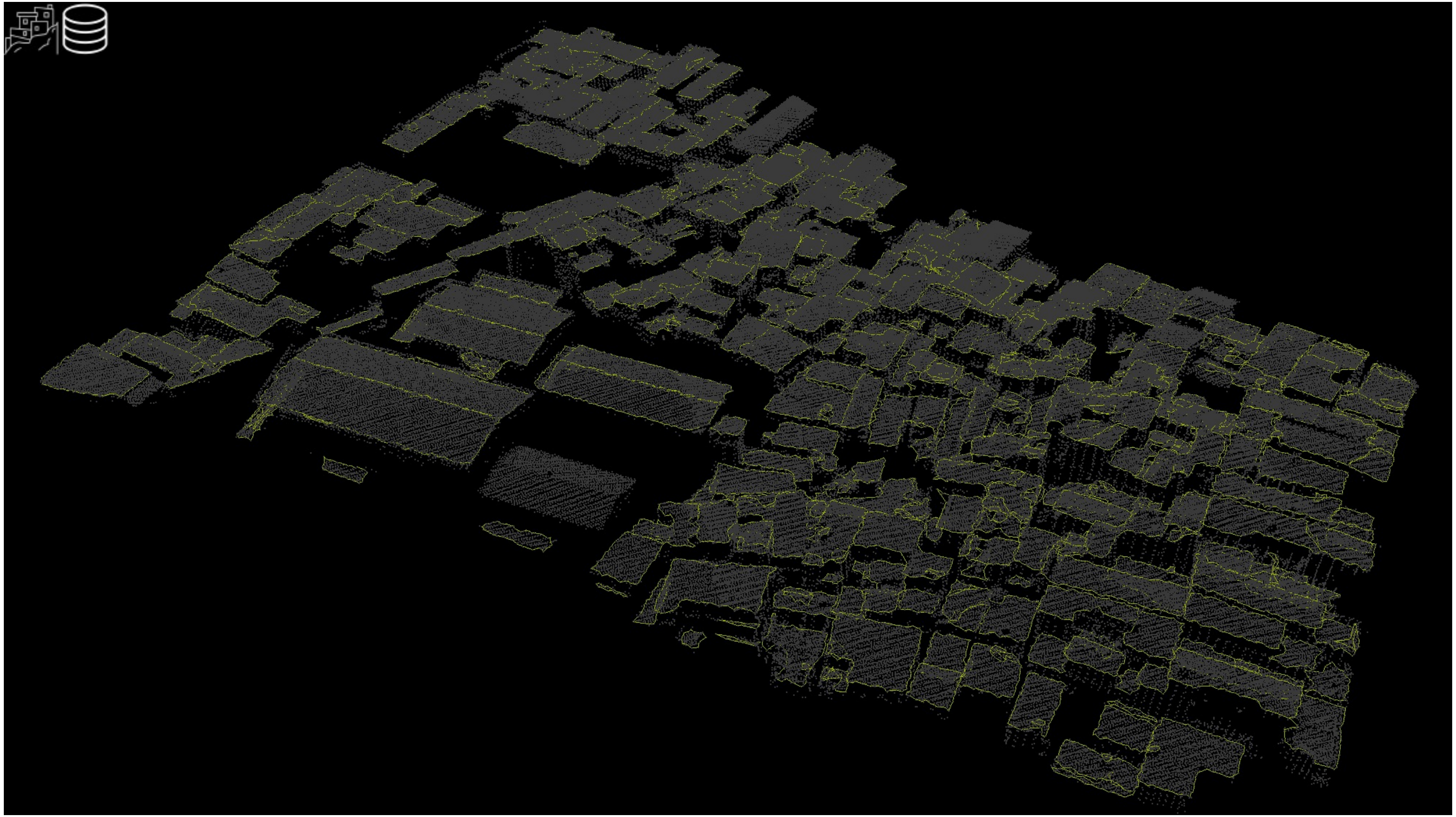

From the point cloud, most clusters of 3D points (white) become roof planes (yellow).

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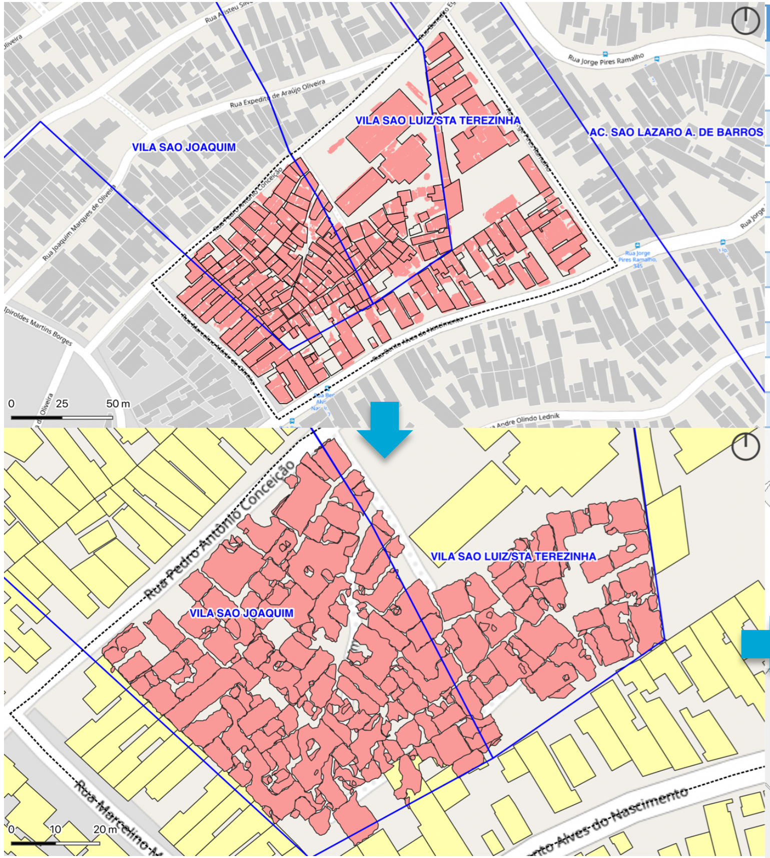
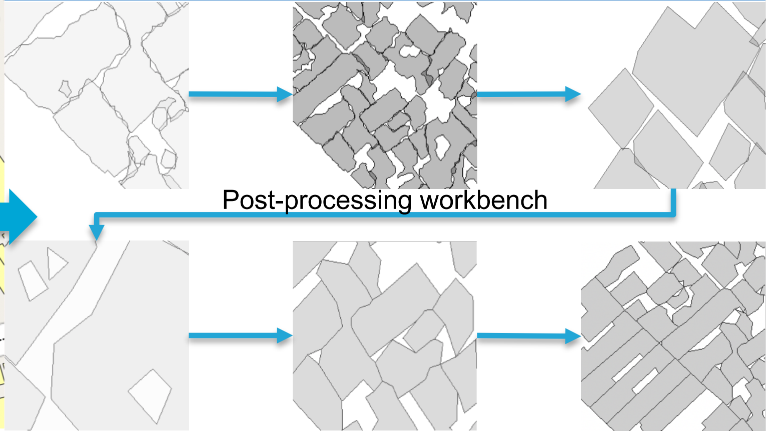
Official vs. Reconstructed Footprints



	Official dataset	Reconstructed dataset
Total Built area	11.629,41 m²	12.305,06 m²
% Official	100 %	105,81 %
Overlapping area	10.148,58 m²	
% Overlapping area	87,27%	82,47%
Footprint polygons	168	525
Footprint area minimum	7,53 m²	0,55 m²
Footprint area median	49,85 m²	9,63 m²
Footprint area average	69,22 m²	23,44 m²
Footprint area maximum	1.307,90m²	312,78 m²
Area standard deviation	111,48 m²	33,51 m²



Common covering area, but more footprints with complex edges; Post-processing work.

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Morphological Overview

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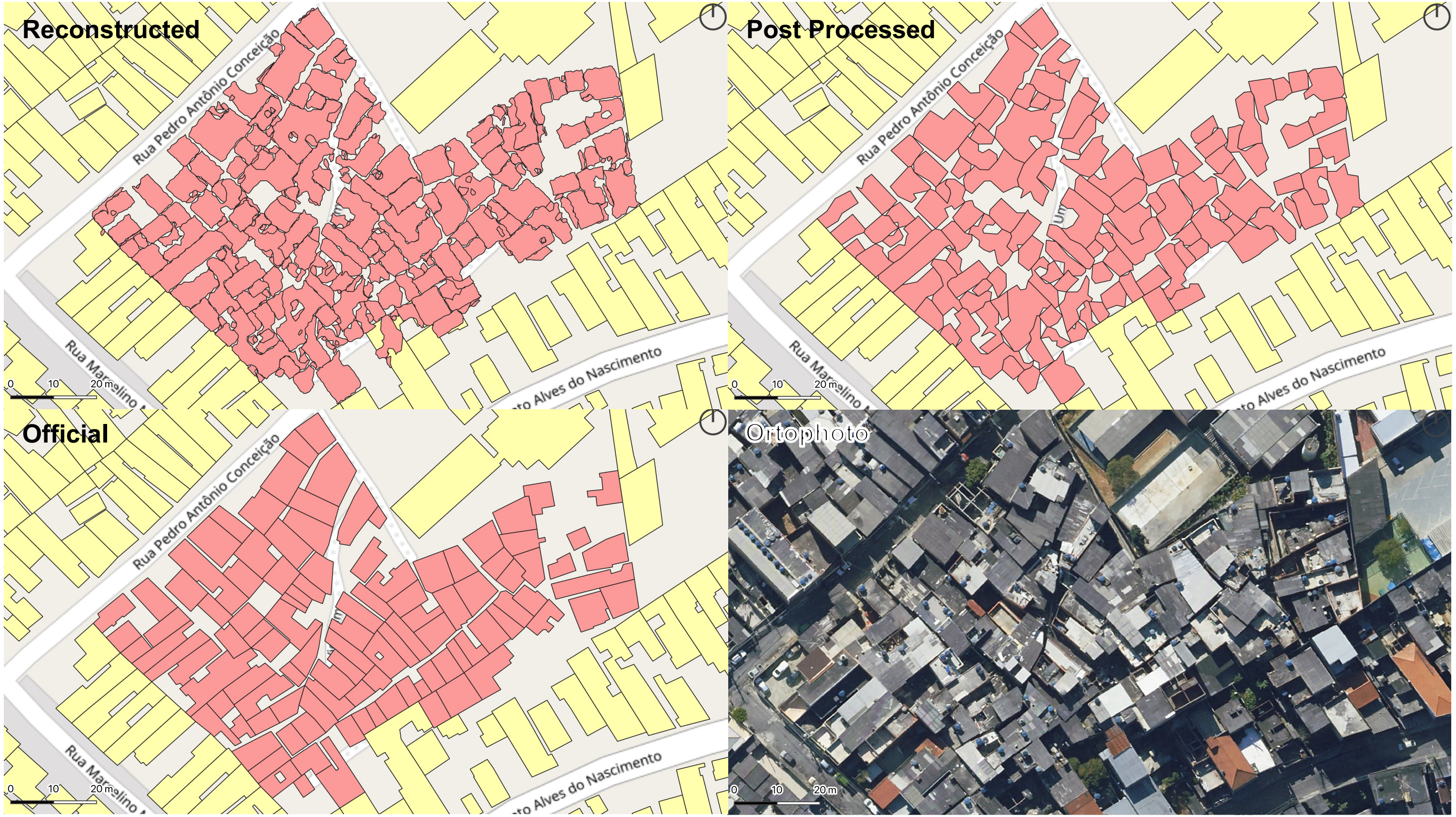

More regular shapes; less small features (water tanks); Overall disposal; Other sites!

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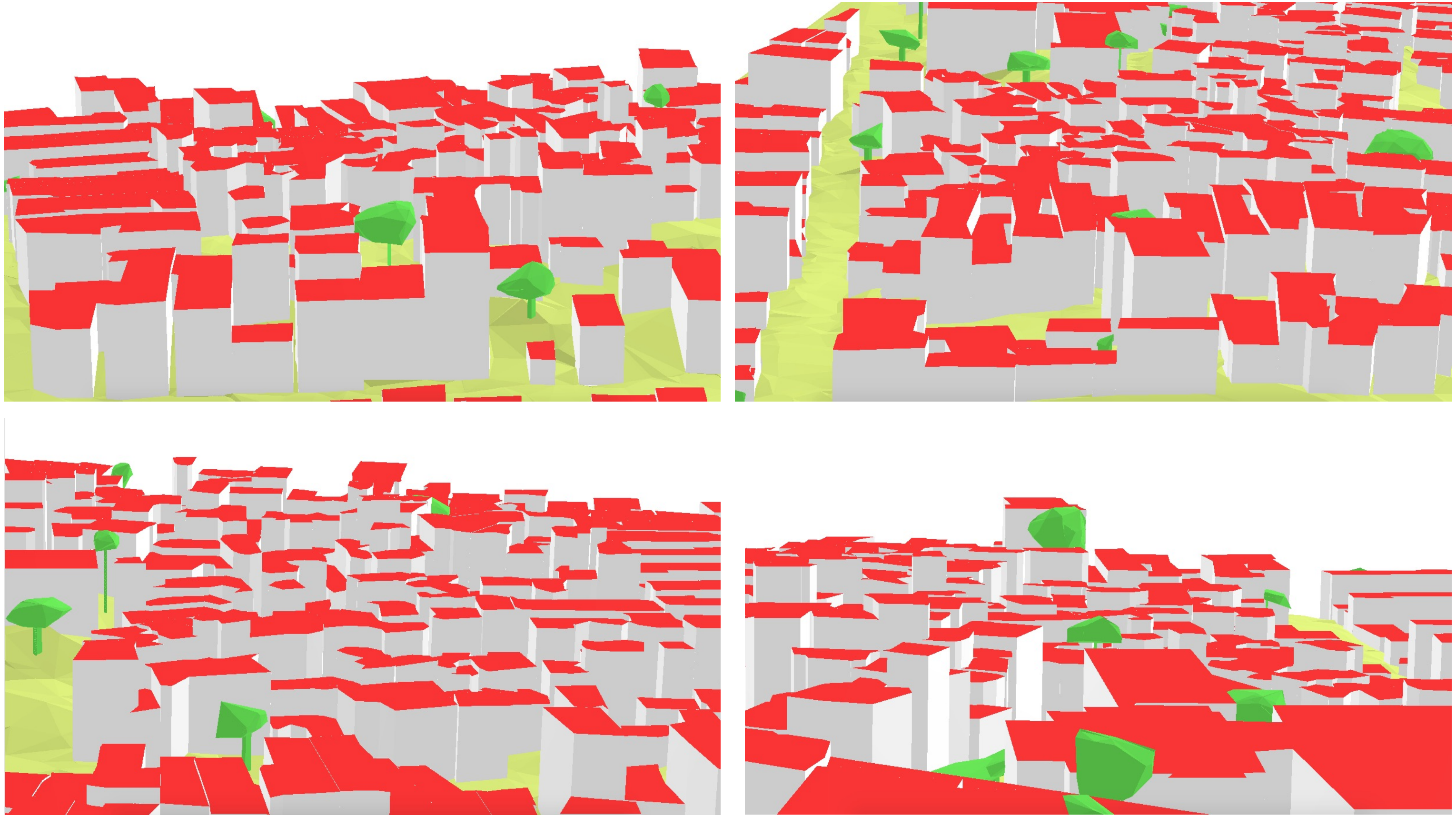
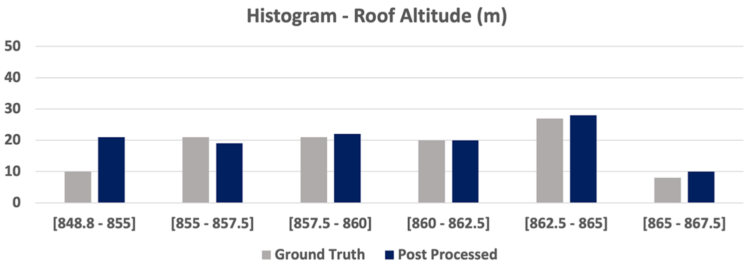
Morphological Overview

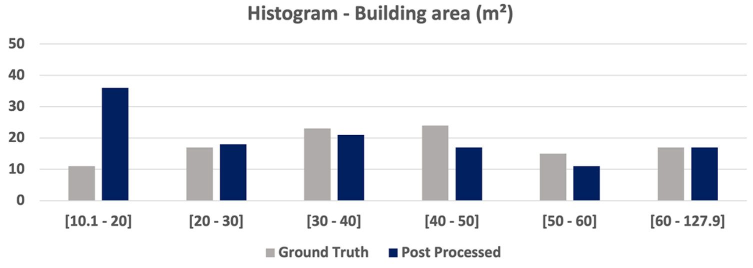


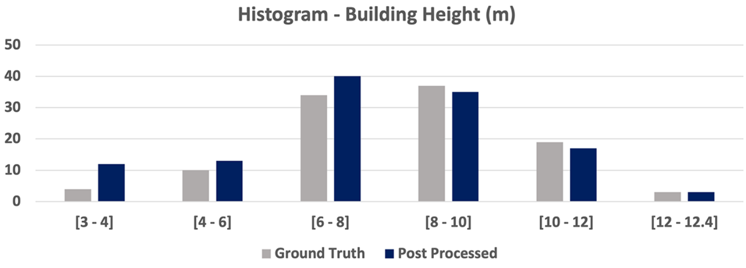
Resulting footprints as input for a new CityGML model: volume and roof height statistics.

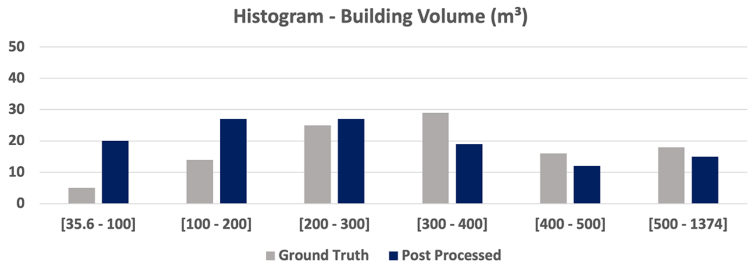
Statistical Analysis

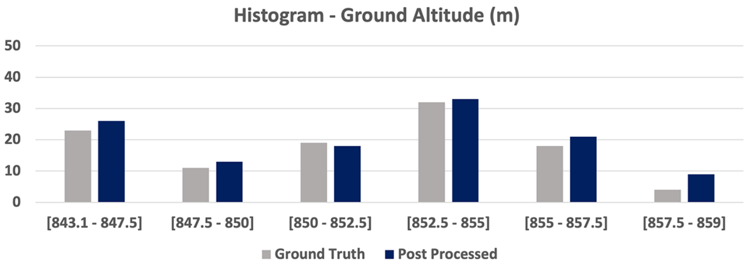
	BUILDINGS	AREA SUMMATION	AREA AVERAGE	AVG. GROUND ALTITUDE	AVG. ROOF ALTITUDE	HEIGHT AVERAGE	VOLUME SUMMATION	VOLUME AVERAGE
	#	m²	m²	m	m	m	m³	m³
GROUND TRUTH DATASET	107	4556.29	42.58	851.59	859.88	8.29	37664.23	352.00
POST PROCESSED DATASET	120	4401.48	36.68	851.75	859.52	7.77	35457.58	295.48
ABSOLUTE DIFFERENCE	13	-154.81	-5.9	0.16	-0.36	-0.52	-2206.65	-56.52
RELATIVE DIFFERENCE	12.1%	-3.4%	-13.9%	0.0%	0.0%	-6.3%	-5.9%	-16.1%











In general, slightly smaller and lower building roofs, satisfactory for **irradiation** analysis!

Results

Roof Mapping

- Coherent overall disposal of the reconstructed building area.
- Still, too many small and complex polygons.
- Attention to water tanks and other elements on building roofs.
- Post-processing pipeline mitigates these issues, but still some complexity remains.
- Final building roofs are slightly lower and smaller, but offer similar designing conditions.
- Solar irradiation (kWh/m²) analysis is still possible as a first approximation.
- Further research with other favelas could evaluate the methodology.

Solar Modules – Qualitative comparison

- Each software offers potentialities but also limitations: no straightforward choice.
- Morphological characteristics of the favela should be considered.

Solar Modules – Quantitative comparison – Santana

- **ArcGIS**: closest annual sum of irradiation values (0.89% higher than ground truth).
- **CitySim**: best correspondence to the ground truth curve (lowest monthly/annual RMSEs).
- **GRASS**: distance to ground truth sum ~ CitySim, but higher RMSE values.
- **SimStadt** & **Ladybug**: direct and diffuse inputs, therefore lower annual sum and higher RMSEs.
- **VCS Solar**: relative low RMSE values, but larger distance to ground truth sum.

Results

Solar Modules – Quantitative comparison – Brasilândia

- **GRASS**: for the general curve and in most specific buildings, major differences both in magnitude (higher values) and in trend (local peaks).
- **Other 5 modules**: relatively similar curves – general but also specific ones – with minor offsetting. The correction factors approximate the results.
- **VCS Solar**: Irradiation differences among adjacent buildings within the month, especially for the informal settlement.

Choosing a Solar Module for Favelas

- Two criteria: geometrical model and weather dataset.
- If post-processed footprints are too complex / unrealistic: raster-based approach for solar overview.
- If resulting CityGML model is simple and representative: CitySim – weather data input is retrievable.

"How far is it possible to perform solar analysis on buildings of favelas in São Paulo, with the goal of estimating PV Potential?"

Roof Mapping – complex technical challenge, post processed footprints as a first approximation.

Solar Modules – solution based on the geometrical model and weather data availability.

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