Generating Urban-Scale Building Data to Support Climate Modeling

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Talk structure

1. Introduction: The evolution of WUDAPT and the need for building scale data

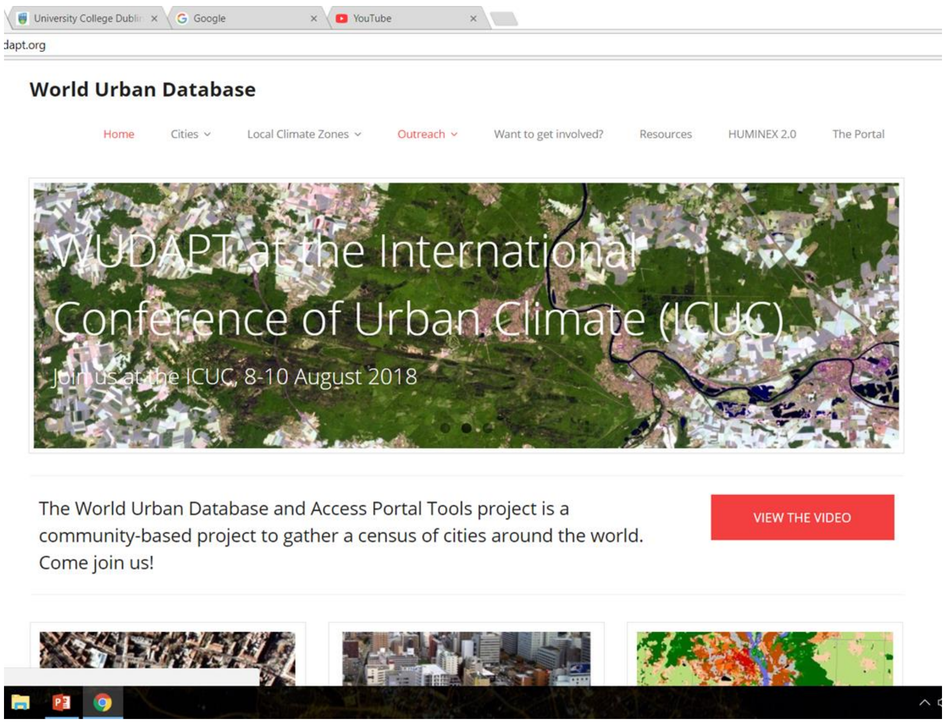
2. a. Developing an archetype approach to the acquisition of building data on form and function (Tabula-Episcope): b. Generating a large scale urban building database (Dublin)

3. Evaluating the value of these data using an Urban Building Energy Model (UBEM) applied to a case-study area.

4. Conclusion

A lack of climate relevant urban data that is consistent in terms of scale and content. This is a major impediment to model application.

WUDAPT
WORLD URBAN DATABASE & ACCESS PORTAL TOOLS



Objectives

1. Acquire information on aspects of form and functions of cities relevant to climate studies.
2. Store the data in a geographic framework that is searchable and widely accessible.
3. Build portal tools to extract parameters and analyse urban properties for cross-urban comparison and model building.

WUDAPT levels of urban detail

Level 2

- Detailed description of urban landscape parameters at a scale suited to boundary-layer models
- Use of all available databases (e.g. building footprints)

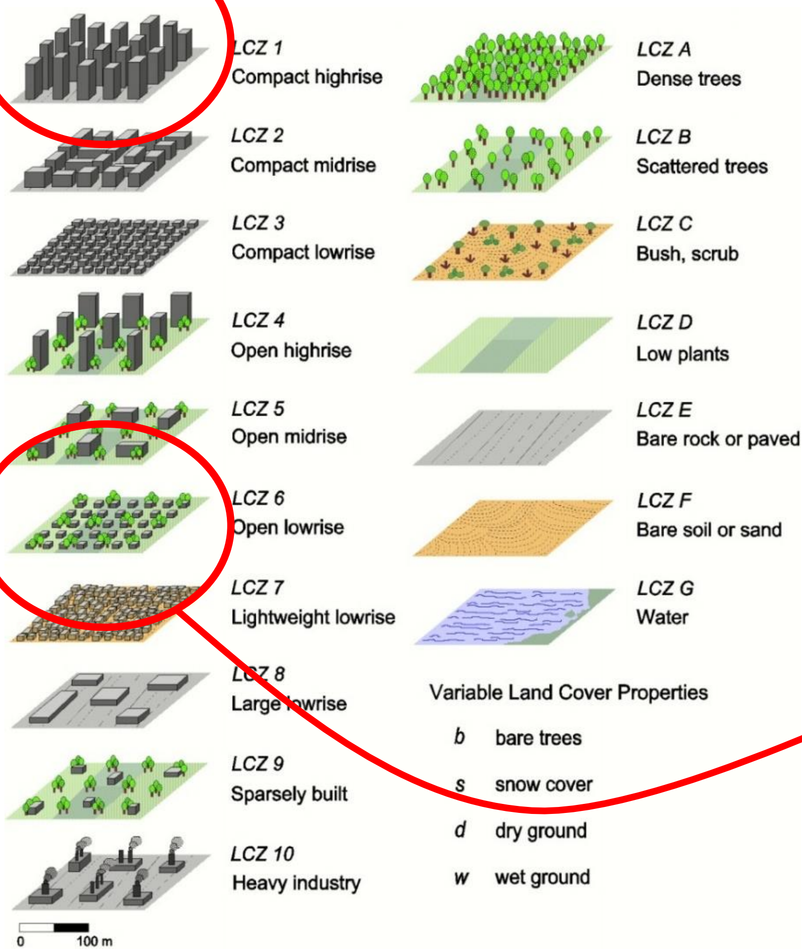
Level 1

- More precise parameter values for each LCZ
- Focus on aspects of form (e.g. building heights, street width) and functions (e.g. building use).
- Sampling of LCZ using GeoWiki

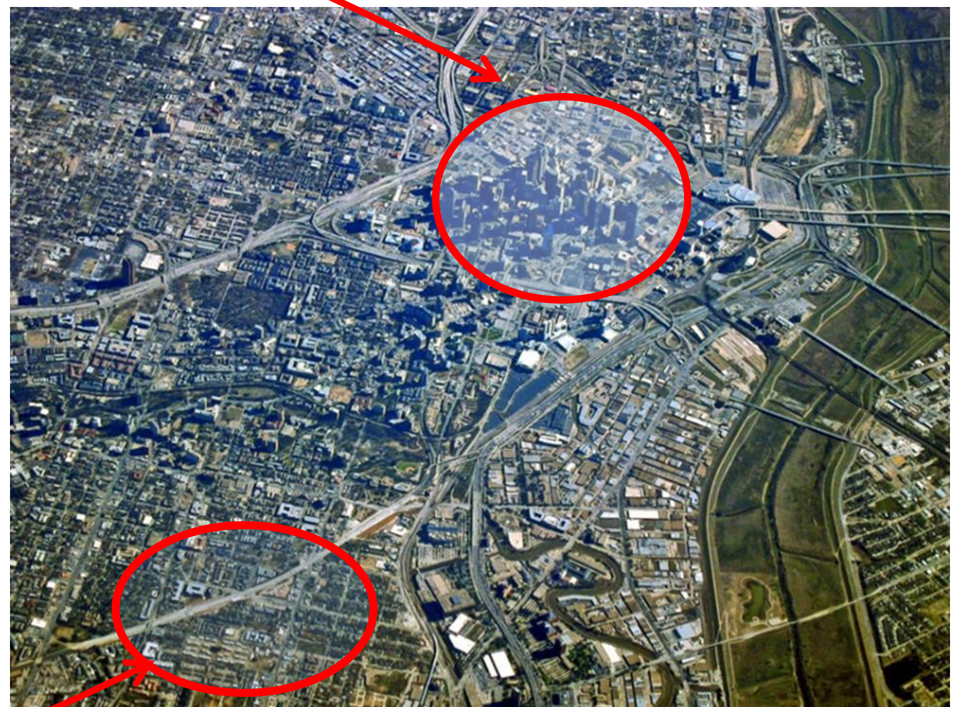
Level 0

- Local Climate Zones (LCZ) along with parameter ranges
- Categorise city neighbourhoods into LCZ types
- Local experts provide training areas
- GoogleEarth, Landsat8 and Saga

Level 0 WUDAPT data



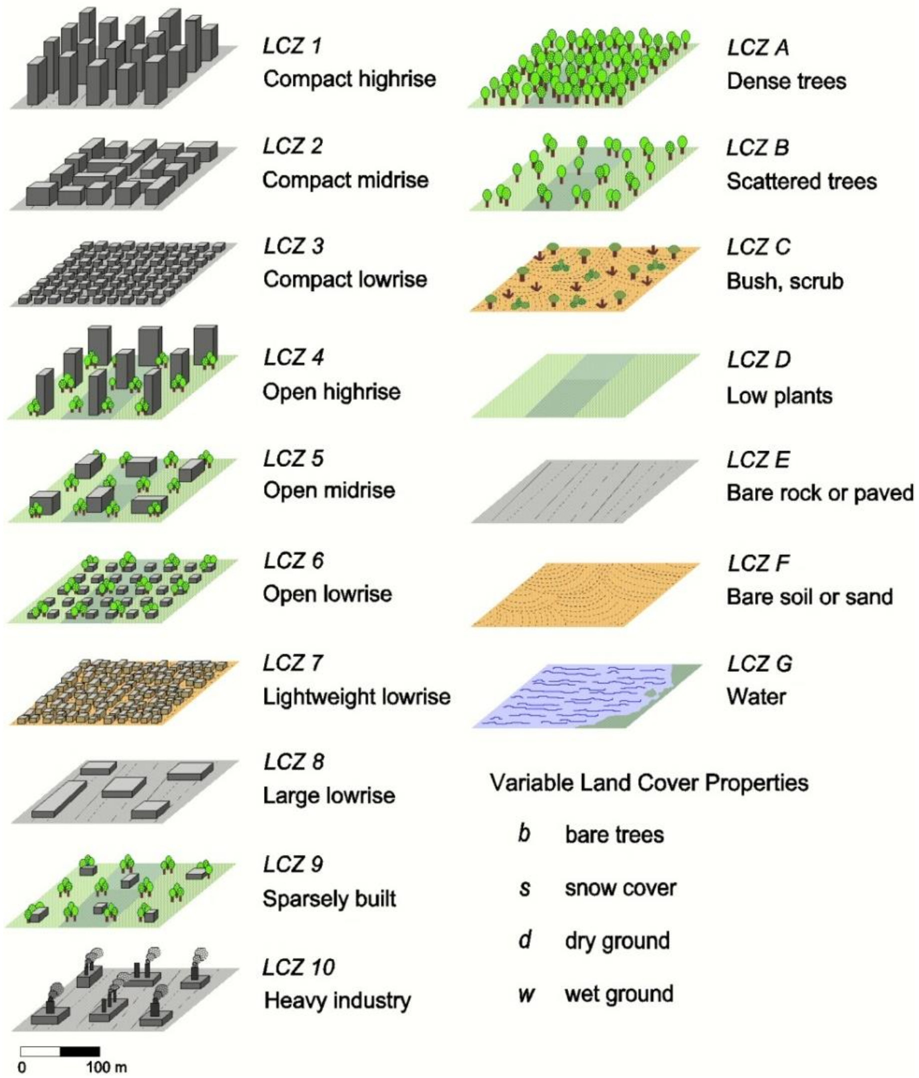
Stewart & Oke, 2012



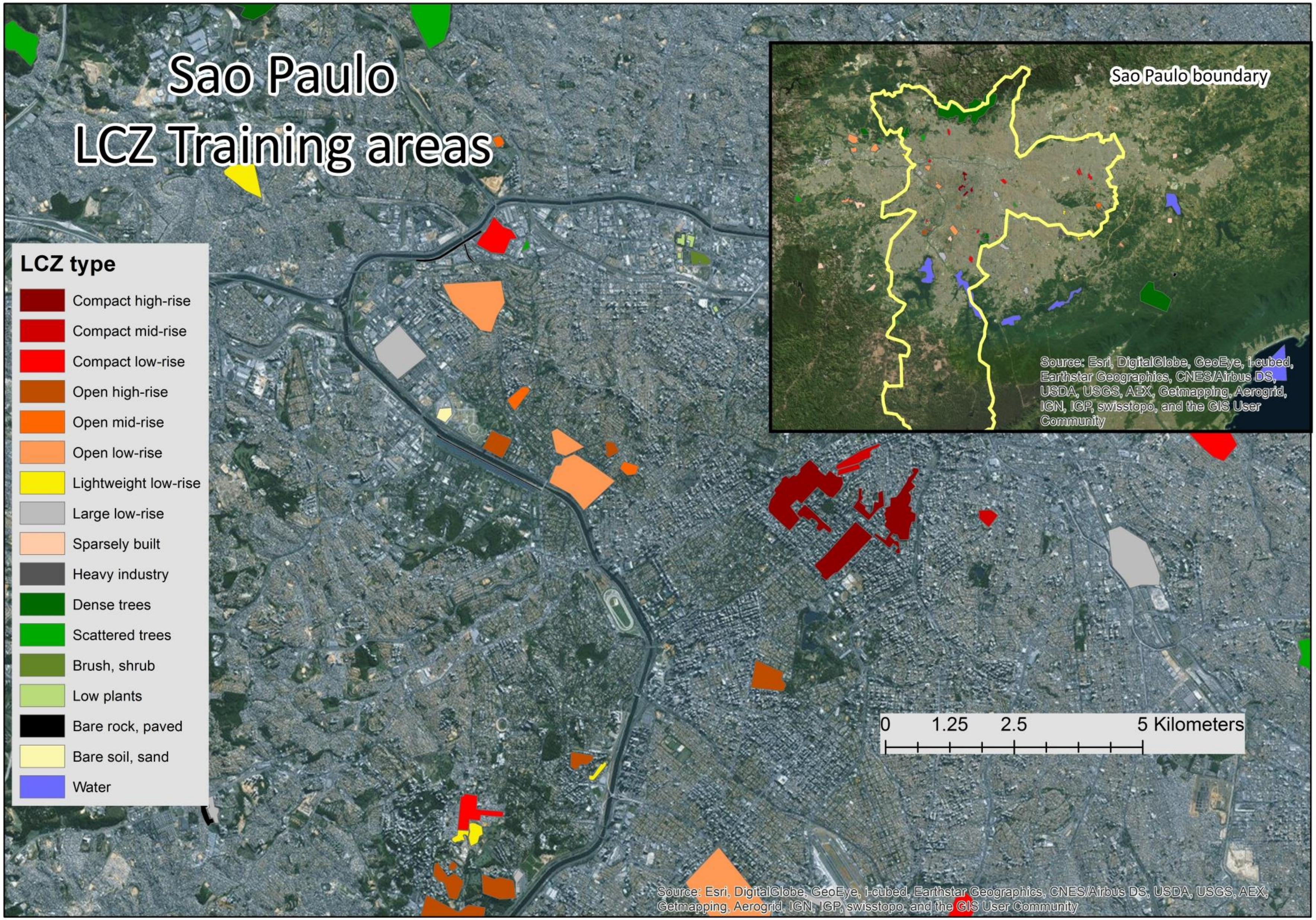
The Local Climate Zone (LCZ) classification provides a scheme for describing the basic physical geography of cities suited to further data gathering.

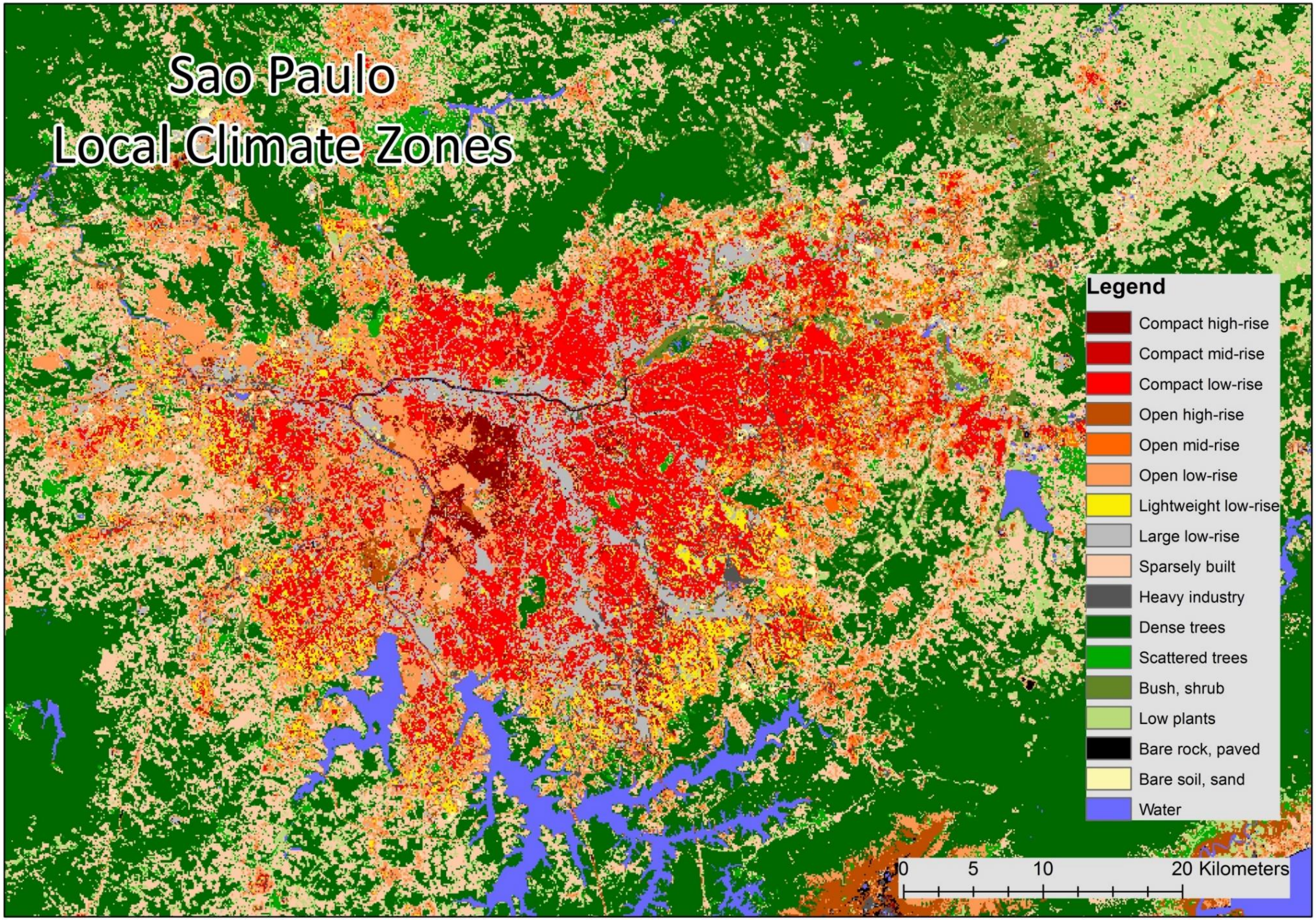
It can be used as a *sampling frame* to gather more detailed urban data (e.g. building materials, cooking fuel, etc.) at more detailed spatial scales.

LCZ Type	Mean Height (m)	Building Surface Fraction	Impervious Surface Fraction	QF (Wm^{-2})
1	>25	40-60%	40-60%	50-300
2	10-25	40-70%	30-50%	<75
3	3-10	40-70%	20-50%	<75
4	>25	20-40%	30-40%	<50
5	10-25	20-40%	30-50%	<25
6	3-10	20-40%	20-50%	<25
7	2-4	60-90%	<20%	<35
8	3-10	30-50%	40-50%	<50
9	3-10	10-20%	<20%	<10
10	5-15	20-30%	20-40%	>300

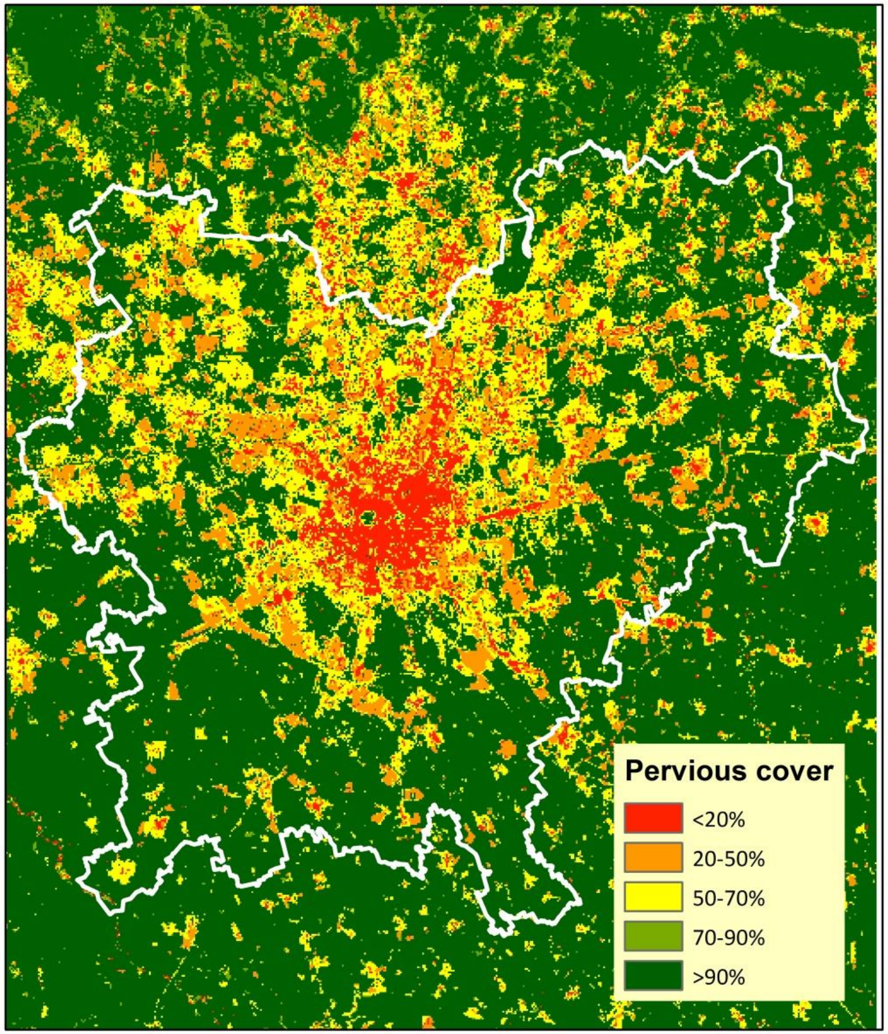


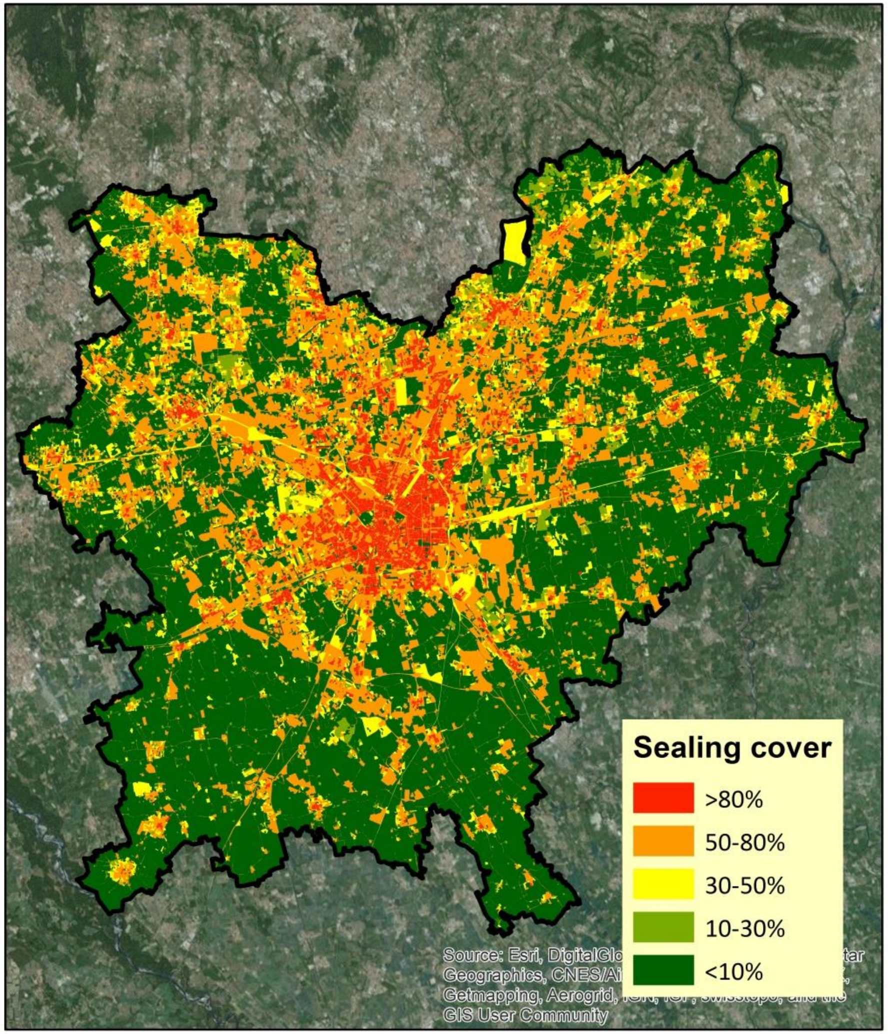
The **Local Climate Zone** approach developed by Iain Stewart and Tim Oke builds on other approaches and provides a classification scheme for urbanised and natural landscapes that can be used to describe **neighbourhoods** within cities.


Sao Paulo
LCZ Training areas
LCZ type
Compact high-rise
Compact mid-rise
Compact low-rise
Open high-rise
Open mid-rise
Open low-rise
Lightweight low-rise
Large low-rise
Sparsely built
Heavy industry
Dense trees
Scattered trees
Brush, shrub
Low plants
Bare rock, paved
Bare soil, sand
Water
Sao Paulo boundary
Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community
0 1.25 2.5 5 Kilometers
Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community


Sao Paulo
Local Climate Zones
Legend
Compact high-rise
Compact mid-rise
Compact low-rise
Open high-rise
Open mid-rise
Open low-rise
Lightweight low-rise
Large low-rise
Sparsely built
Heavy industry
Dense trees
Scattered trees
Bush, shrub
Low plants
Bare rock, paved
Bare soil, sand
Water
0 5 10 20 Kilometers

Quality

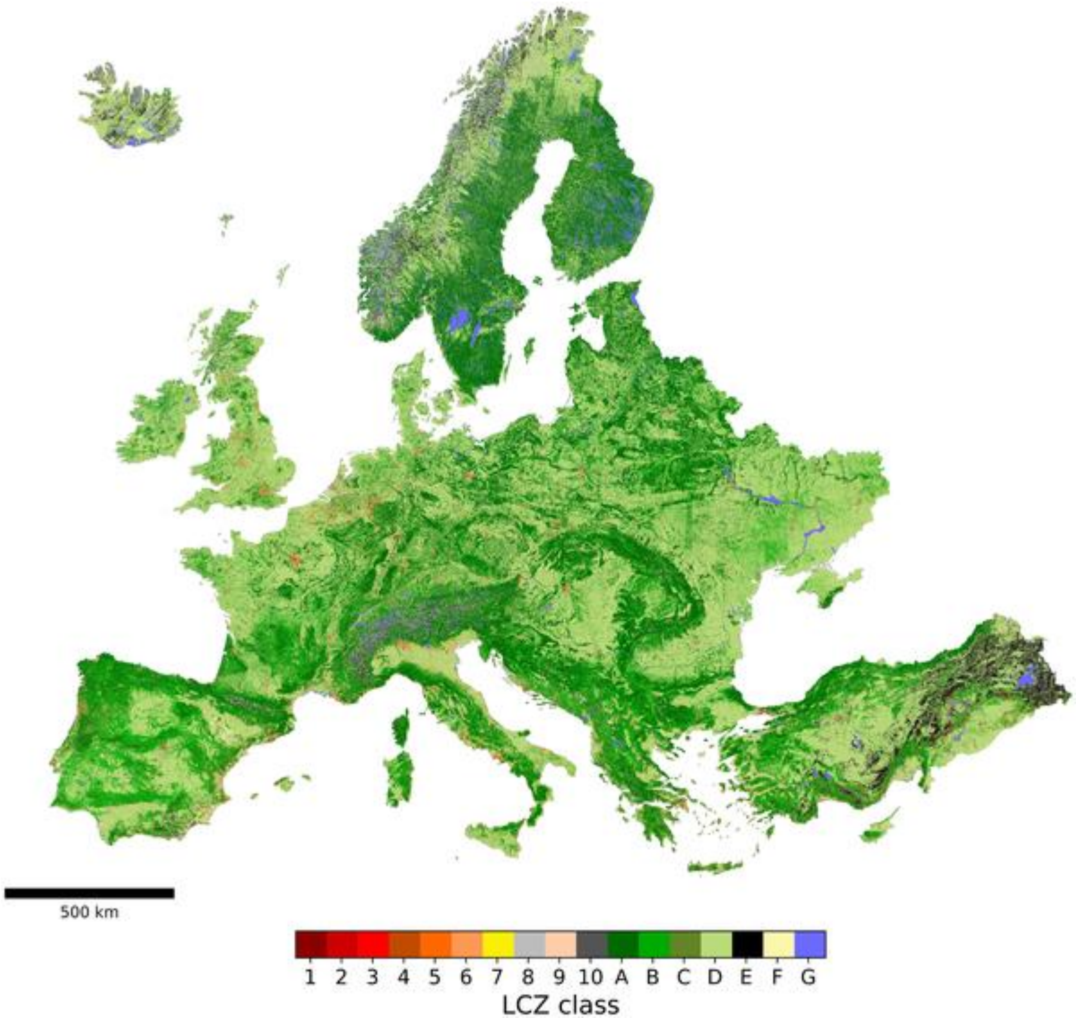




WUDAPT product

Urban Atlas

Fig 7. European local climate zone map.



Demuzere M, Bechtel B, Middel A, Mills G (2019) Mapping Europe into local climate zones. PLOS ONE 14(4): e0214474.
https://doi.org/10.1371/journal.pone.0214474
https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0214474

Getting to levels 1 & 2

Acquiring more precise parameter values at a finer spatial resolution

1. Approximating urban-scale detailed morphology


(b) Chicago - Aerial


(a) Chicago - Synthetic

The Digital Synthetic City (DSC) tool can generate a realistic representation of buildings and their distribution across the urban landscape, using a variety of satellite and complimentary information.

The DSC data can be used to derive building related UCPs far more precisely that the LCZ approach which is of great value for simulating the effects of cities on airflow (pollution dispersal) and energy exchanges at street level.

The Digital Synthetic City (Daniel Aliaga, Purdue)

2. Acquiring building scale data
Photo to Building

https://www.youtube.com/watch?v=zPvCnorXERQ&t=175s

1. email photo2building@gmail.com and we give you a free login.
2. Login to photo2building.com.

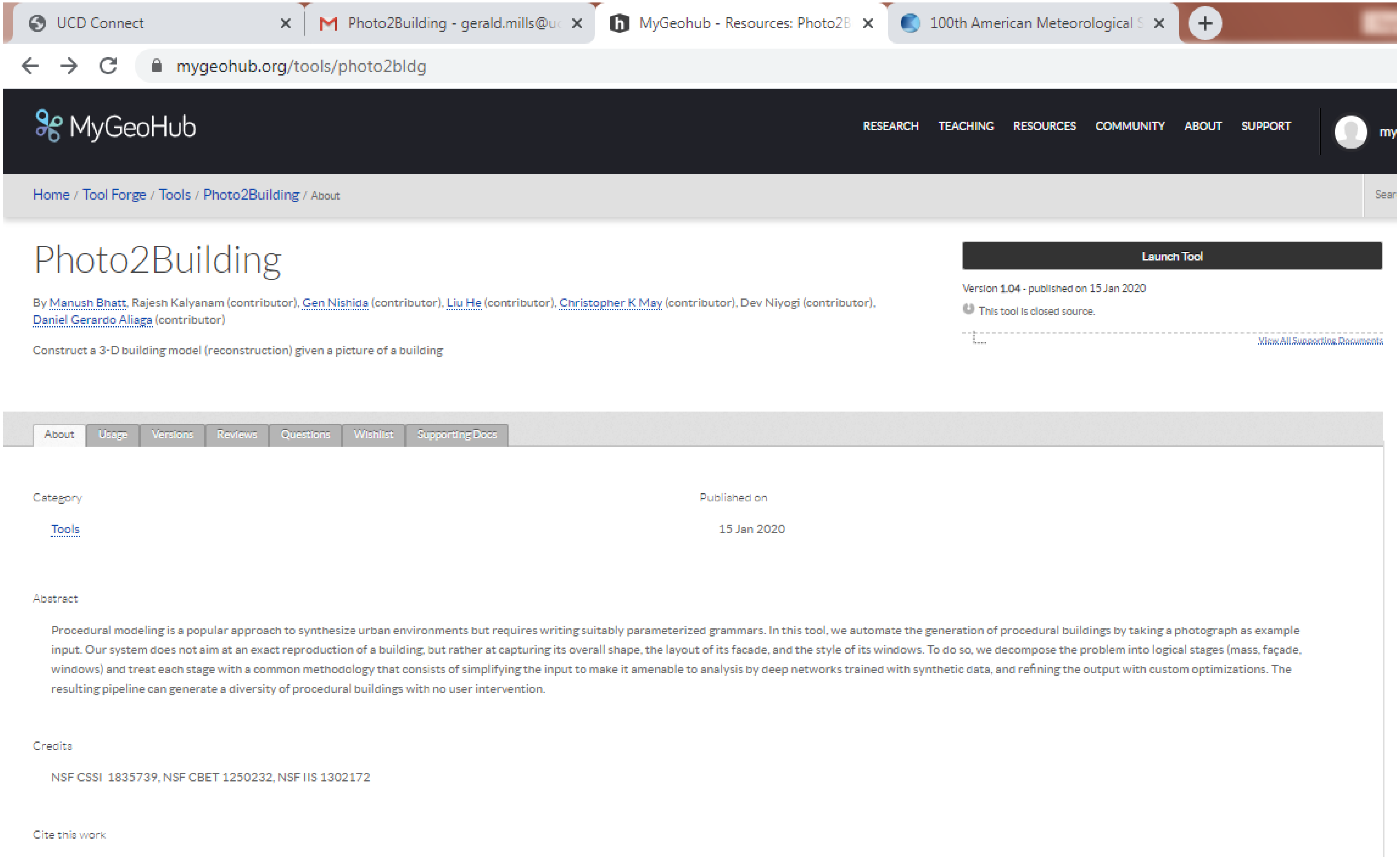


Photo2Building: By Manush Bhatt, Rajesh Kalyanam (contributor), Gen Nishida (contributor), Liu He (contributor), Christopher K May (contributor), Dev Niyogi (contributor), Daniel Gerardo Aliaga (contributor)

Potential value of urban scale building data
Urban building energy models

UBEMs apply 'physical models of heat and mass flows in and around buildings to predict operational energy use as well as indoor and outdoor environmental conditions for groups of buildings' (Reinhart & Cerezo-Davila, 2016, p. 197).

Reinhart, C.F. and Davila, C.C., 2016. Urban building energy modeling–A review of a nascent field. Building and Environment, 97, pp.196-202.

Urban Modelling Interface (UMI)

UMI is designed by the Sustainable Design Lab in Massachusetts Institute of Technology (MIT) for simulating environmental performances of buildings at a neighbourhood scale. It employs the Rhinoceros CAD programme to generate the building database that is then used by Energy Plus (DOE 2) to simulate energy profiles. It is free to use and has not yet been tested outside of North America.

The basic information required for each building includes:

- The georeferenced location;
- The dimensions (height, width and depth) and orientation;
- Details on the envelope fabric and on the HVAC systems and;
- Profiles of the occupants.

2. Acquiring building data on form and function (Dublin)

Linking individual buildings to a building typology that provides details on the typical construction materials and operational systems.

TABULA

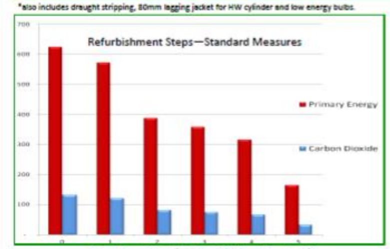
7. Terraced house, solid brick wall, 1900-1929

Building elements :		Insulation	U - value
Walls	Solid brick, 325 mm	none	1.64
Roofs	Pitched, insulation between joists	50 mm	0.68
Floors	Suspended timber floor Solid floor (kitchen)	none none	0.69 0.79
Windows	Single glazed, wooden frame Single glazed, metal frame	N/A N/A	4.8 5.7
Doors	Solid timber	none	3.0
Heating systems characteristics:		**Fuel**	**Efficiency**
Primary	Central heating boiler, pipe work un-insulated	Mains gas	65%
Secondary	Open fire in grate	Smokeless	30%
Hot water	From primary heating system. Electric immersion used in Summer.		
Cylinder	Insulated with 25mm lagging jacket, no cylinder thermostat.		
Controls	Programmer only		

Description:
Typical redbrick house found in Dublin, Cork, Limerick etc from late 1800s up to 1930s. Often includes a flat roof extension to rear. Suited to a mix of internal and external wall insulation. Suspended timber floors are common that can be retrofitted with insulation.

	Refurbishment steps — standard				Prim. energy kWh/m²/y	Carbon Dioxide kgCO₂/m²/y	Energy Rating
0	Building fabric upgrade steps:			Expected U-values	625 (actual state)	132 (actual state)	G
1	Roof insulation and standard package*	Add	250 mm of mineral wool between and over the ceiling joists and installation of required roof vents	0.13	573	121	G
2	Wall insulation	Add	Dry line/internally insulate with 72.5-82.5mm thermal laminate board	0.27	389	82	F
3	Flat roof	Add	Thermal laminate (82.5mm) board fixed to underside or rigid board applied on top of roof (100-150mm)	0.22	358	75	E2
4	Windows and Doors	Replace	Double glazed, low-e windows, air filled, 16mm gap Insulated doors	1.4 / 2.0	317	67	E1
	Systems upgrade:						
5	Space and water heating system and controls and renewable energy	Replace	Condensing boiler 90% efficient, two separated heating zones with time and thermostatic control, independent water heating. Hot water cylinder insulated with 50 mm spray foam. Secondary heating system is replaced by a solid fuel burner (75% efficient)		165	33	C1

*also includes draught stripping, 80mm lagging jacket for HW cylinder and low energy bulbs.



Primary Energy: kWh/m²/y, Carbon Dioxide emissions: kg/m²/y

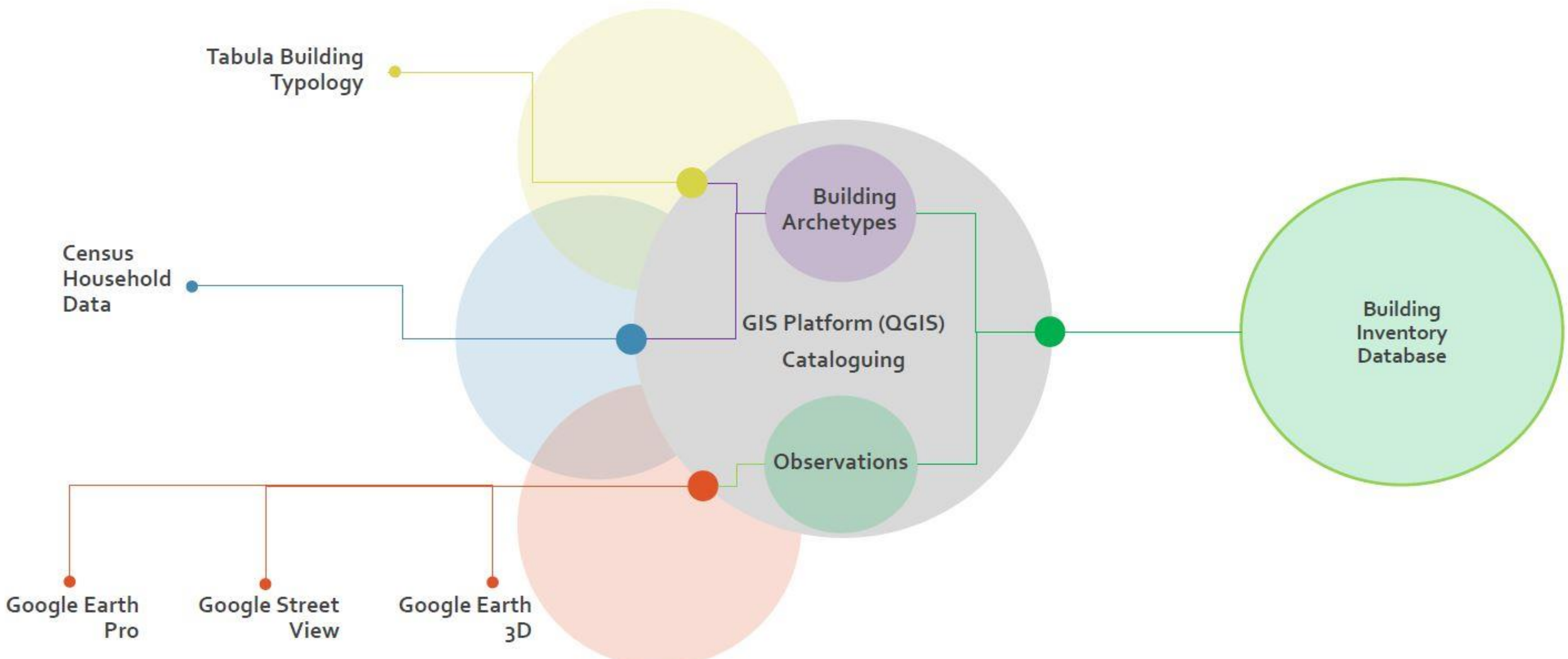
Estimated costs and payback time**		
Measure	Estimated costs	Payback (y)
Step 1	€ 1,296	3.8
Step 2	€ 12,770	13.3
Step 3	€ 668	4.2
Step 4	€ 6,412	29.7
Step 5	€ 6,535	7.5
Total:	€ 27,681	10.9

Standard upgrade summary	
Primary energy reduced by:	460 kWh/m²/y
Carbon dioxide reduced by:	99 kg CO_2/m²/y

30

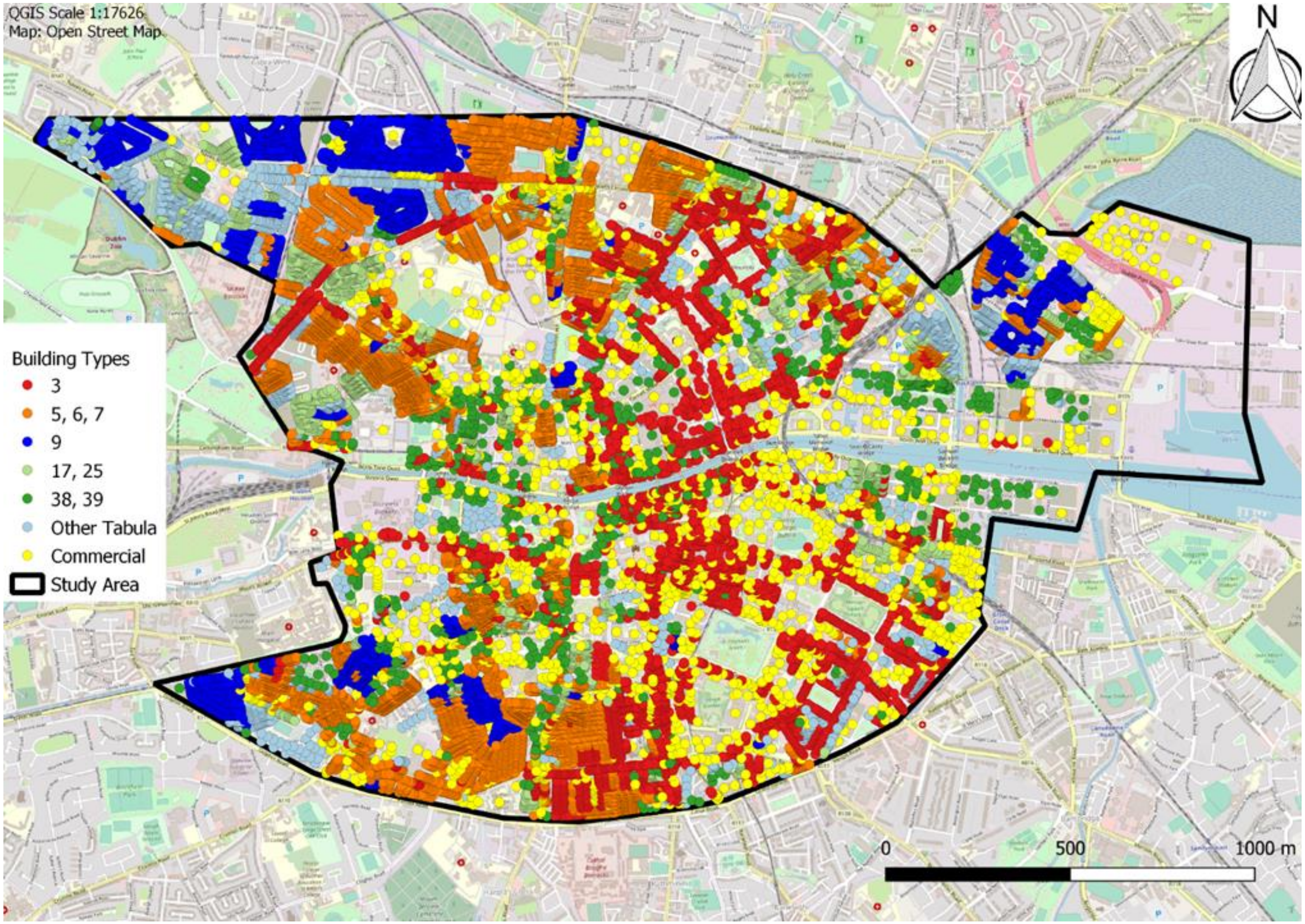
The urban landscape could be sampled strategically (based on geometry, LCZ types, age of construction, etc.) to acquire details on the building stock. The challenge here is to devise a suitable typology that could be used across cities and cultures.

Methodology Workflow



Representative photographs of the nine common Tabula types.

Type	Construction period	Wall	Roof	Windows	Energy Rating
(3) Terraced house	Pre- 1900	Uninsulated brick 325/225 mm thick.	Front pitched with 100mm of mineral wool in ceiling joists/ Rear pitched roof no insulation.	Single glazed, wooden frames.	352 (O) 95 (R)
N=5435		U = 1.64/1.41	U = 0.4/2.3	Glazed fraction 6% U = 4.8	
(7) Terraced house	1900-1929.	Uninsulated brick walls 325 mm thick.	Pitched roof with 50mm of mineral wool in ceiling joists.	Single glazed , wooden/steel frame	624 (O) 178 (R)
N=5365		U = 1.64	U = 0.68	Glazed fraction 6% U= 4.8/5.7	
(9) Terraced house	1930-1949	Solid mass concrete	Pitched, insulation between the joists	Single gazed, metal frame	392 (O) 106 (R)
N=2760		U = 2.2	U = 0.68	Glazed fraction 6% U= 5.7	
(17) Terraced house	1978-1982.	300 mm walls, partially filled	Pitched, insulated between the joists	Double-glazed, metal frame, 6 mm gap	311 (O) 117 (R)
N=1235		U = 1.1	U = 0.4	Glazed fraction 9% U= 3.7	
(25) Terraced house	1994-2004.	Cavity walls, partially filled	Pitched, insulated between the joists	Double glazed, PVC/wood, 12 mm gap	177 (O) 119 (R)
N=869		U=0.55	U= 0.36	Glazed fraction 10% U= 2.8	
(38) Apartment block	1994-2004	Block with part filled cavity walls 300mm thick.	Flat roof with insulation.	Double-glazed, air filled windows with 12mm gap, wood/PVC frames.	175 (O) 63 (R)
N=1109		U = 0.55	U = 0.35	Glazed fraction 10% U= 2.8	
(39) Apartment block	2005- 2010	Solid reinforced concrete externally insulated.	Flat roof with insulation.	Double-glazed, air filled windows with 16mm gap, wood/ PVC frames.	145 (O) 6 (R)
N=458		U = 0.27	U = 0.22	Glazed fraction 40% U= 2.0	

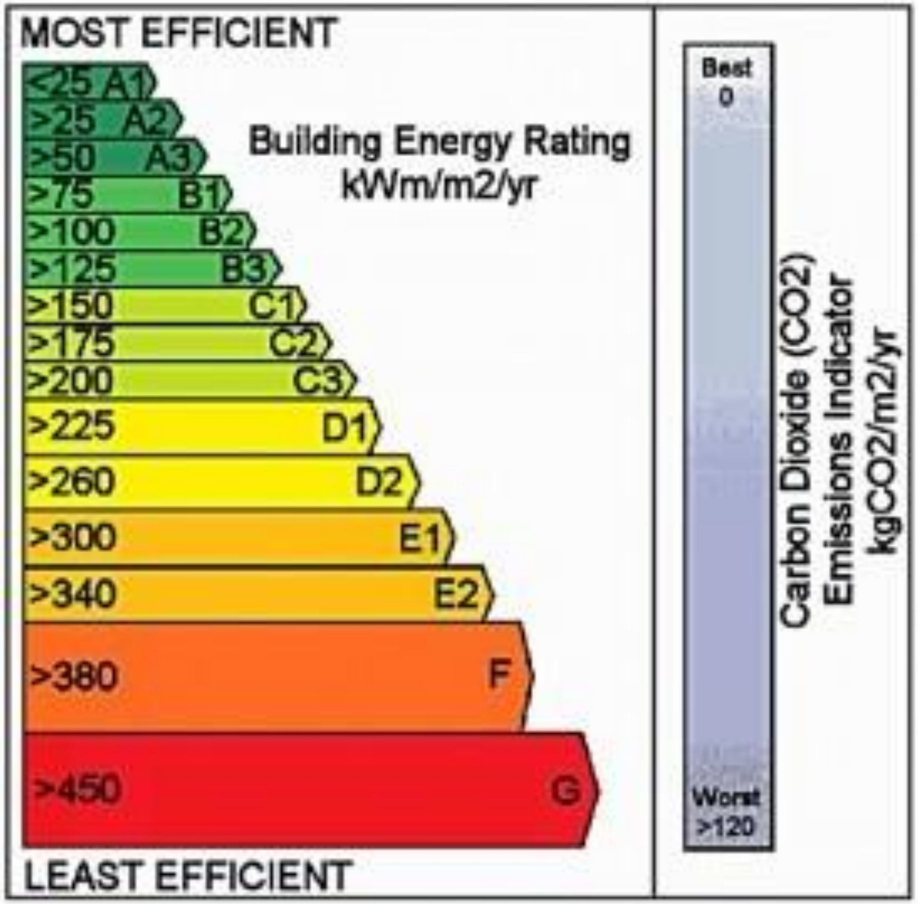


The geography of Tabula building types across the city centre N=25,000.

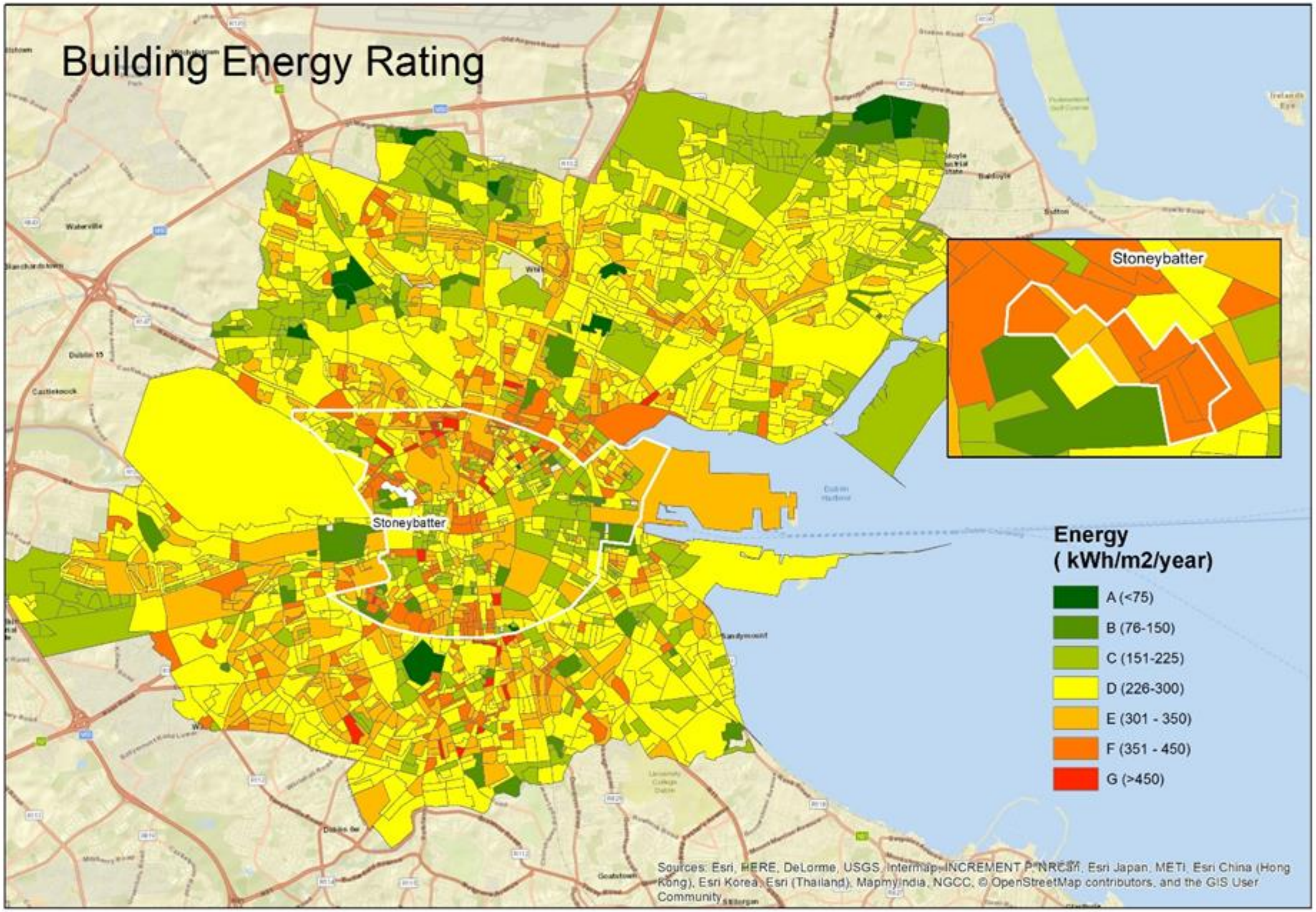
Energy regulations on buildings were first implemented in 1978 and have become progressively more stringent over time. Buildings constructed before 1950 have solid walls and are not amenable to simple refurbishment.

There is no energy use/demand data available at a building/neighbourhood scale. The available energy data consists of Building Energy Rating (BER) information that is required for all buildings bought or rented after 2006. This information is available at the same level as census data (Small Areas).

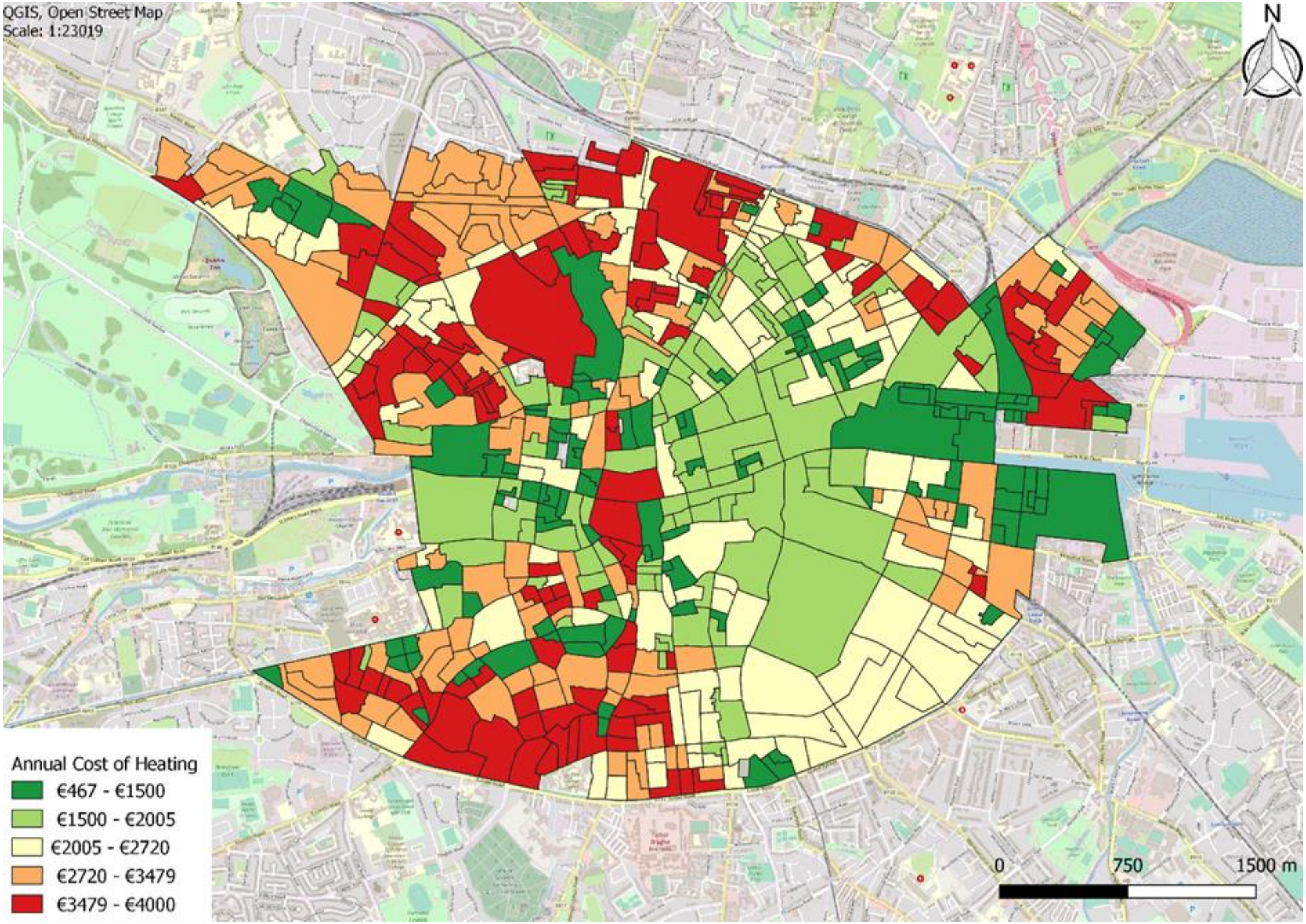
Energy use and CO2 emissions



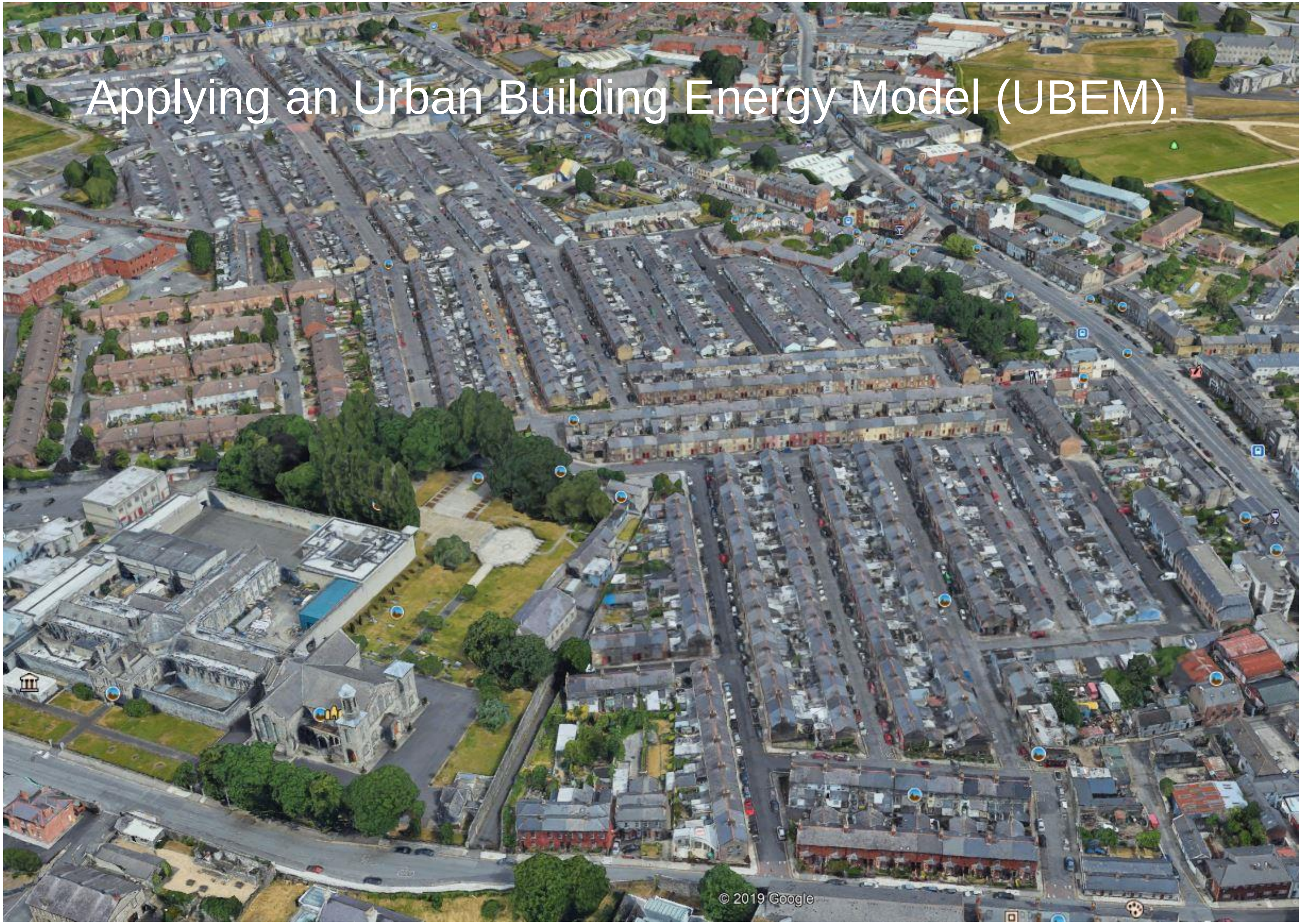
Building Energy Rating values are in KWh$m^{-2}y^{-1}$, which represents the expected energy cost of heating a residential space to a comfortable level for typical occupancy levels.



BER data at the Small Area level for Dublin City. The inset map shows details for the neighbourhood of Stoneybatter, which is used here to test the UBEM model.

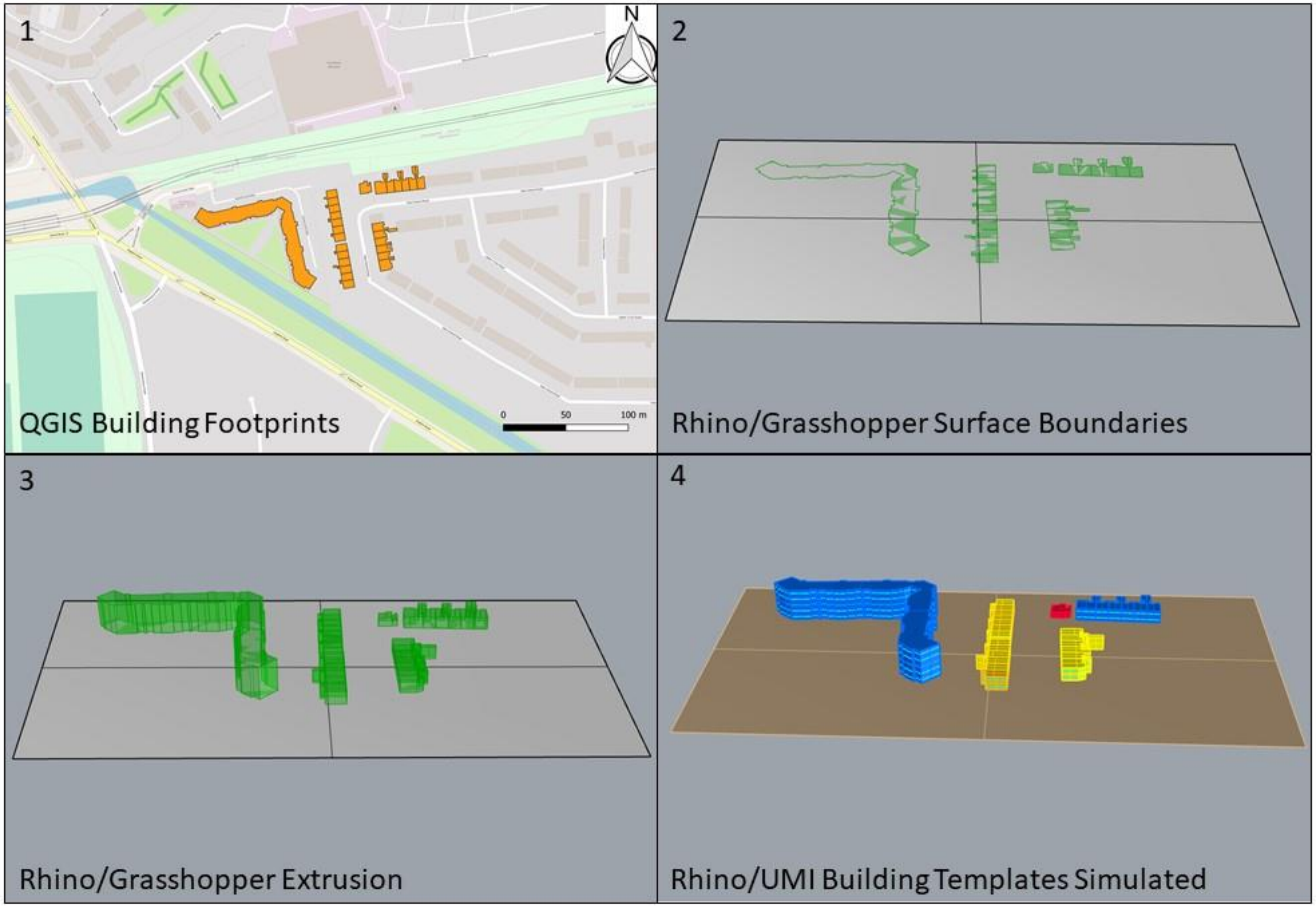


The estimated average energy cost per dwelling based on typical occupancy and heating to a comfortable level.



Stoneybatter (compact low-rise) neighbourhood constructed between 1900-1930

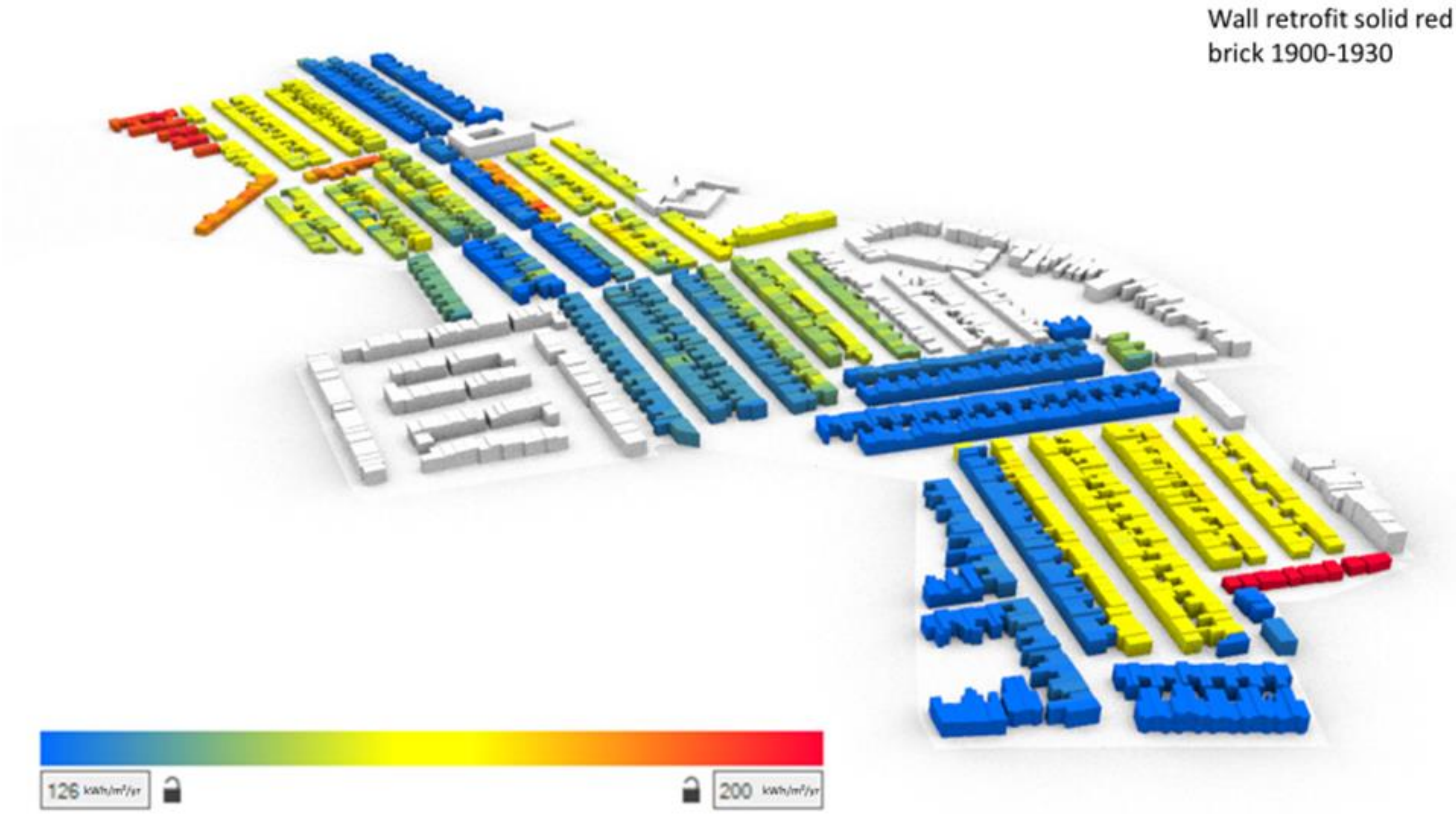
A typical row of houses in the case-study area (left) and a graphic decomposition of its fabric components in Design Build.



1
N
0
50
100 m
QGIS Building Footprints
2
Rhino/Grasshopper Surface Boundaries
3
Rhino/Grasshopper Extrusion
4
Rhino/UMI Building Templates Simulated

SEAI BER data - Current			UMI simulated original		
kWh/m²/ yr	BER	kgCO2m²/ yr	**kWh/m²/ yr**	BER	kgCO/m²/ yr
377	E2	104.2	**372**	E2	102.8
480	G	132.6	**410**	F	113.3
369	E2	102.0	**396**	F	109.4
382	F	105.6	**398**	F	110.0
350	E2	96.7	**388**	F	107.2
366	E2	101.1	**383**	F	105.8
384	F	106.1	**409**	F	113.0
425	F	117.4	**399**	F	110.2
377	E2	104.2	**383**	F	105.8
390	F	108	**393**	F	109

Comparison of the BER data for the Small Areas that comprise Stoneybatter with aggregated building scale information from UMI simulations.



A depiction of the Stoneybatter neighbourhood and the energy rating following wall retrofit in the UMI simulation program. Buildings in white are not part of the simulations .

Conclusions

A typology approach is a viable approach to gathering building level data on form and function.

Knowledge of form and function attributes is needed for both urban climate/meteorology (outdoor) and building energy (indoor) applications.

These data may be sufficient to run urban building energy models that can address neighbourhood scale energy demand, anthropogenic heating, CO_2 emissions, etc.

The picture to building tool developed at Purdue could help create an international typology suited for WUDAPT purposes.