Urban Building Energy Models

UBEMs developed from BEMs and can simulate the energy exchanges of multiple buildings simultaneously. The data needed to run these models includes the form (morphology, materials) and functions of each building and their layout (geography).

In effect, they can simulate neighbourhoods and provide links between the climate (including urban effects) and energy demand. As such they can be integrated into larger scale models.

Much of the data they need overlaps with that needed by other models but the software used by UBEMs is distinct.

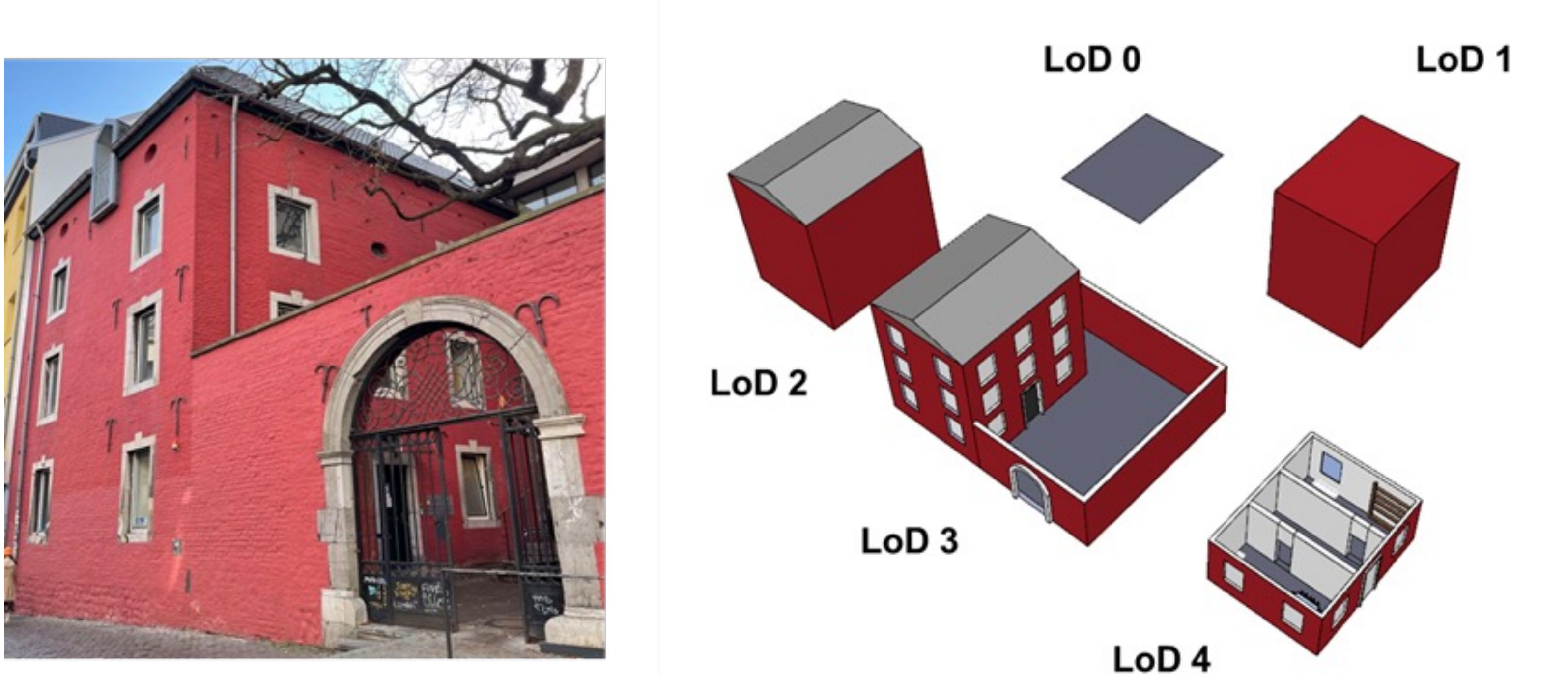
How best to integrate architectural/building models into climate models?

https://www.youtube.com/watch?v=O46GkHSYvYE

UBEMs	Input meteorological data file	Building geometry dataset (LoD)	Scales	Thermal modeling
CityBES	EPW	CityGML (LoD1-3)	district, city	EnergyPlus
CEA	EPW/TMY	GIS-based (LoD1-3)	neighbourhood, district, city	Reduced-order RC Model
CitySim	TMY	GIS-based (LoD1-2)	neighbourhood, district, city	Reduced-order RC Model (CitySim solver)
UMI	EPW/UWG	GIS-based (LoD1-3)	neighbourhood	EnergyPlus
TEASER	EPW	CityGML (LoD1-2)	building, neighbourhood, district, city	Reduced-order RC Model

Weather file sources, building geometry datasets, scales and thermal modeling for common UBEM tools

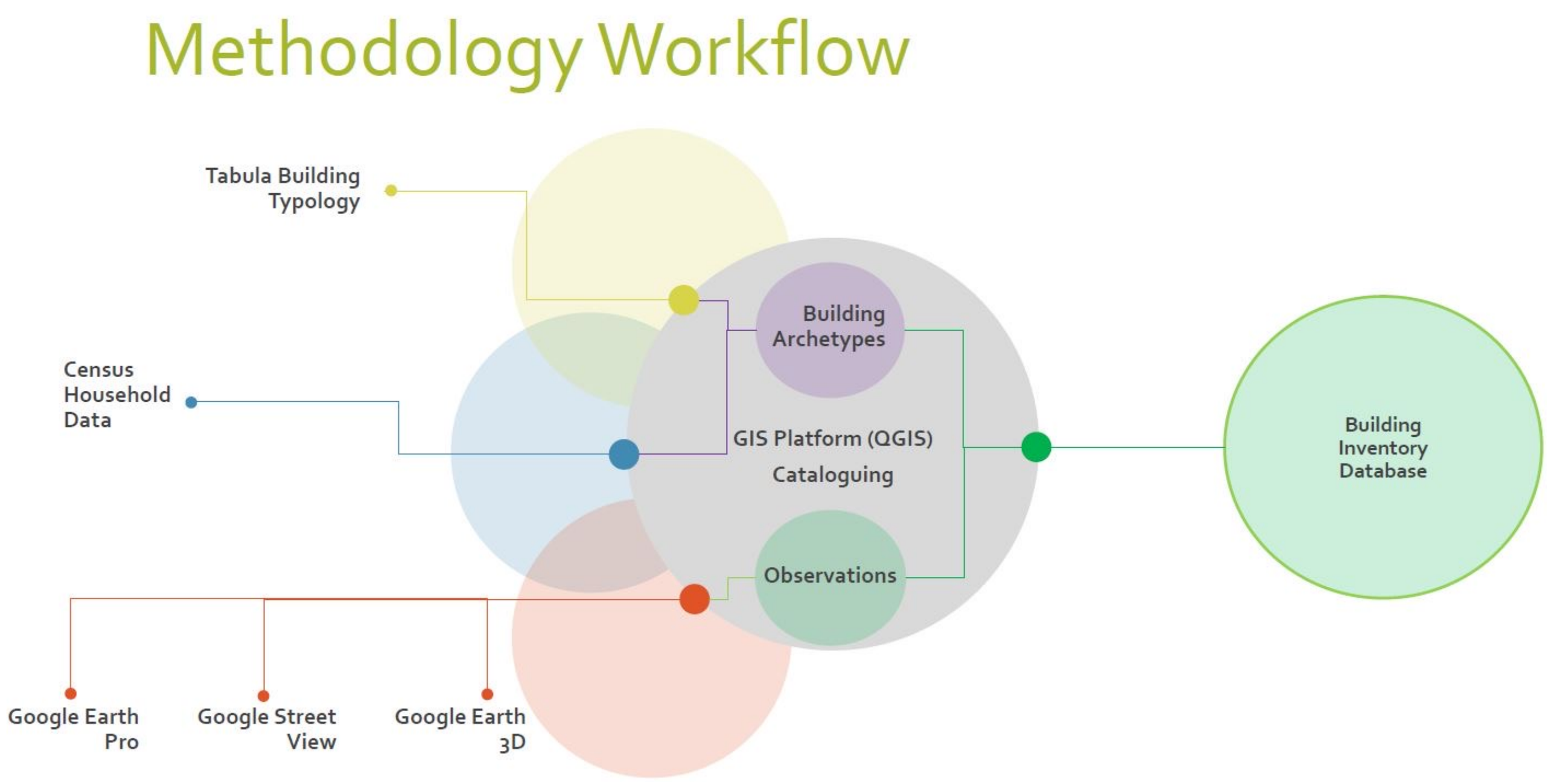
Qinhua Yu



Five Levels-of-Detail (LoD) provided by CityGML in building modelling: Take one of RWTH institute buildings as an example. Own representation after Löwner et al. (2013)

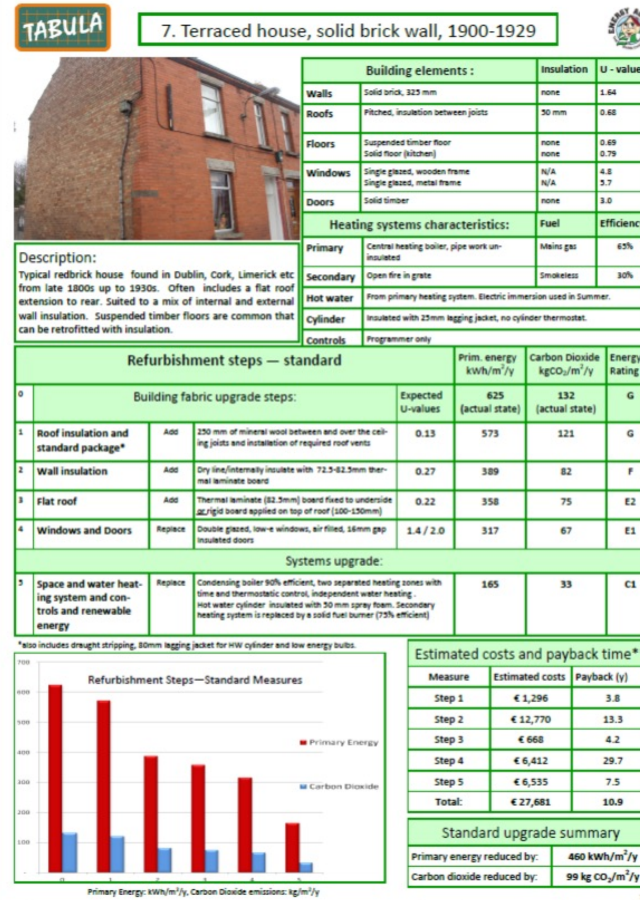
Qinhua Yu

Approach 1: Map building typologies to create neighbourhood databases



Niall Buckley

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 $kWh/m^2/y$	Carbon Dioxide $kgCO_2/m^2/y$	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.

Refurbishment Steps—Standard Measures

700
600
500
400
300
200
100
Primary Energy
Carbon Dioxide

Primary Energy: $kWh/m^2/y$, Carbon Dioxide emissions: $kg/m^2/y$

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

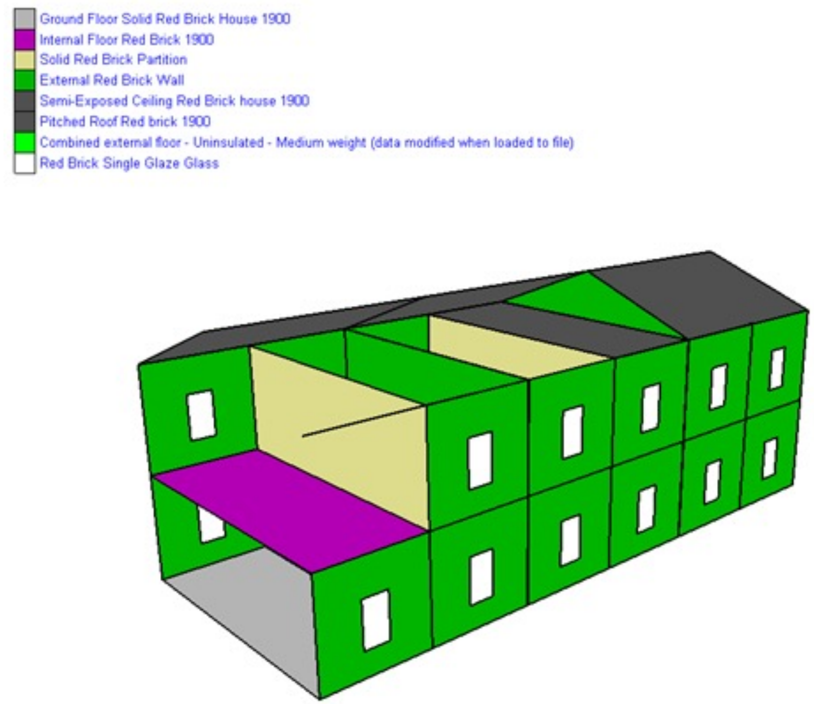
Primary energy reduced by:	460 $kWh/m^2/y$
Carbon dioxide reduced by:	99 kg $CO_2/m^2/y$

30

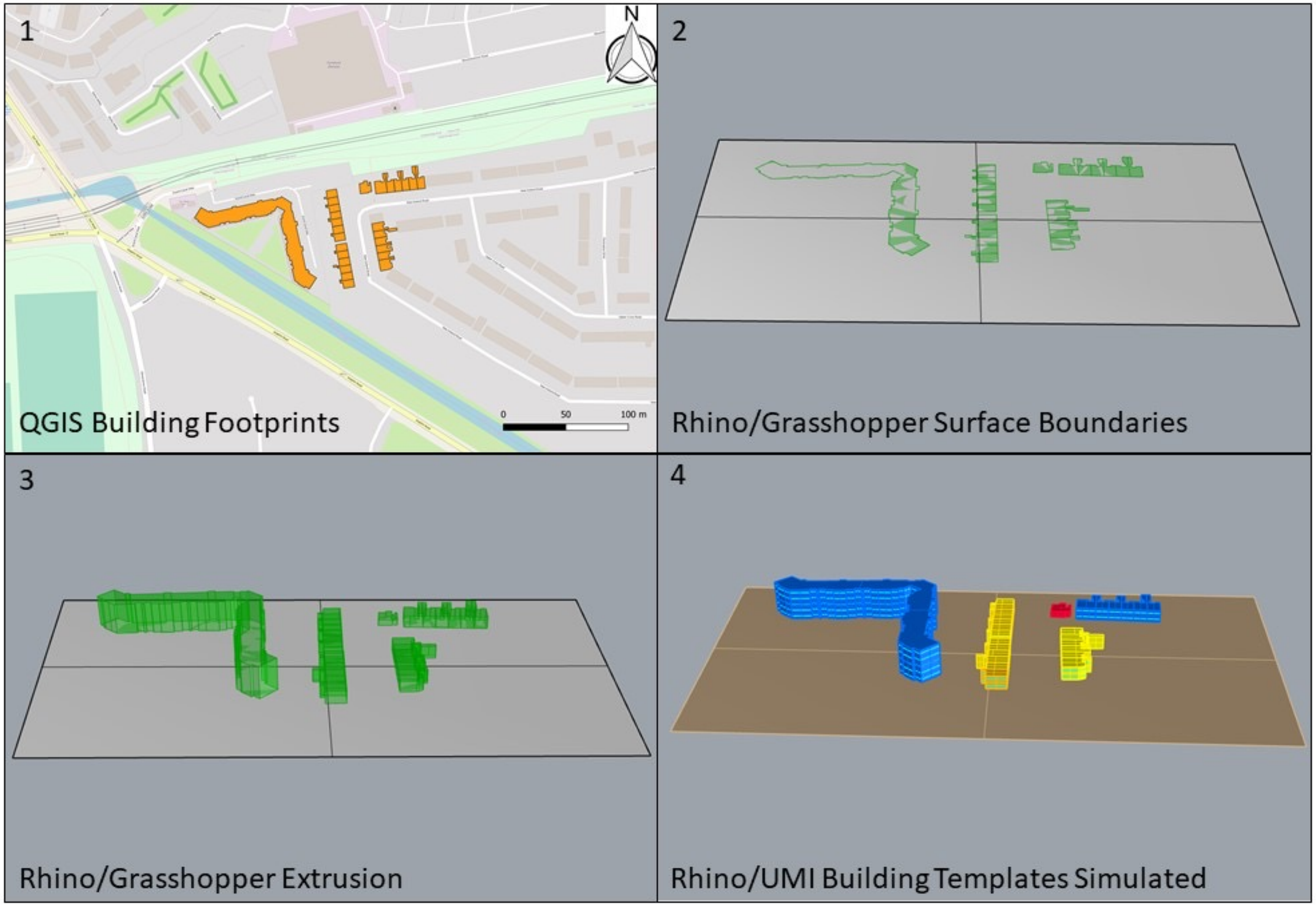
The urban landscape could be sampled strategically (based on geometry, LCZ types, age of construction, etc.) to acquire details on the building stock. The challenge here is to devise a suitable typology that could be used across cities and cultures.

Representative photographs of the nine common Tabula types.

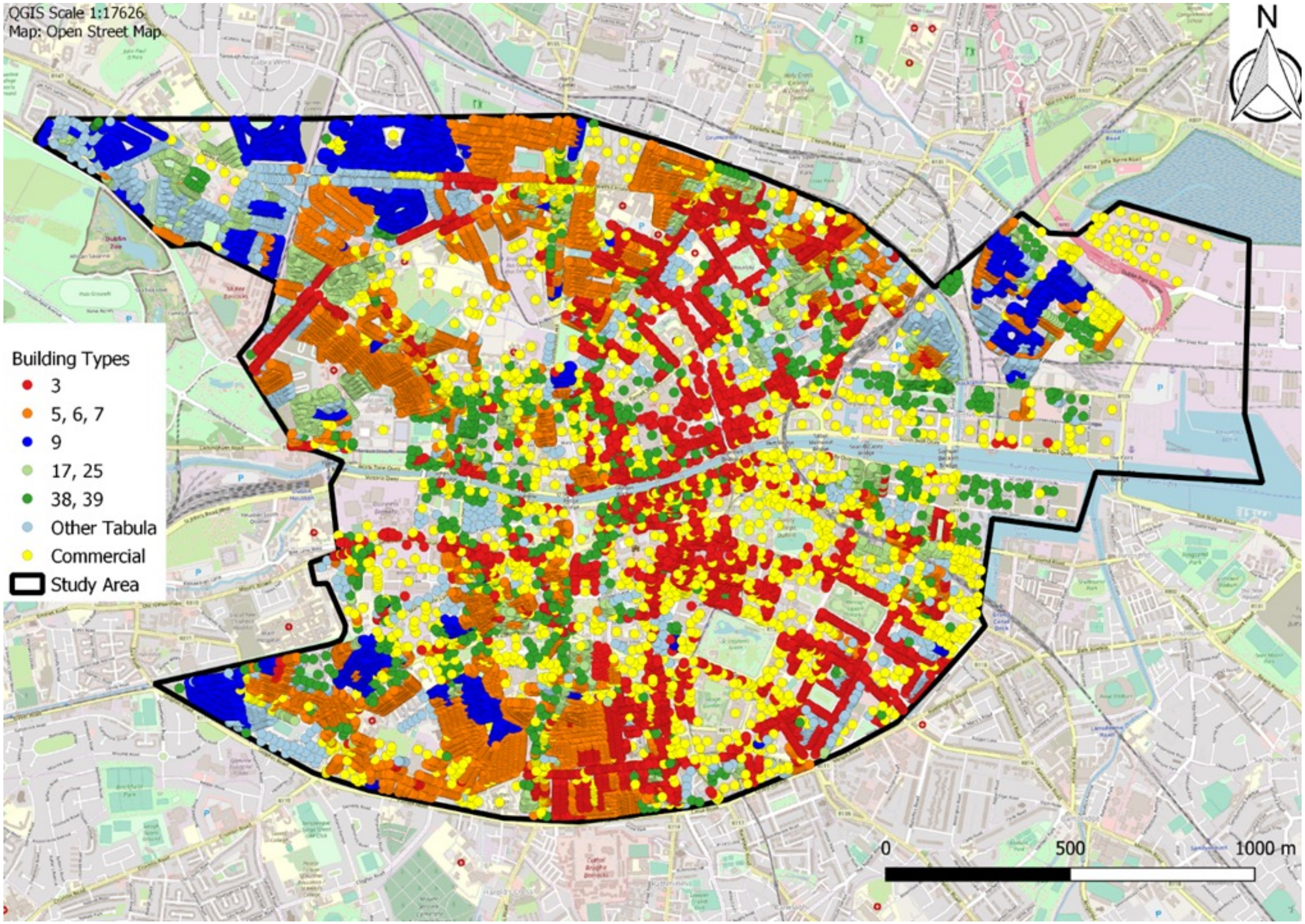
Type	Construction period	Wall	Roof	Windows	Energy Rating
(3) Terraced house	Pre- 1900	Uninsulated brick 325/225 mm thick.	Front pitched with 100mm of mineral wool in ceiling joists/ Rear pitched roof no insulation.	Single glazed, wooden frames.	352 (O) 95 (R)
N=5435		U = 1.64/1.41	U = 0.4/2.3	Glazed 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	



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



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

Approach 2: Create neighbourhood typologies based on LCZ types

Hashemi, Farzad

A parametric approach for investigating canopy heat island effects on building energy performance: a case study of seven U.S. cities

1: Albuquerque, NM in Mixed-Dry region

2: Denver, CO in Cold region

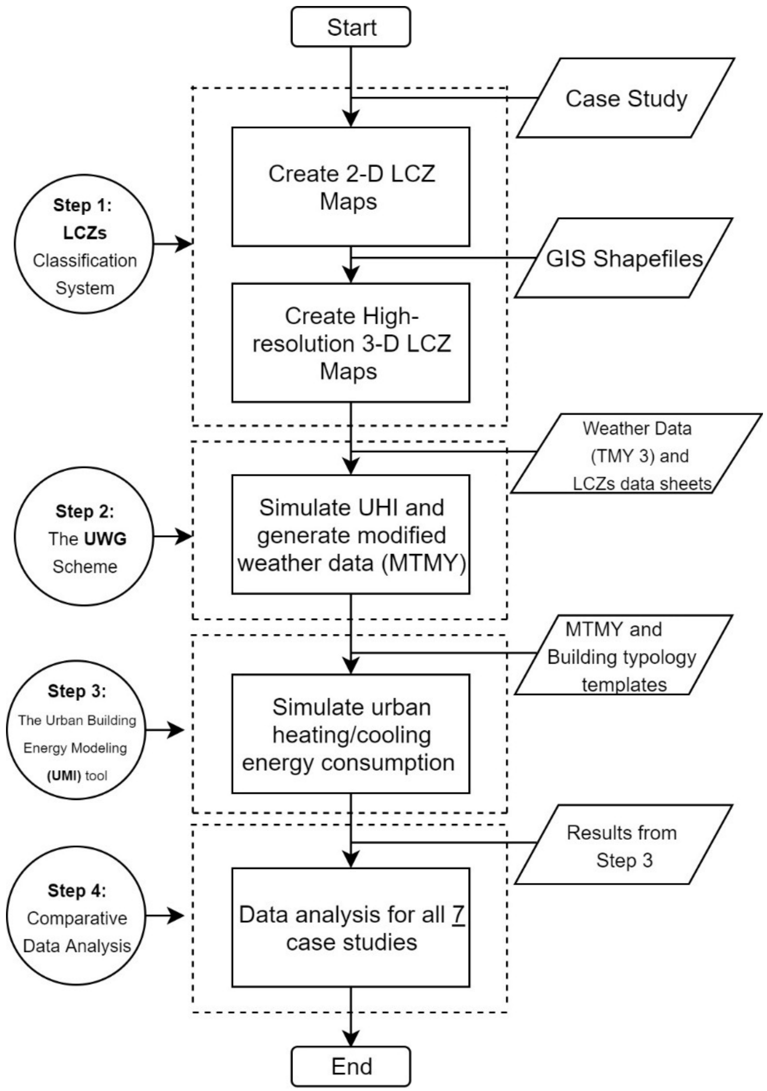
3: Duluth, MN in Very Cold region

4: Philadelphia, PA in Mixed-Humid region

5: Phoenix, AZ in Hot-Dry region

6: Portland, OR in Marine region

7: San Antonio, TX in Hot-Humid region



The proposed study workflow

Building Energy Modeling (BEM)

NREL

U.S. Department of Energy Commercial Reference Building Models of the National Building Stock

Michael Deru, Kristin Field, Daniel Studer, Kyle Benne, Brent Griffith, and Paul Torcellini
National Renewable Energy Laboratory

Bing Liu, Mark Halverson, Dave Winiarski, and Michael Rosenberg
Pacific Northwest National Laboratory

Mehry Yazdanian
Lawrence Berkeley National Laboratory

Joe Huang
Formerly of Lawrence Berkeley National Laboratory

Drury Crawley
Formerly of the U.S. Department of Energy

Table 25 Window Solar Heat Gain Coefficient by Reference Building Vintage

Location	90.1-2004 Climate Zone	90.1-1989 Table	Pre-1980	Post-1980	New Construction
Miami, FL	1A	8A-15	0.54	0.25	0.25
Houston, TX	2A	8A-10	0.54	0.25	0.25
Phoenix, AZ	2B	8A-18	0.54	0.25	0.25
Atlanta, GA	3A	8A-8	0.54	0.25	0.25
Los Angeles, CA	3B-CA	8A-6	0.54	0.44	0.25
Las Vegas, NV	3B-other	8A-14	0.54	0.25	0.25
San Francisco, CA	3C	8A-5	0.54	0.39	0.34
Baltimore, MD	4A	8A-25	0.54	0.36	0.39
Albuquerque, NM	4B	8A-23	0.54	0.36	0.39
Seattle, WA	4C	8A-19	0.54	0.39	0.39
Chicago, IL	5A	8A-26	0.41	0.39	0.39
Denver, CO	5B	8A-28	0.41	0.39	0.39
Minneapolis, MN	6A	8A-33	0.41	0.39	0.39
Helena, MT	6B	8A-32	0.41	0.39	0.39
Duluth, MN	7	8A-36	0.41	0.49	0.49
Fairbanks, AK	8	8A-38	0.41	NR	NR

Table 24 Window Overall U-Value (Btu/h·ft^2·°F) by Reference Building Vintage

Location	90.1-2004 Climate Zone	90.1-1989 Table	Pre-1980	Post-1980	New Construction
Miami, FL	1A	8A-15	1.22	1.22	1.22
Houston, TX	2A	8A-10	1.22	1.22	1.22
Phoenix, AZ	2B	8A-18	1.22	1.22	1.22
Atlanta, GA	3A	8A-8	1.22	0.72	0.57
Los Angeles, CA	3B-CA	8A-6	1.22	1.22	0.57
Las Vegas, NV	3B-other	8A-14	1.22	1.22	0.57
San Francisco, CA	3C	8A-5	1.22	0.72	1.22
Baltimore, MD	4A	8A-25	1.22	0.59	0.57
Albuquerque, NM	4B	8A-23	1.22	0.72	0.57
Seattle, WA	4C	8A-19	1.22	0.72	0.57
Chicago, IL	5A	8A-26	0.62	0.59	0.57
Denver, CO	5B	8A-28	0.62	0.59	0.57
Minneapolis, MN	6A	8A-33	0.62	0.52	0.57
Helena, MT	6B	8A-32	0.62	0.52	0.57
Duluth, MN	7	8A-36	0.62	0.52	0.57
Fairbanks, AK	8	8A-38	0.62	0.52	0.35

Table 21 Mass Wall U-Values (Btu/h·ft^2·°F) by Reference Building Vintage

Location	90.1-2004 Climate Zone	90.1-1989 Table	Pre-1980		Post-1980		New Construction	
			Btu/ h·ft^2·°F	W/m^2·K	Btu/ h·ft^2·°F	W/m^2·K	Btu/ h·ft^2·°F	W/m^2·K
Miami, FL	1A	8A-15	0.230	1.306	1.000	5.678	0.580	3.293
Houston, TX	2A	8A-10	0.230	1.306	0.340	1.931	0.580	3.293
Phoenix, AZ	2B	8A-18	0.230	1.306	0.410	2.328	0.580	3.293
Atlanta, GA	3A	8A-8	0.225	1.278	0.290	1.647	0.151	0.857
Los Angeles, CA	3B-CA	8A-6	0.230	1.306	1.000	5.678	0.151	0.857
Las Vegas, NV	3B-other	8A-14	0.230	1.306	0.290	1.647	0.580	3.293
San Francisco, CA	3C	8A-5	0.224	1.272	0.490	2.782	0.580	3.293
Baltimore, MD	4A	8A-25	0.178	1.011	0.120	0.681	0.580	3.293
Albuquerque, NM	4B	8A-23	0.184	1.045	0.190	1.079	0.151	0.857
Seattle, WA	4C	8A-19	0.175	0.994	0.100	0.568	0.151	0.857
Chicago, IL	5A	8A-26	0.156	0.886	0.100	0.568	0.151	0.857
Denver, CO	5B	8A-28	0.161	0.914	0.140	0.795	0.151	0.857
Minneapolis, MN	6A	8A-33	0.145	0.823	0.071	0.403	0.123	0.698
Helena, MT	6B	8A-32	0.145	0.823	0.079	0.449	0.123	0.698
Duluth, MN	7	8A-36	0.136	0.772	0.061	0.346	0.123	0.698
Fairbanks, AK	8	8A-38	0.125	0.710	0.047	0.267	0.104	0.591

Table 18 Recommended Wall Constructions by Building Type

Building Type	Pre-1980	Post-1980	New Construction
Small Office	Steel frame	Mass	Mass
Medium Office	Steel frame	Steel frame	Steel frame
Large Office	Mass	Mass	Mass
Primary School	Steel frame	Steel frame	Steel frame
Secondary School	Steel frame	Steel frame	Steel frame
Stand-Alone Retail	Steel frame	Mass	Mass
Strip Mall	Steel frame	Steel frame	Steel frame
Supermarket	Mass	Mass	Mass
Quick Service Restaurant	Mass	Wood frame	Wood frame
Full Service Restaurant	Steel frame	Steel frame	Steel frame
Small Hotel	Steel frame	Steel frame	Steel frame
Large Hotel	Mass	Mass	Mass
Hospital	Mass	Mass	Mass
Outpatient Healthcare	Steel frame	Steel frame	Steel frame
Warehouse	Metal building	Metal building	Metal building
Midrise Apartment	Steel frame	Steel frame	Steel frame

Overview

The first approach requires the identification of the location of buildings and allocating these to types – the building templates profiles for each type is generated.

- Creating international typology a challenge.
- LCZs in this methodology could be used to sample the urban landscape but it would need to be supported by detailed urban GIS data.
- Census information on age of buildings could speed up the process, which is laborious.

The second approach provides a direct link to the LCZ scheme and could be used to generate a variety of neighbourhood typologies that match with the LCZ types.

- Creating international building typologies.
- Developing neighbourhood typologies to math LCZ parameters.
- Drive simulation using local scale weather data.