‘The application of boundary layer climatology and urban wind power potential in smarter electricity networks’

Dr. Keith Sunderland[1], Dr. Gerald Mills[2], Prof. Michael Conlon[1]

[1] School of Electrical & Electronic Engineering, Dublin Institute of Technology, Ireland
[2] School of Geography, Planning and Environmental Policy, University College Dublin, Ireland

AMERICAN METEOROLOGICAL SOCIETY CONFERENCE

SCHOOL OF ELECTRICAL AND ELECTRONIC ENGINEERING

12th June, 2014

Overview

- Aims and Objectives
- Research Context/ Motivation
- Methodology
- Findings
- Future Work
- Conclusions

Overview

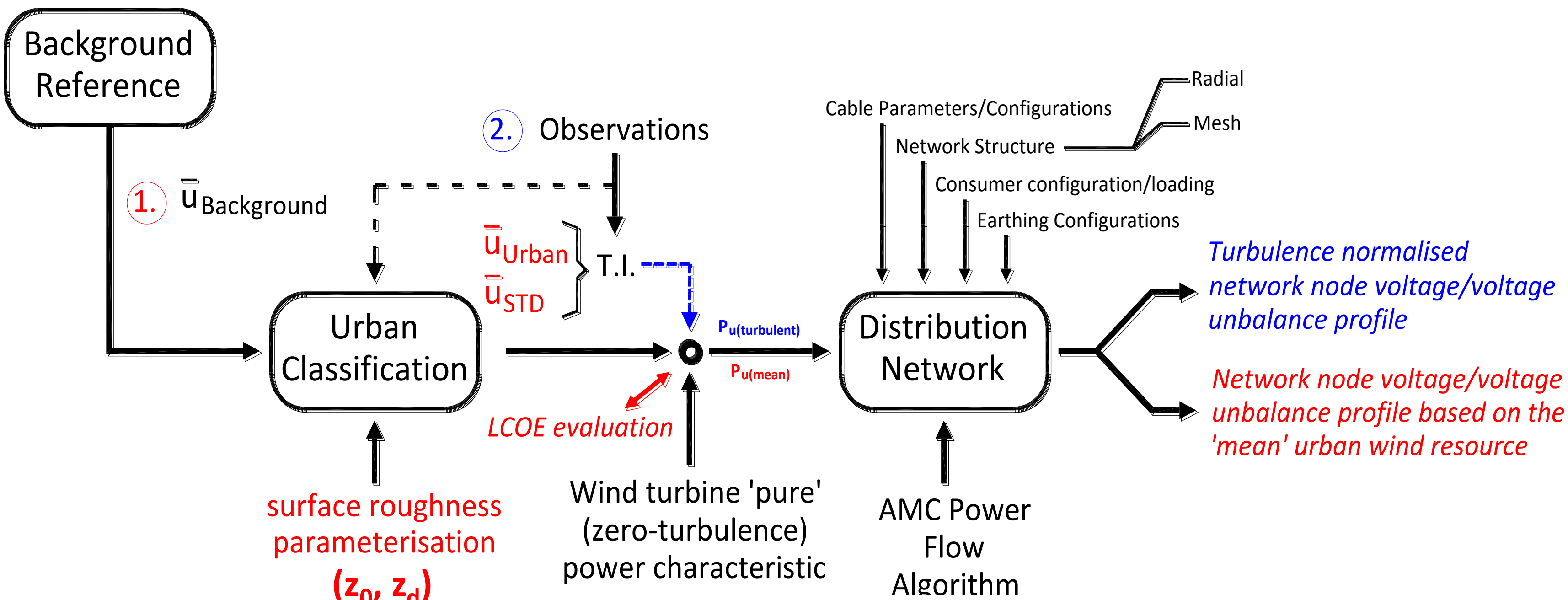
- **Aims and Objectives**
- Research Context/ Motivation
- Methodology
- Findings
- Future Work
- Conclusions

Aims & Objectives

SCHOOL OF ELECTRICAL AND ELECTRONIC ENGINEERING

- **Research Aim:**

  To develop novel modelling capability that is inclusive of the power engineering complexities associated with urban (electricity) network integration of small/micro wind generation, and informed by urban climate research

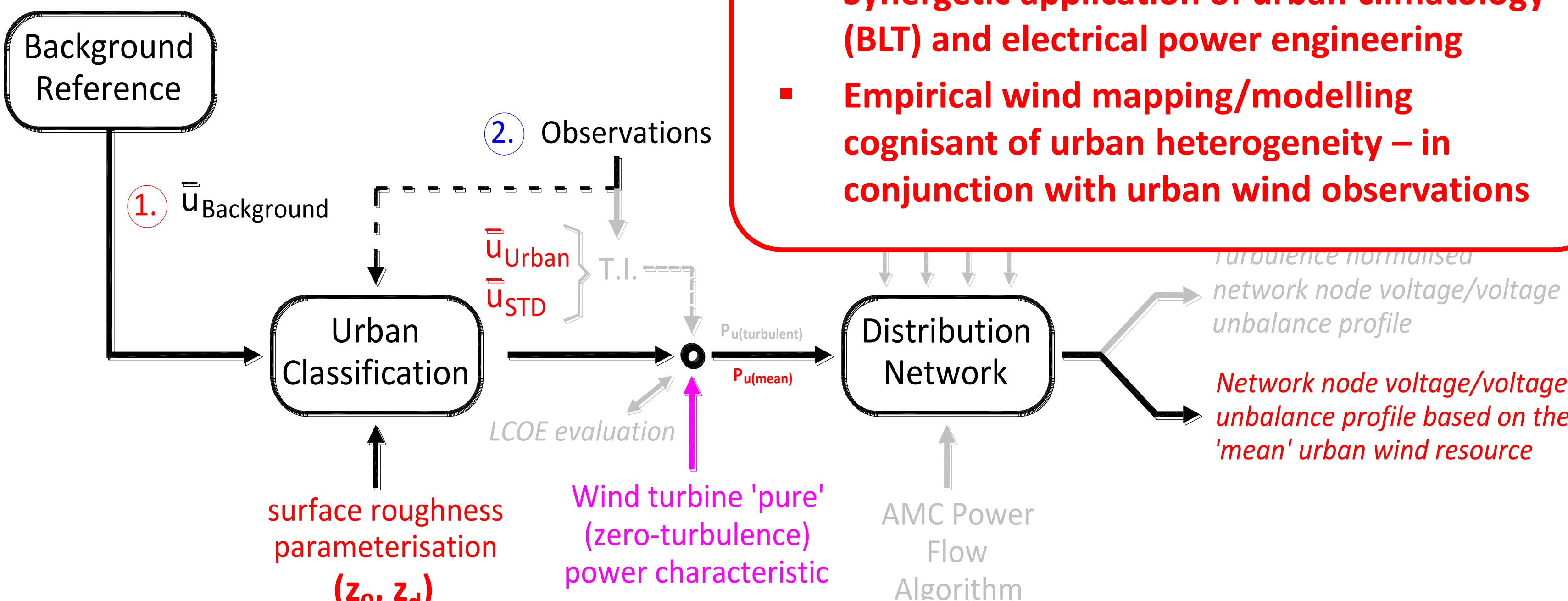


Aims & Objectives

- **Research Aim:**

  To develop novel modelling capability that is inclusive of the power engineering complexities associated with urban (electricity) network integration of small/micro wind generation, and informed by urban climate research

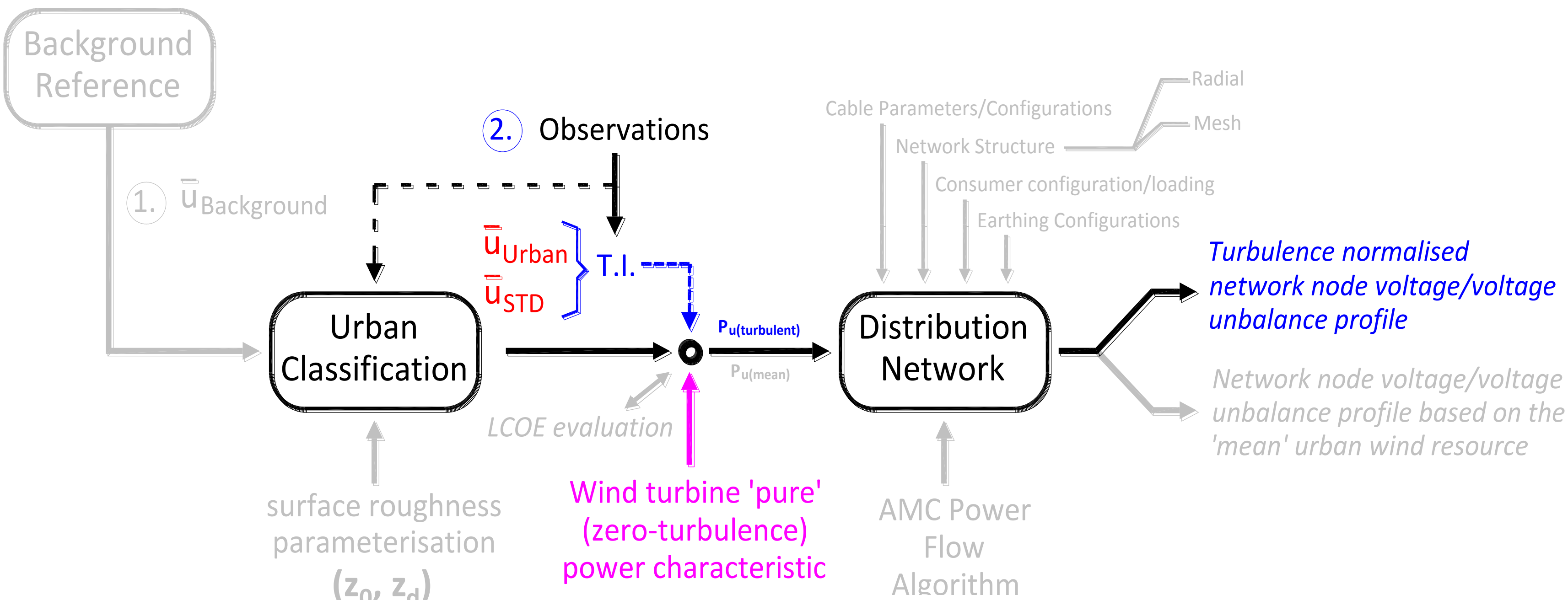
- **Synergetic application of urban climatology (BLT) and electrical power engineering**
- **Empirical wind mapping/modelling cognisant of urban heterogeneity – in conjunction with urban wind observations**



Aims & Objectives

- **Research Aim:**

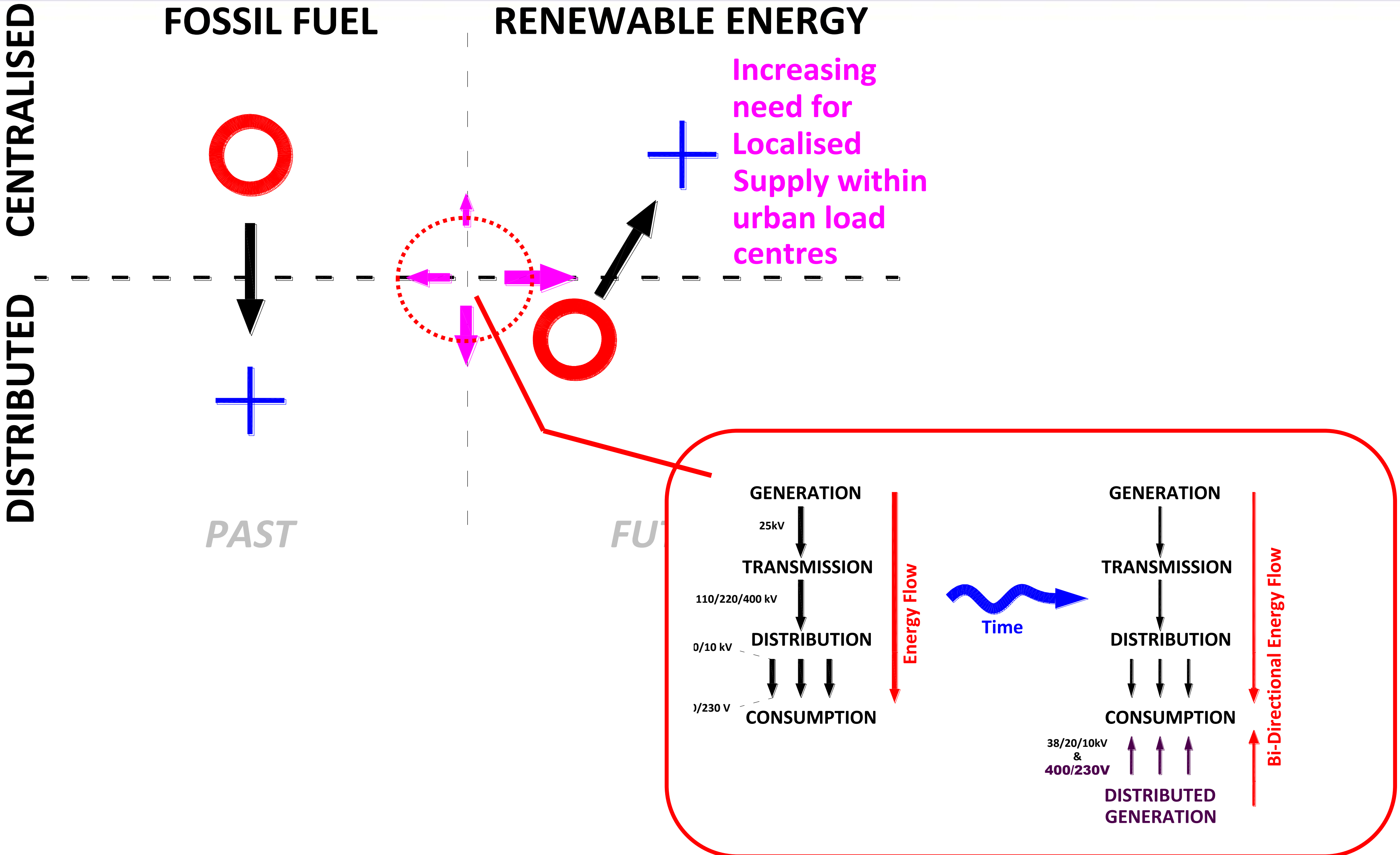
  To develop novel modelling capability that is inclusive of the power engineering complexities associated with urban (electricity) network integration of small/micro wind generation, and informed by urban climate research



Overview

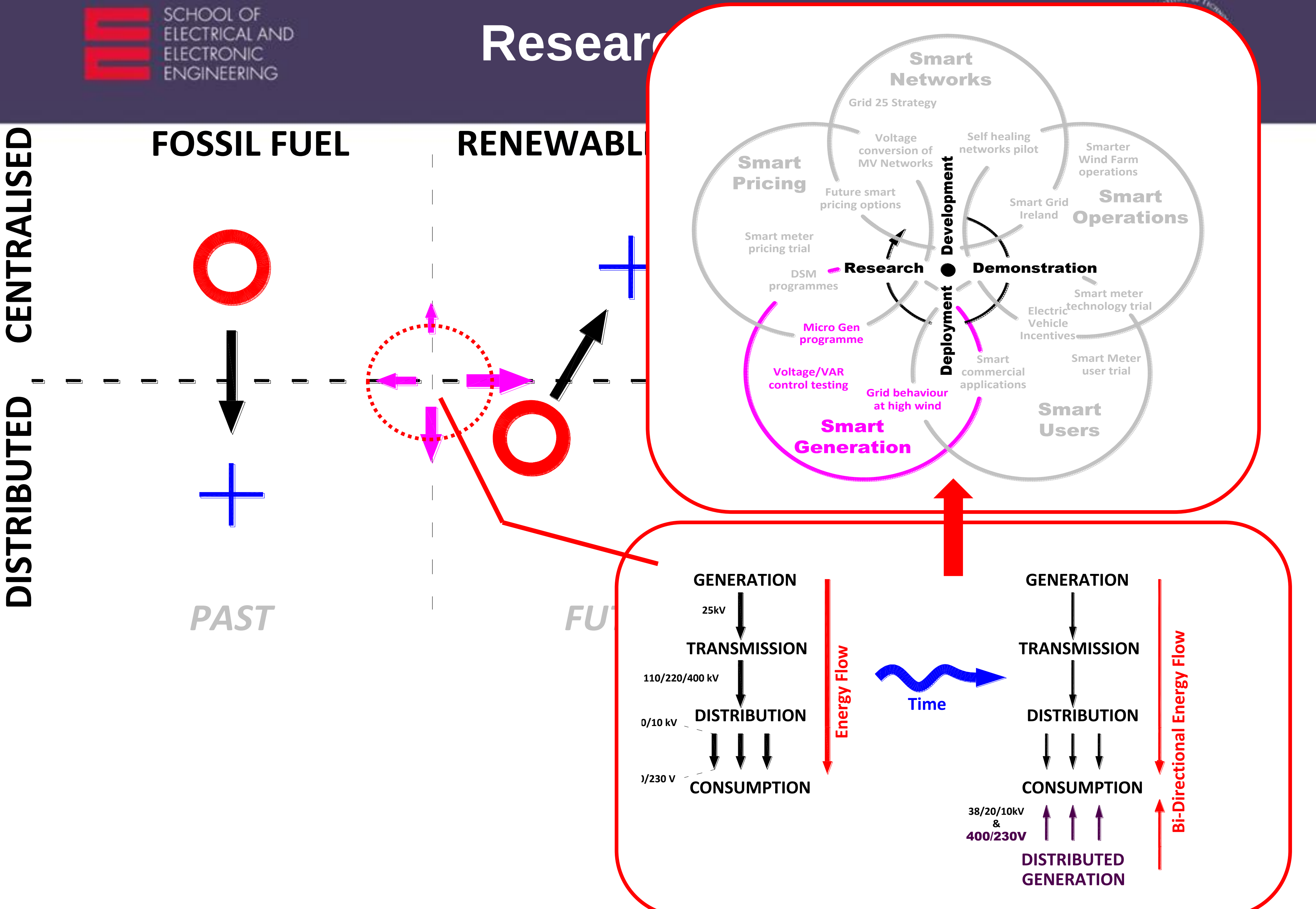
- Aims and Objectives
- **Research Context/ Motivation**
- Methodology
- Findings
- Future Work
- Conclusions

Research Context



SCHOOL OF ELECTRICAL AND ELECTRONIC ENGINEERING

Researc



Research Motivation

Micro/Small Wind *Electricity* Generation

Rural Locations

Uninhibited Air Flows

Statistically Predictable Airflows

Maximum Energy Optimisation

Urban Locations

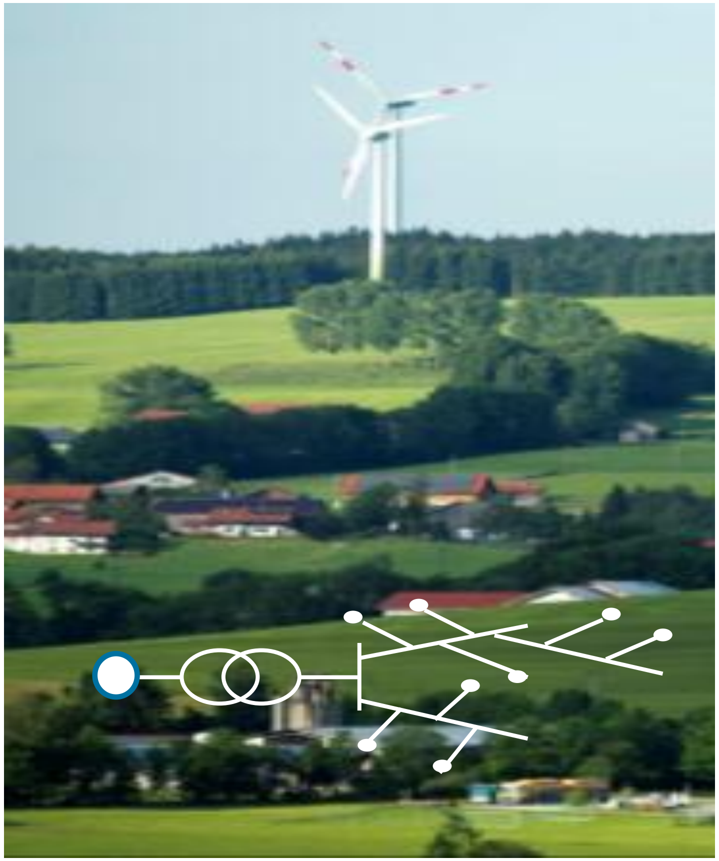
Heterogeneity, Complex Building Morphology

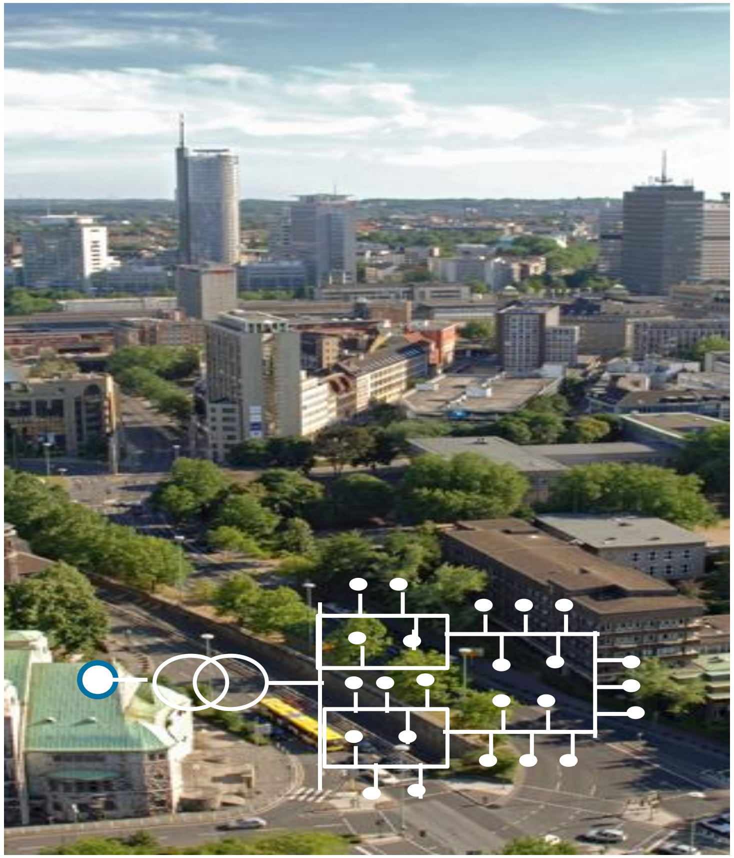
Chaotic, Turbulent Airflows

Energy Capture Capability?

Research Motivation

Micro/Small Wind *Electricity* Generation





Research Motivation

Micro/Small Wind *Electricity* Generation

Rural Locations

Urban Locations

Uninhi

Complex
ology

Stati

irflows

Maxim
Optimis

Capability?

WHY URBAN WIND?

Population Centres

Transmission/Distribution losses

Green solutions must include wind

Smarter energy diversification must be inclusive of wind within urban centres BUT solutions predicated on the resource and not specifically the technology are needed

Research Motivation

- **Smart Cities…. *Smart Grids***
  - An amalgamation of communication and electrical capabilities that allow utilities to understand, optimize, and regulate demand, supply, costs and reliability.

Facilitating electrical providers to interact with the power delivery system and determine whether electricity is being used and from where it can be drawn during the time of crisis and peak demand.

On the demand side – the smart grid empowers the consumer to become a 'prosumer'…

Research Motivation

- **Why is a Smart Grid needed?**
  - Future grid networks must be competitive and supportive of environmental objectives and sustainability
  - Reliability, flexibility, accessibility and cost-effectiveness are the primary objectives
  - Should accommodate both central and dispersed generation
  - Options for end-users to be more interactive with both market and grid; promoting the concept of a '*prosumer*'

Research Motivation

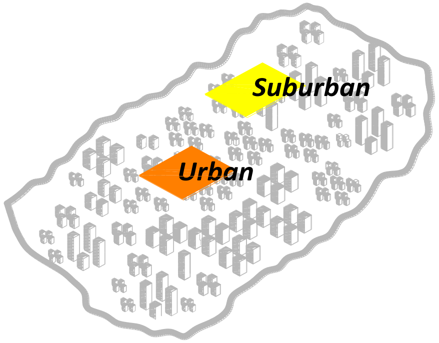
- **Why is a Smart Grid needed?**
  - Future grid networks must be competitive and supportive of environmental objectives and sustainability
  - Reliability, flexibility, accessibility and cost-effectiveness are the primary objectives
  - Should accommodate both central and dispersed generation
  - Options for end-users to be more interactive with both market and grid; promoting the concept of a '*prosumer*'

Therefore the means of applying the primary energy resource (Wind) in this regard <u>within</u> urban centres must be achieved

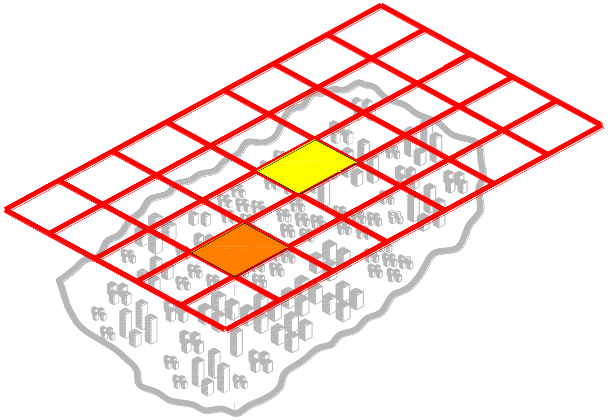
Overview

- Aims and Objectives
- Research Context/ Motivation
- **Methodology**
- Findings
- Future Work
- Conclusions

Urban Effects & Wind Modelling

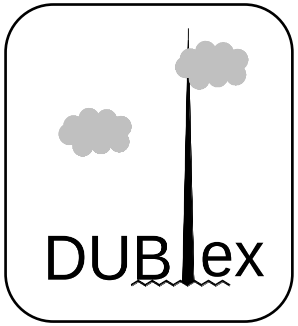


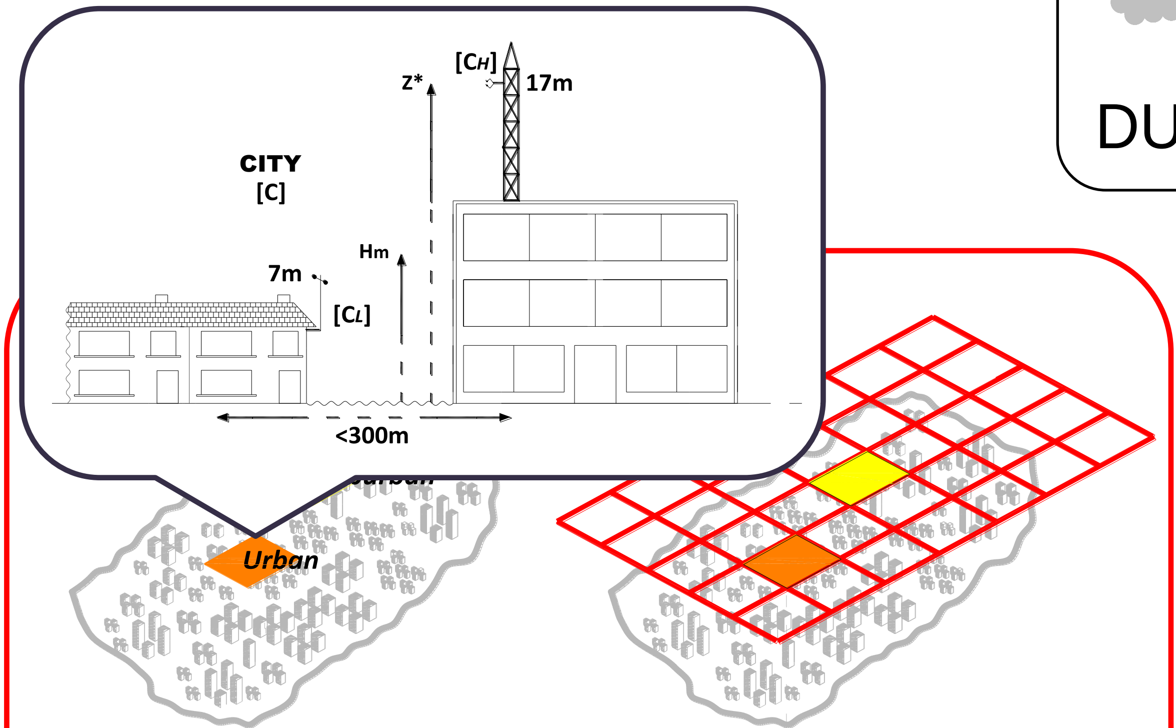
Urban Environmnet



Two zones categorised in terms of local heterogeneity: (Urban and Suburban)

Urban Effects & Wind Modelling



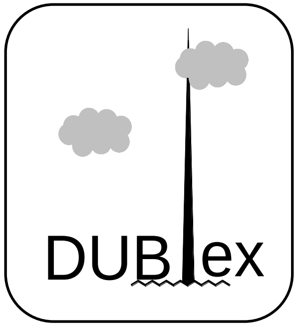


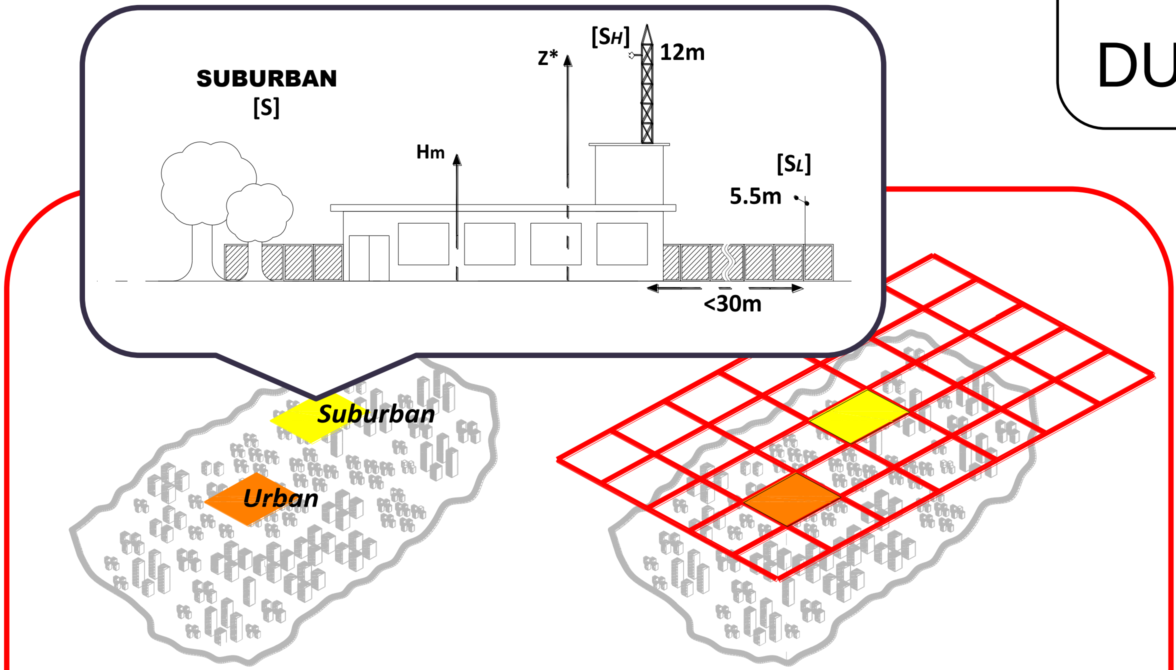
Urban Environmnet

Two zones categorised in terms of local heterogeneity: (Urban and Suburban)

Research Methodology

Urban Effects & Wind Modelling

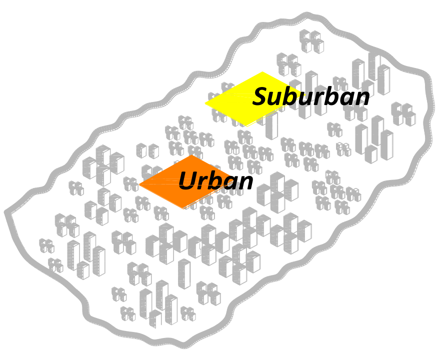




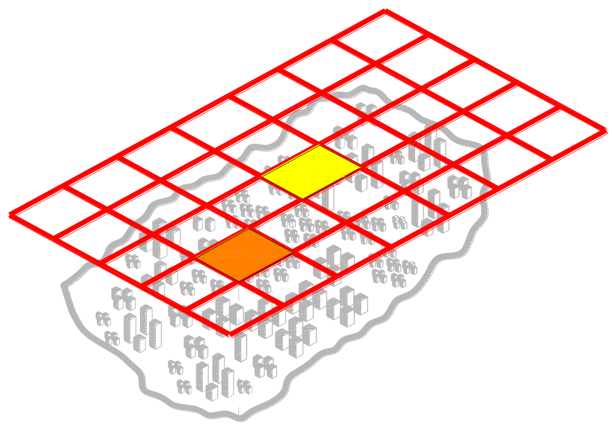
Urban Environmnet

Two zones categorised in terms of local heterogeneity: (Urban and Suburban)

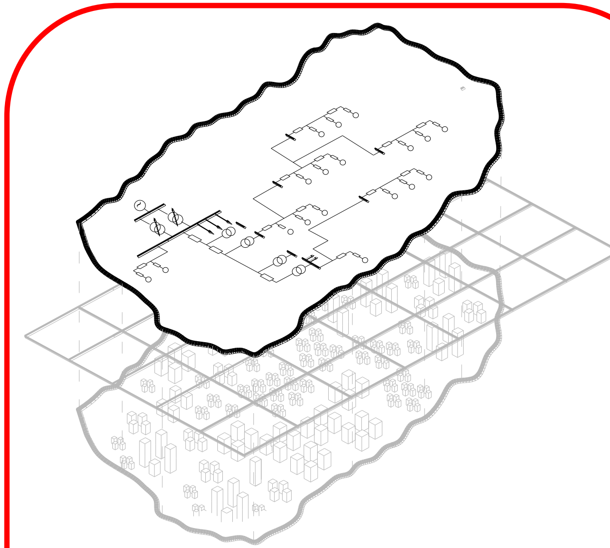
Urban Effects & Wind Modelling



Urban Environmnet

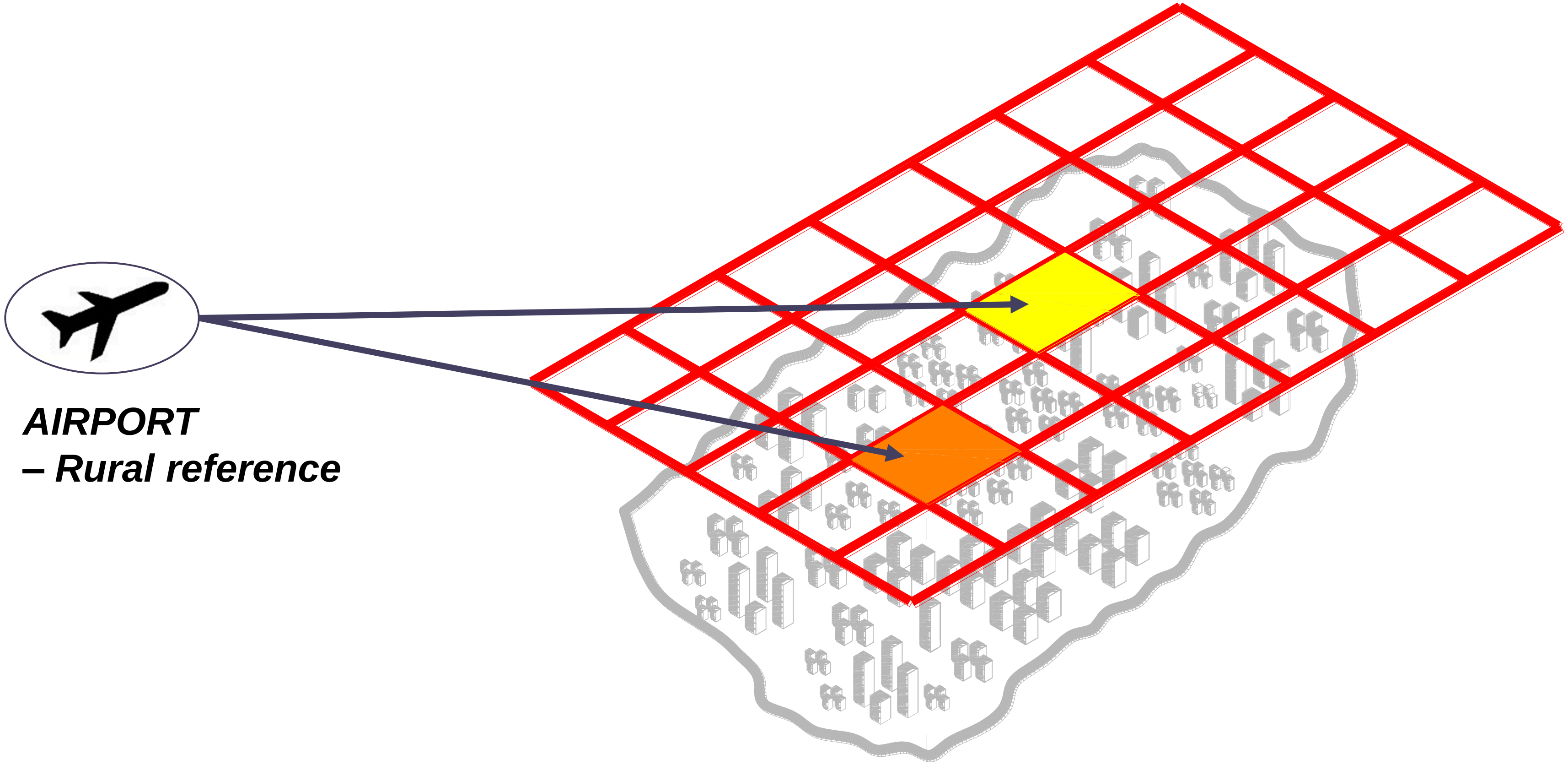


Two zones categorised in terms of local heterogeneity: (Urban and Suburban)



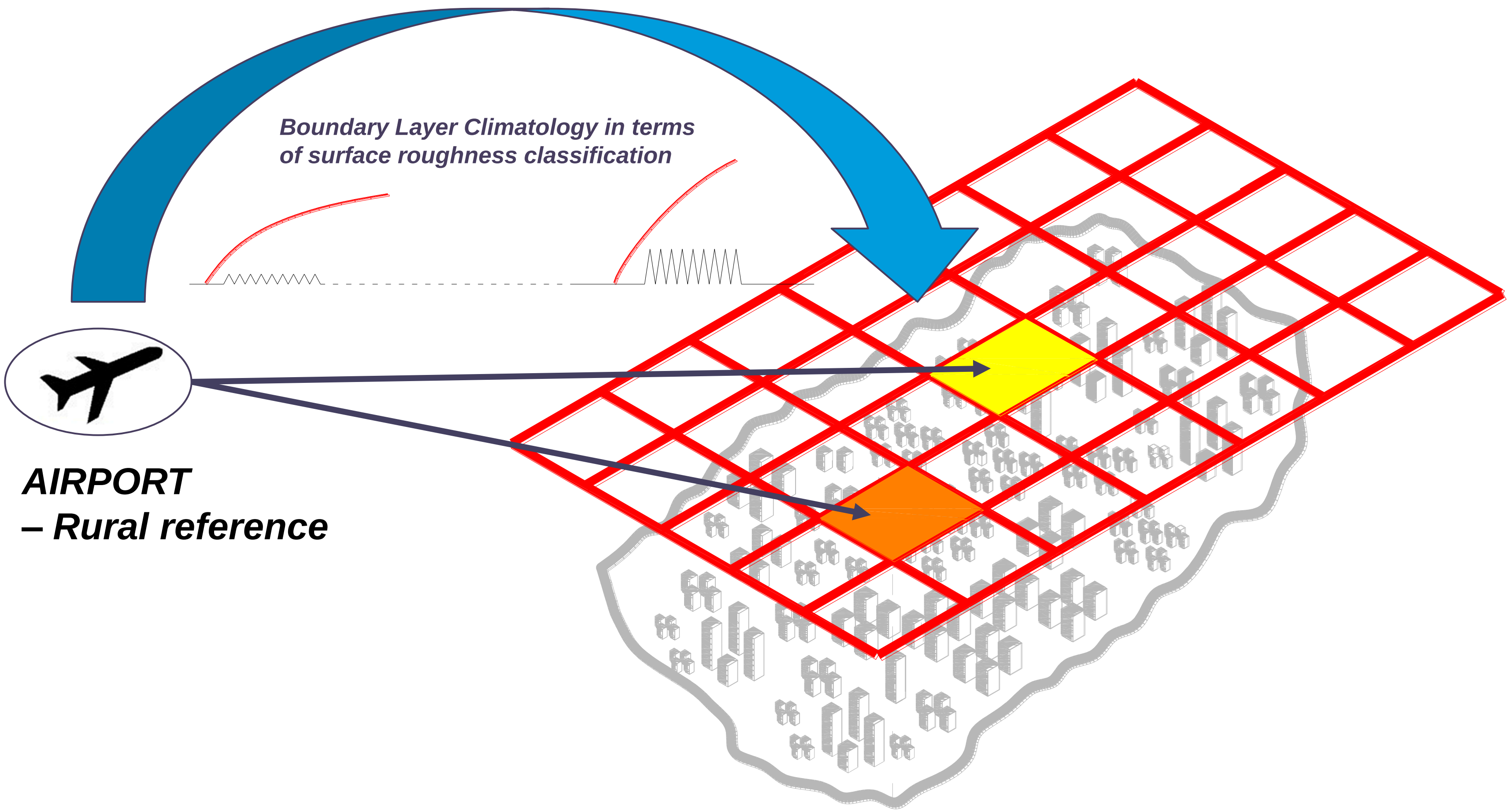
(Electrical) Distribution Network considered in terms of both local climate zones

Urban Effects & Wind Modelling

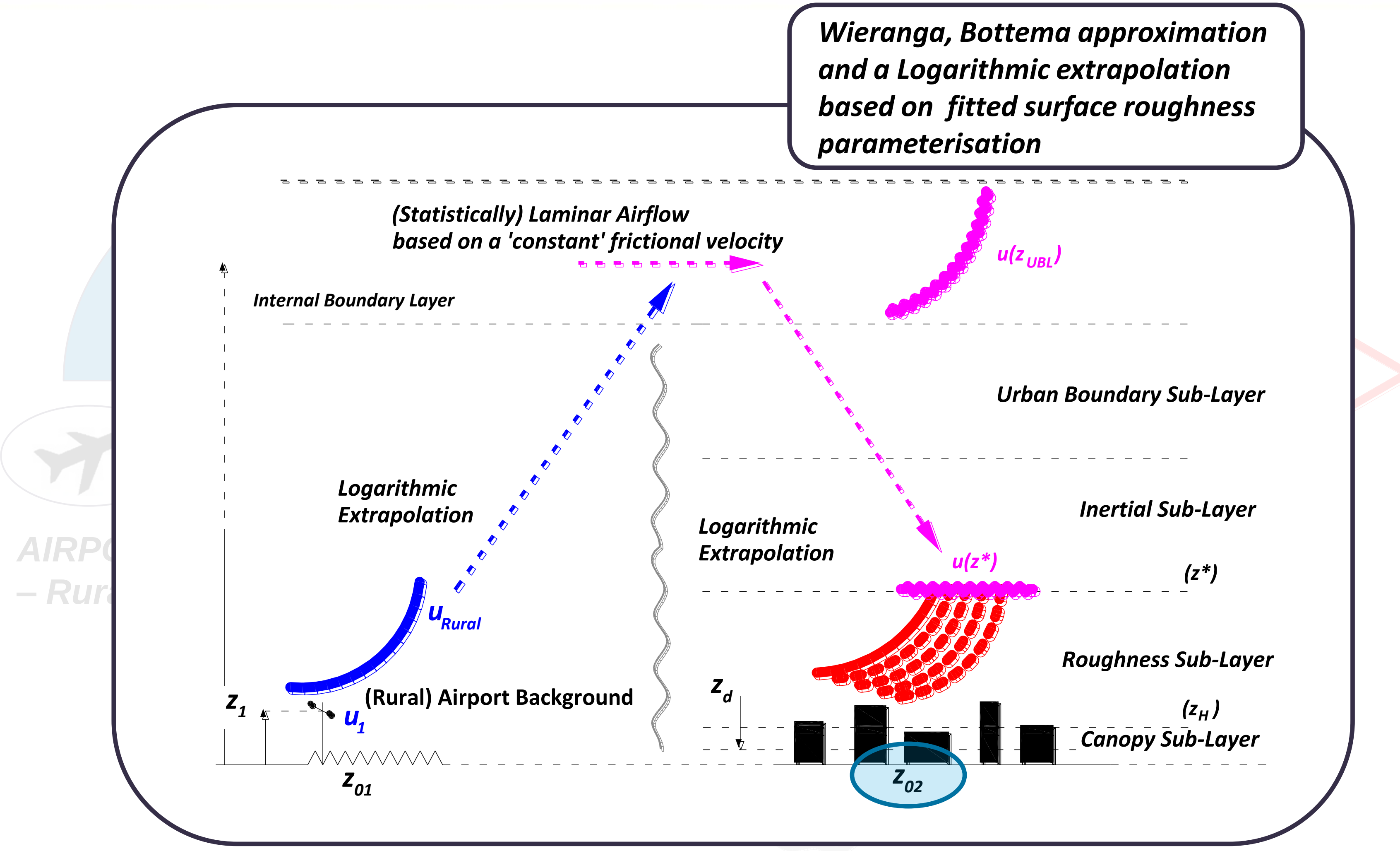


Research Methodology

Urban Effects & Wind Modelling

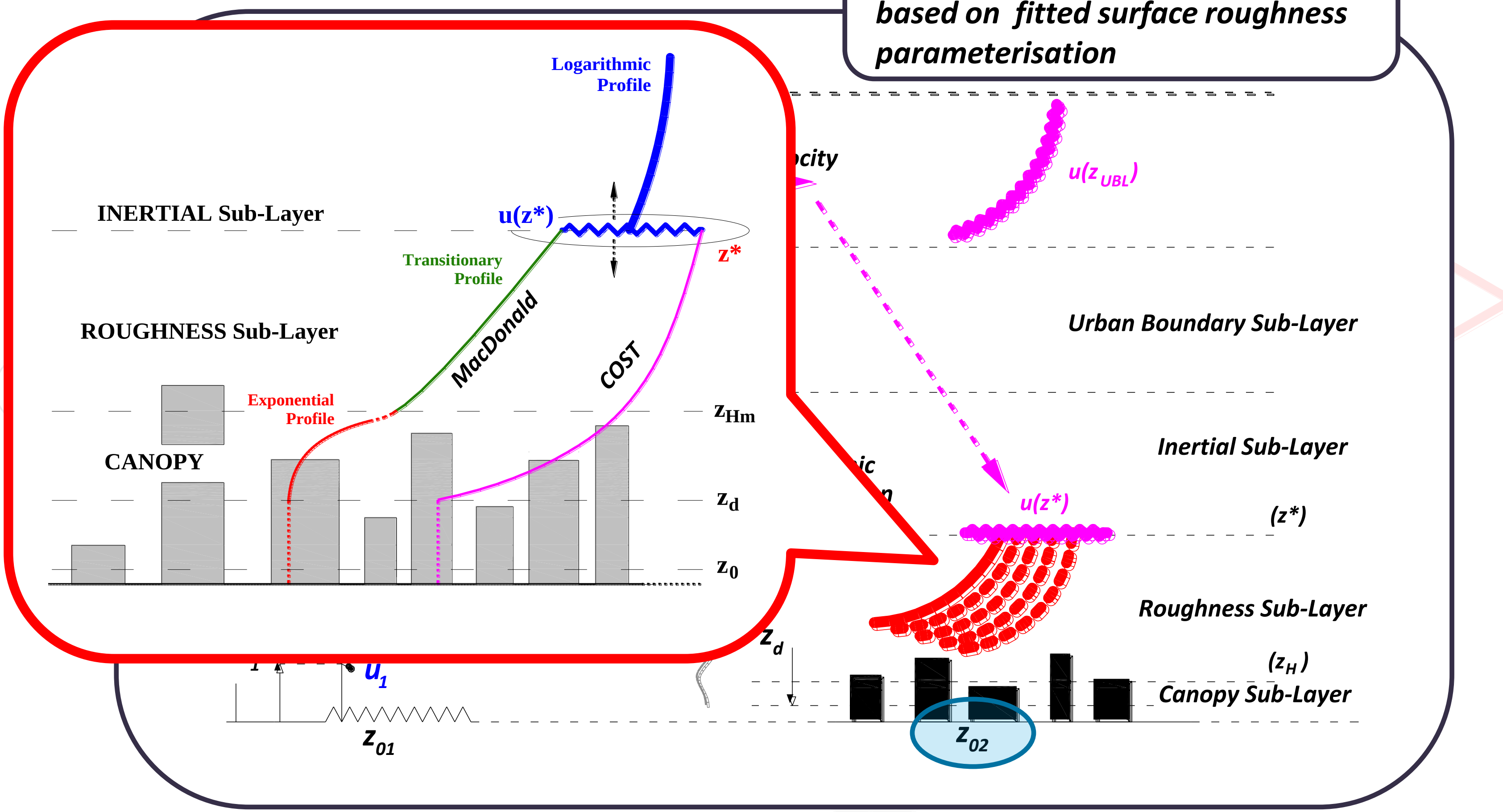


Urban Effects & Wind Modelling

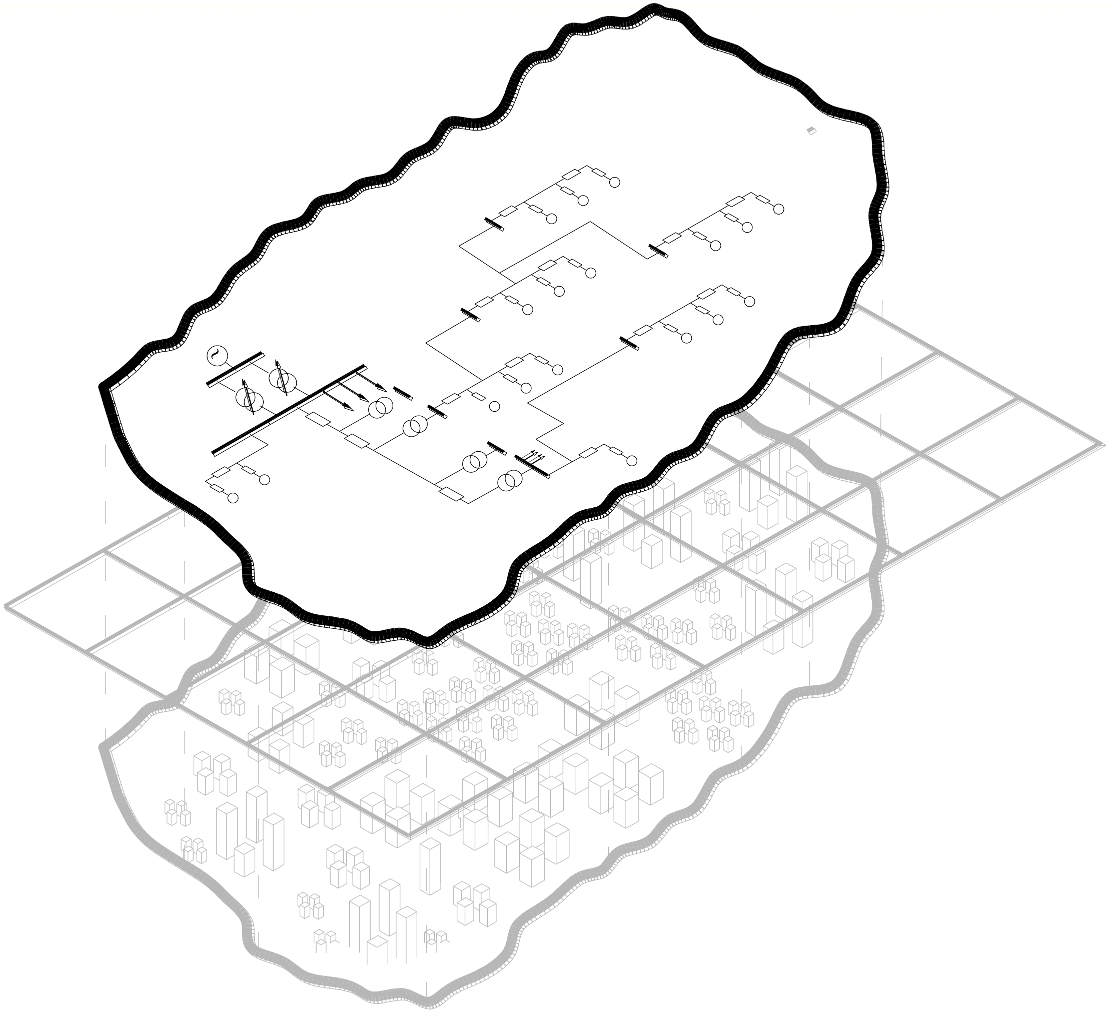


Urban Effects & Wind Modelling

Wieranga, Bottema approximation and a Logarithmic extrapolation based on fitted surface roughness parameterisation



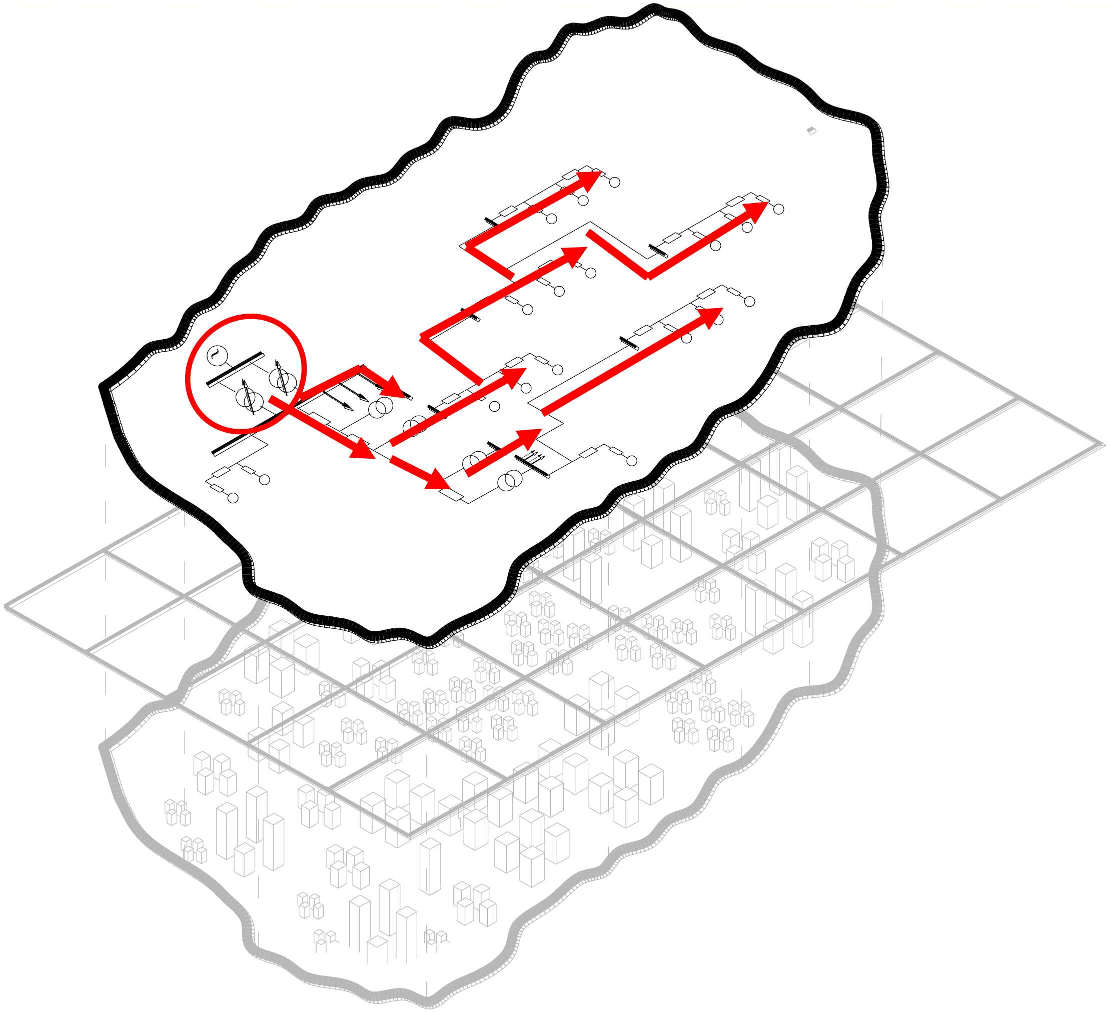
DwG & DN Implications



(Standardised) Distribution Network analysis

- Single-phase 4-Wire (and Ground)
- Complex/unbalanced (consumer) load configurations

DwG & DN Implications



(Standardised) Distribution Network analysis

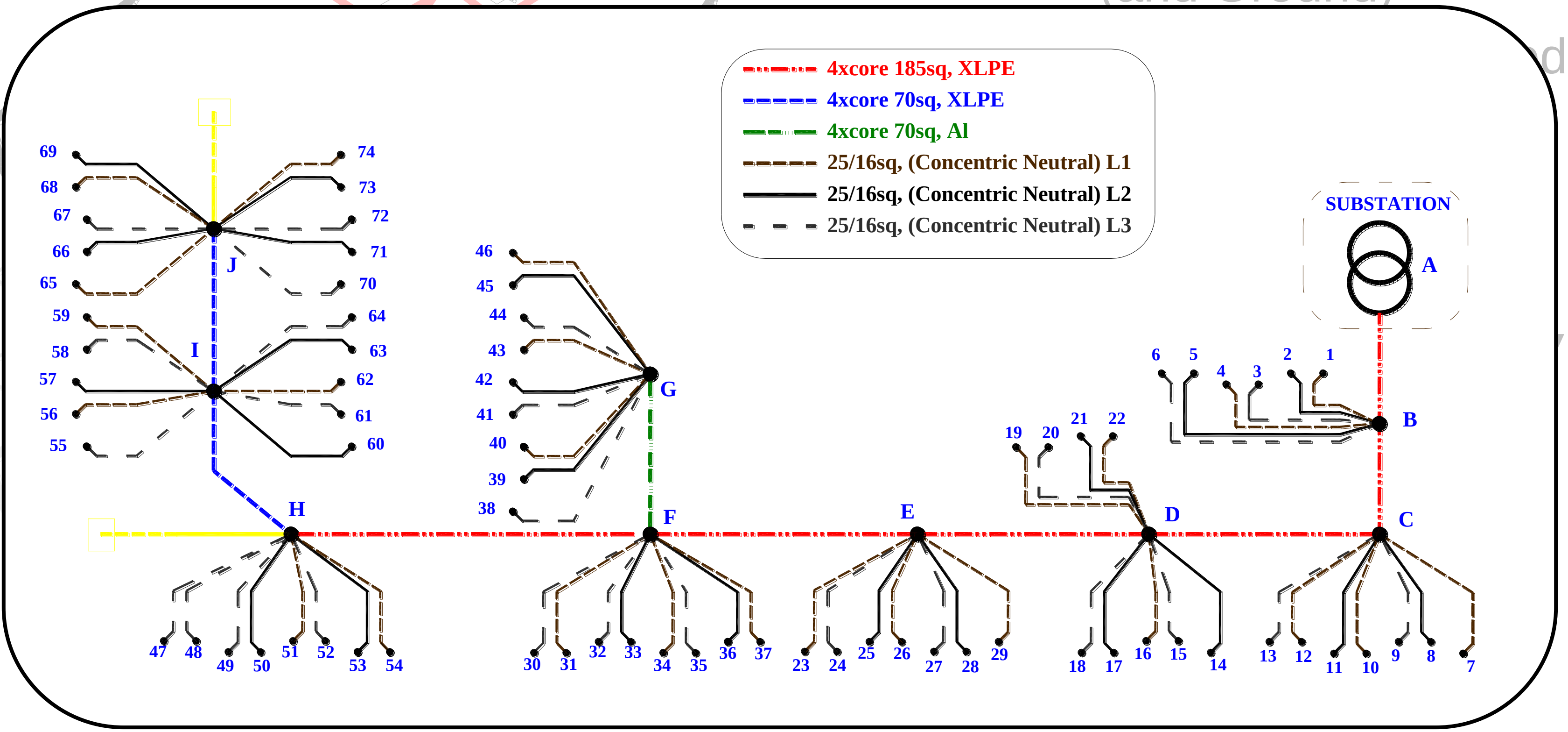
- Single-phase 4-Wire (and Ground)
- Complex/unbalanced (consumer) load configurations

Energy flow - Mono-directional Power Flow

DwG & DN Implications

(Standardised) Distribution Network analysis

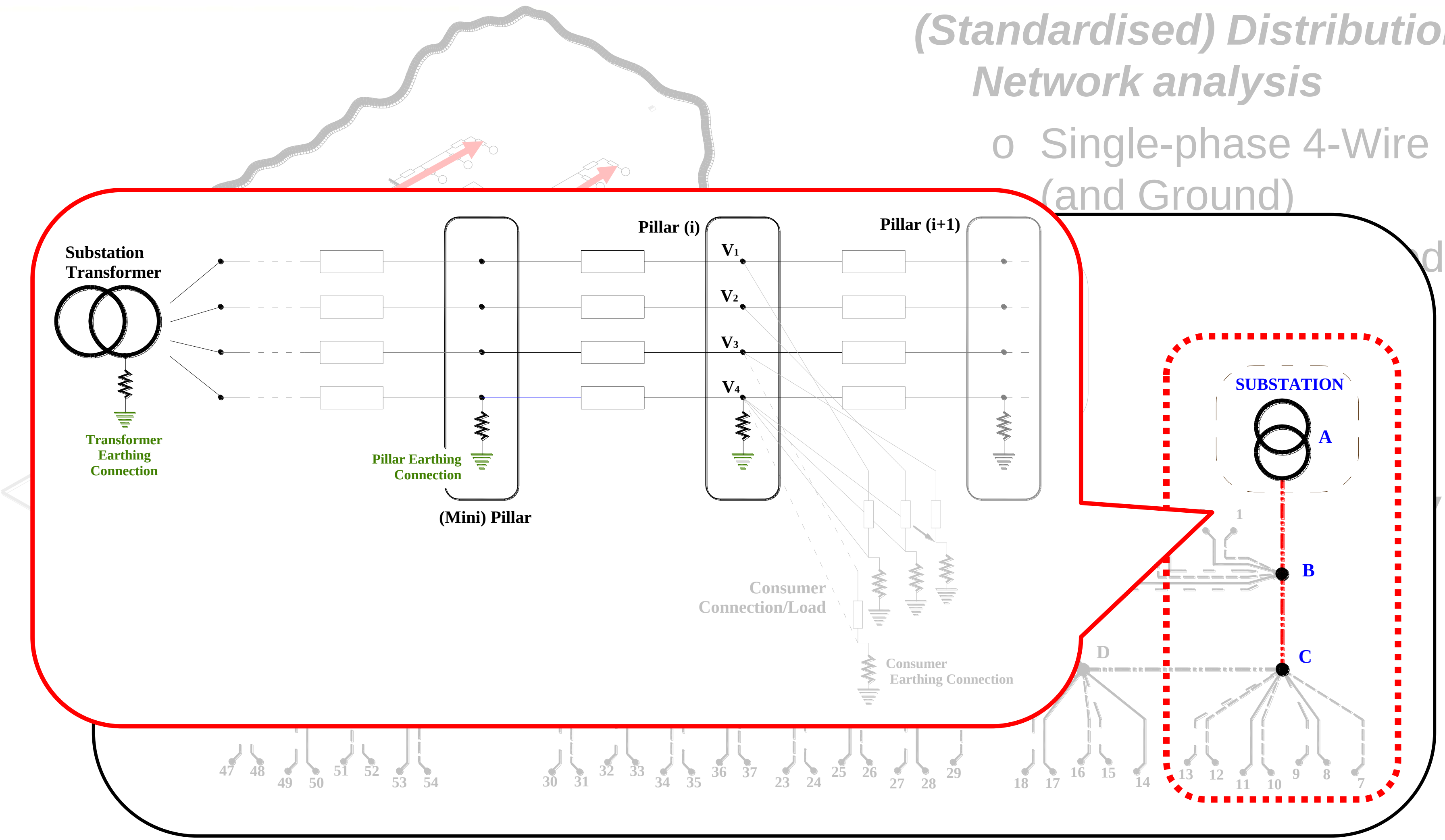
- Single-phase 4-Wire (and Ground)



DwG & DN Implications

(Standardised) Distribution Network analysis

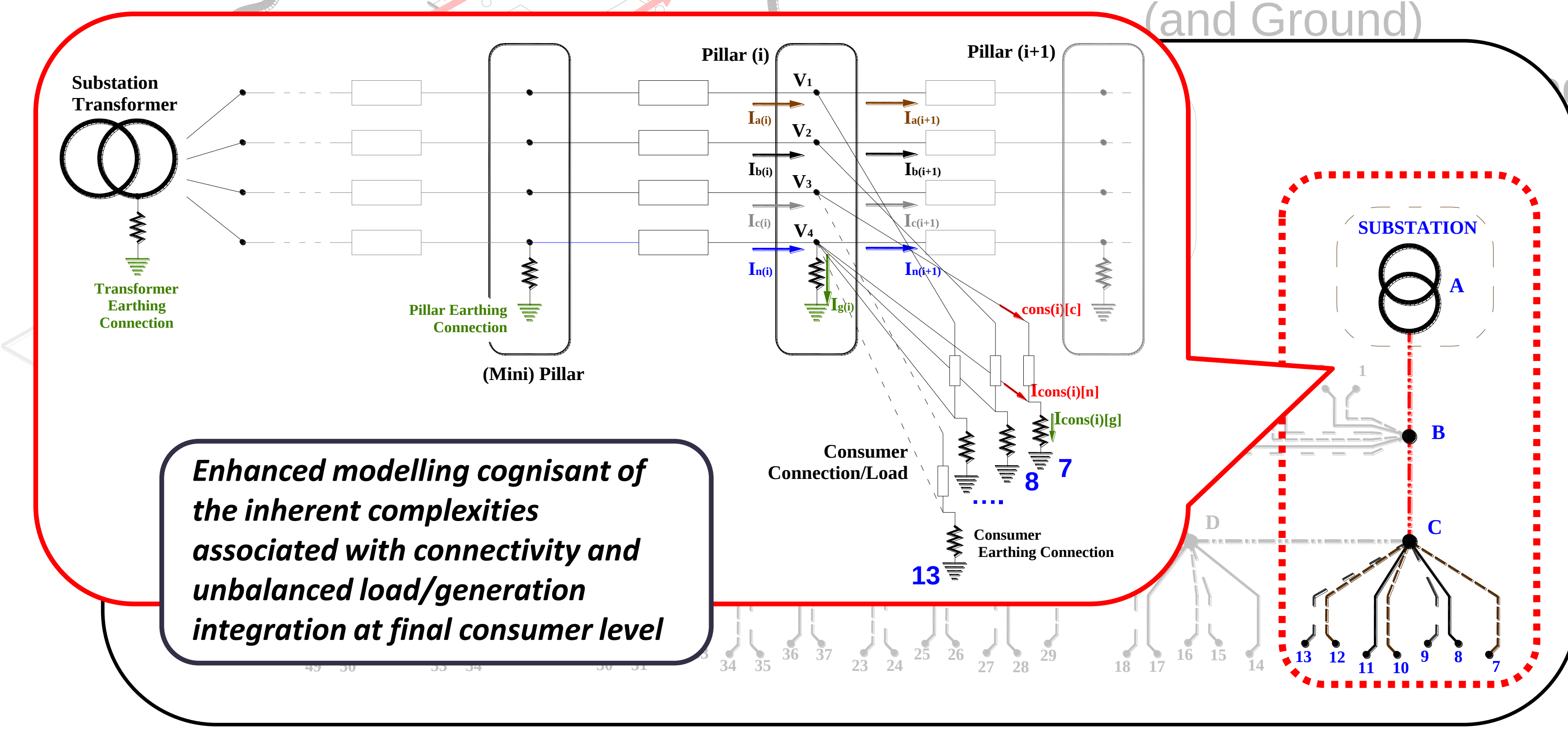
- Single-phase 4-Wire (and Ground)



DwG & DN Implications

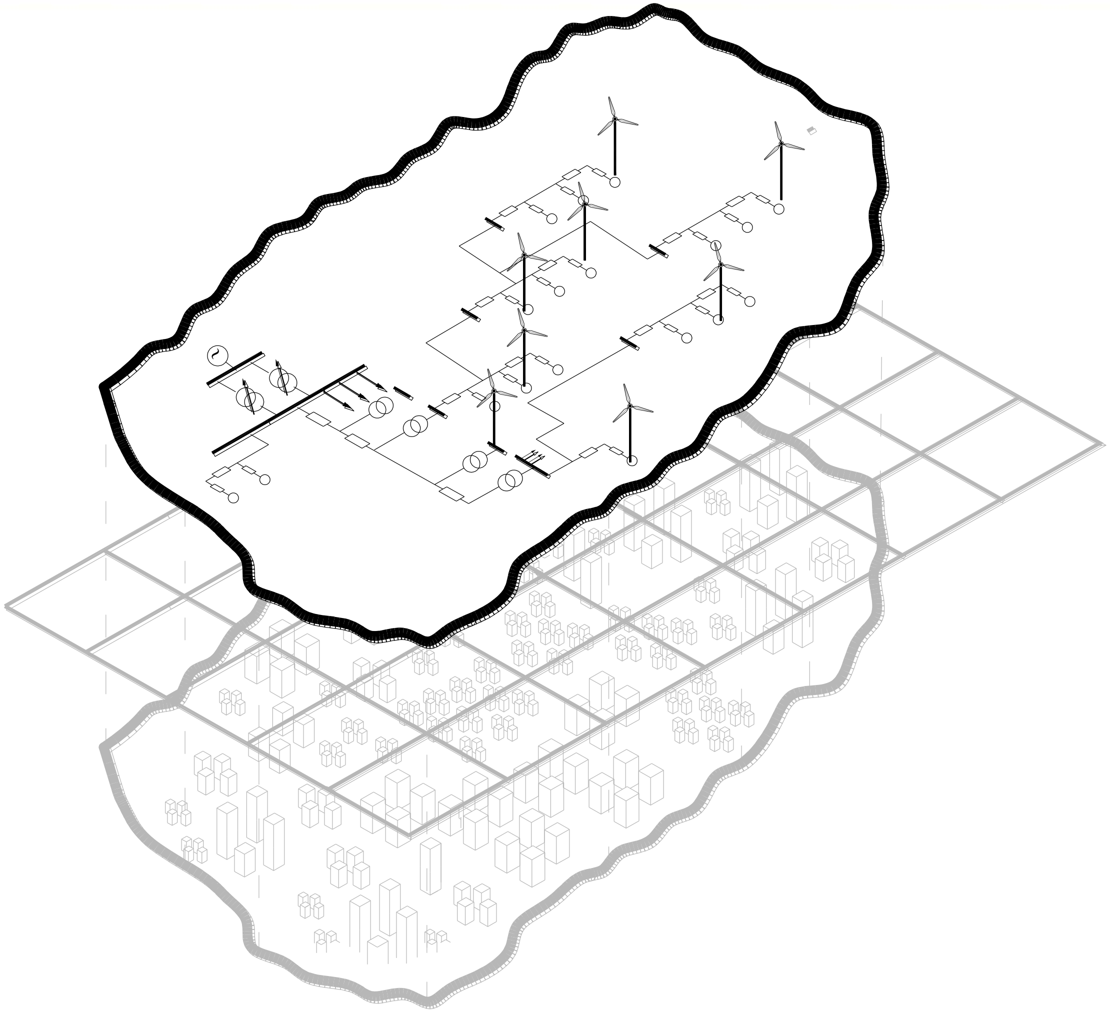
(Standardised) Distribution Network analysis

- Single-phase 4-Wire (and Ground)



Enhanced modelling cognisant of the inherent complexities associated with connectivity and unbalanced load/generation integration at final consumer level

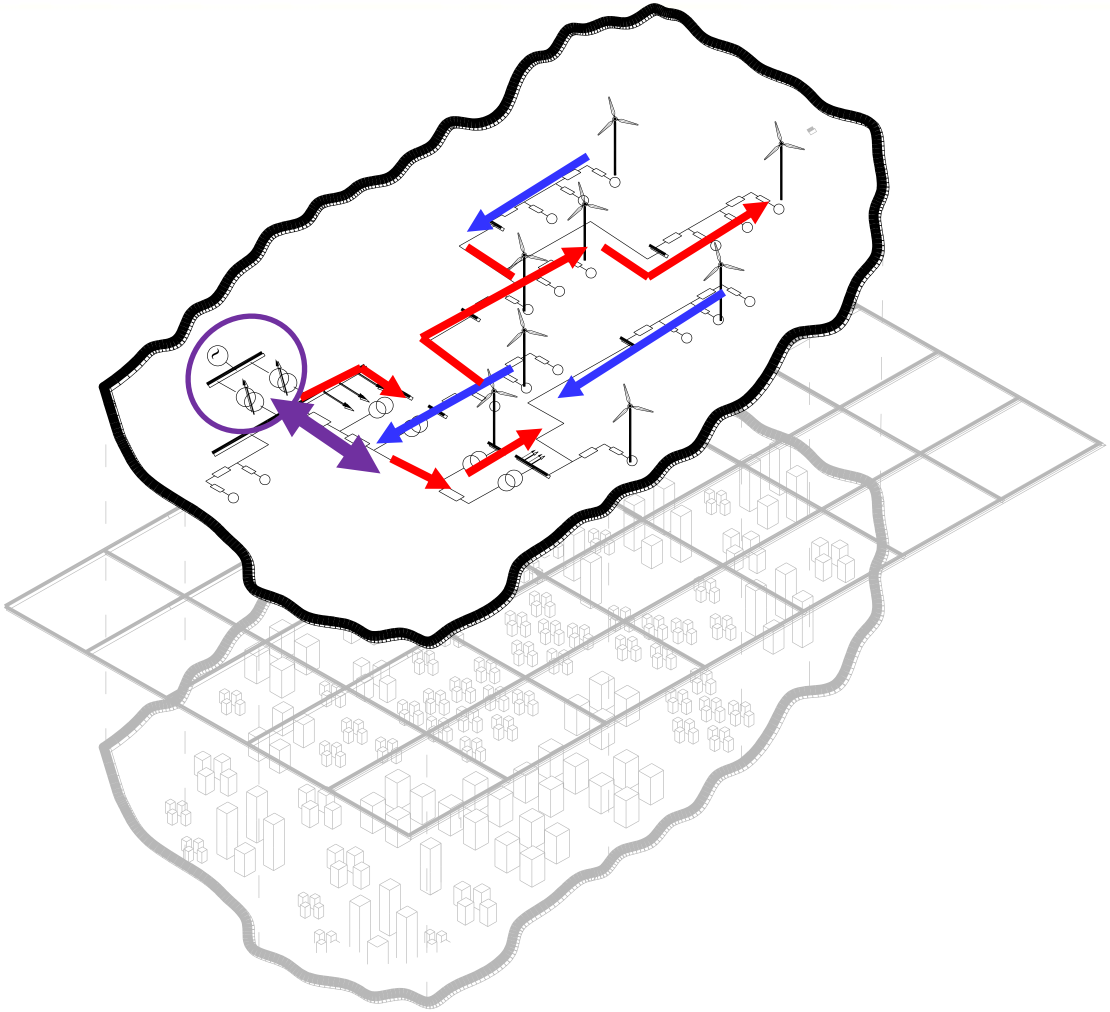
DwG & DN Implications



Embedded Generation Issues

- Bi-directional power flow
- Network Power Quality management
- Safety implications

DwG & DN Implications



Embedded Generation Issues

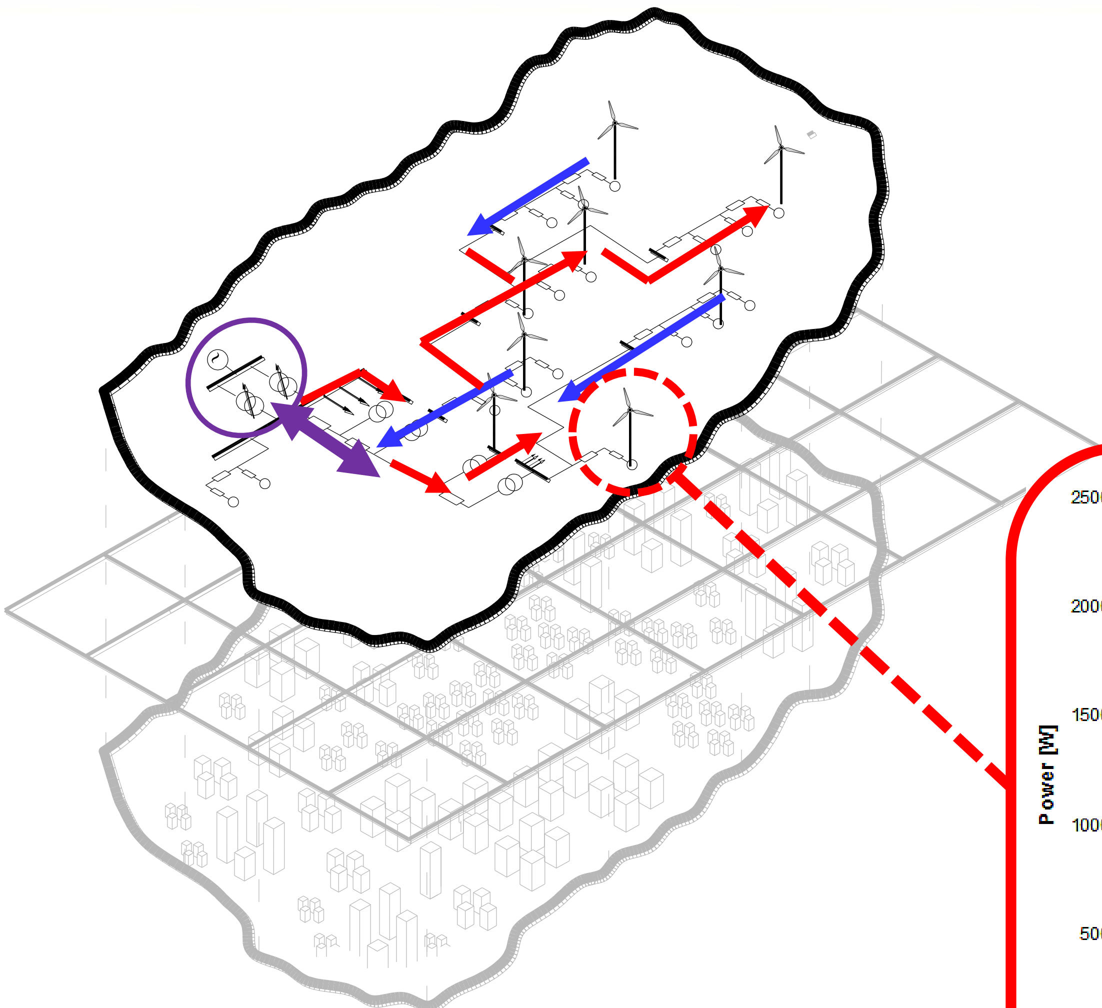
- ***Bi-directional power flow***
- Network Power Quality management
- Safety implications

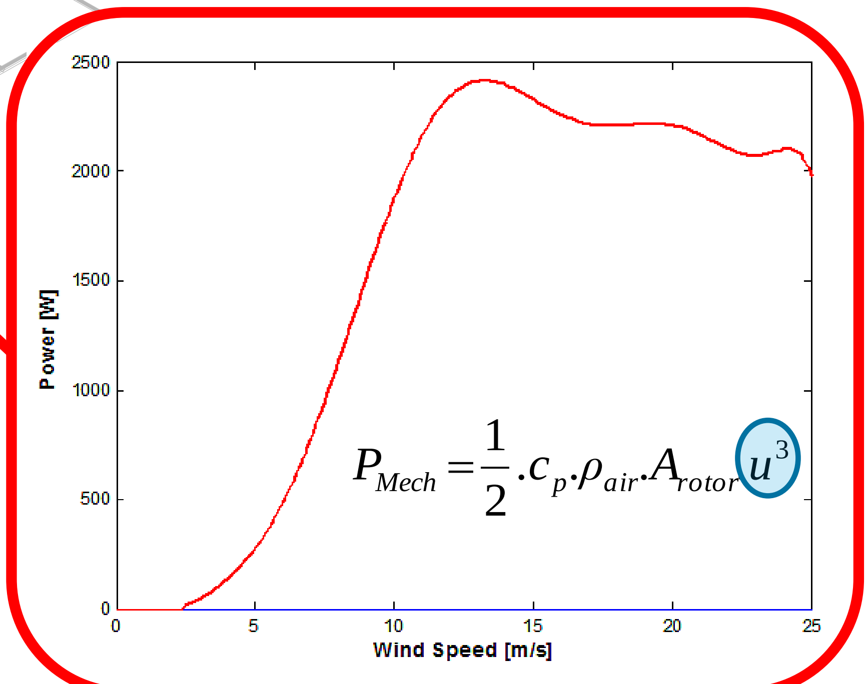
SCHOOL OF ELECTRICAL AND ELECTRONIC ENGINEERING

DwG & DN Implications

Embedded Generation Issues

- Bi-directional power flow
- Network Power Quality management
- Safety implications





$$P_{Mech} = \frac{1}{2}.c_p.\rho_{air}.A_{rotor}u^3$$

Overview

- Aims and Objectives
- Research Context/ Motivation
- Methodology
- **Findings**
- Ongoing Work
- Conclusions

Urban Observations & Modelling

Surface Roughness Parameterisation

	S_H						C_H					
Dir.[deg.]	Obs. Freq. [%]	u_M [m/s]	u_S [m/s]	Dir_M [deg.]	Dir_S [deg.]	z_0 [m]	Obs. Freq. [%]	u_M [m/s]	u_S [m/s]	Dir_M [deg.]	Dir_S [deg.]	z_0 [m]
0-30	1.8%	1.9	0.9	104	86		1.9%	2.3	1.0	82	86	
30-60	2.9%	2.4	1.0	91	47		3.0%	3.3	1.5	76	46	
60-90	3.5%	3.0	1.3	103	42		3.8%	4.1	1.8	91	34	
90-120	4.6%	2.8	1.6	127	51		3.9%	3.3	1.8	113	42	
120-150	12.1%	3.4	1.9	151	49	***0.924***	10.1%	3.6	1.8	139	42	***1.145***
150-180	5.8%	3.7	1.8	179	37	***0.395***	4.4%	3.4	1.7	167	39	***0.870***
180-210	10.1%	5.2	2.4	218	27	***0.180***	9.0%	4.9	2.2	211	26	***0.640***
210-240	21.2%	5.0	2.2	244	23	***0.342***	22.0%	5.0	2.2	239	18	***0.791***
240-270	22.4%	4.8	2.1	268	18	***0.660***	24.3%	5.1	2.1	263	14	***1.0575***
270-300	10.1%	3.4	1.6	281	30	***0.602***	11.3%	3.9	1.8	282	17	***0.724***
300-330	3.7%	2.6	1.4	286	55		4.0%	3.0	1.6	287	45	
330-360	2.0%	2.1	1.1	219	115		2.2%	2.2	0.9	231	117	
					$z_{0(average)}$	**0.5171**					*$z_{0(average)}$*	**0.8713**

Urban Observations & Modelling

Surface Roughness Parameterisation

For each 30^0 sector, surface roughness was estimated by varying iteratively until the best fit was achieved so as to minimise the error between the predicted wind speed, based on the background climate, and the observed wind speed

							C_H					
Dir.[deg.]	Obs Fre								u_S [m/s]	Dir_M [deg.]	Dir_S [deg.]	z_0 [m]
0-30	1								1.0	82	86	
30-60	2.9								1.5	76	46	
60-90	3.5%							1	1.8	91	34	
90-120	4.6%	2.8	1.6	127	51		3.9%	3.3	1.8	113	42	
120-150	12.1%	3.4	1.9	151	49	*0.924*	10.1%	3.6	1.8	139	42	*1.145*
150-180	5.8%	3.7	1.8	179	37	*0.395*	4.4%	3.4	1.7	167	39	*0.870*
180-210	10.1%	5.2	2.4	218	27	*0.180*	9.0%	4.9	2.2	211	26	*0.640*
210-240	21.2%	5.0	2.2	244	23	*0.342*	22.0%	5.0	2.2	239	18	*0.791*
240-270	22.4%	4.8	2.1	268	18	*0.660*	24.3%	5.1	2.1	263	14	*1.0575*
270-300	10.1%	3.4	1.6	281	30	*0.602*	11.3%	3.9	1.8	282	17	*0.724*
300-330	3.7%	2.6	1.4	286	55		4.0%	3.0	1.6	287	45	
330-360	2.0%	2.1	1.1	219	115		2.2%	2.2	0.9	231	117	
					$z_{0(average)}$	**0.5171**					*$z_{0(average)}$*	**0.8713**

Observation/Modelling: high-platform observations

	C_H				S_H			
	Observed	***Wieranga Model***	***Bottema Model***	***Log-Model***	***Observed***	***Wieranga Model***	***Bottema Model***	***Log-Model***
Roughness length (z_0)	--	1.15	1.15	0.8713	--	0.55	0.55	0.5171
Friction velocity ratio	--	1.0	1.3312	1.7022	--	1.0	1.2636	1.5512
u_M *[m/s]*	4.5992	4.9728	3.2281	4.6165	4.4401	4.9804	3.5795	4.3940
u_S *[m/s]*	2.1288	2.2497	1.4604	2.0885	2.1712	2.2269	1.6005	1.9647
MAE [m/s]	--	0.7113	1.4248	0.6133	--	0.9392	1.0635	0.7594
RMSE[m/s]	--	0.9790	1.6878	0.8651	--	1.2202	1.3873	1.0479

Urban Observations & Modelling

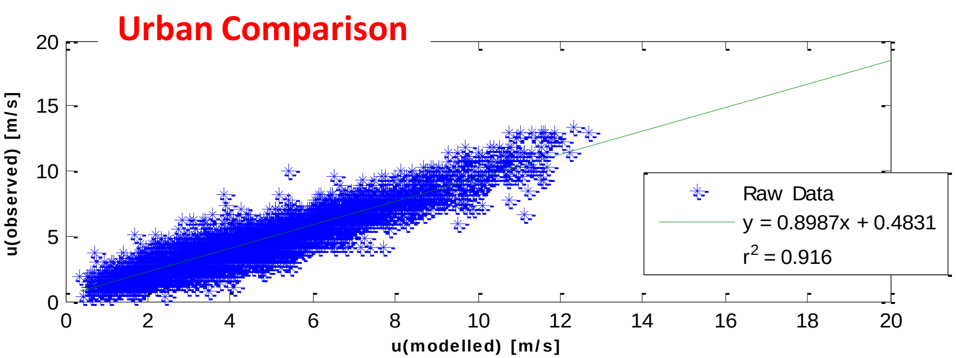
Observation/Modelling: high-platform observations

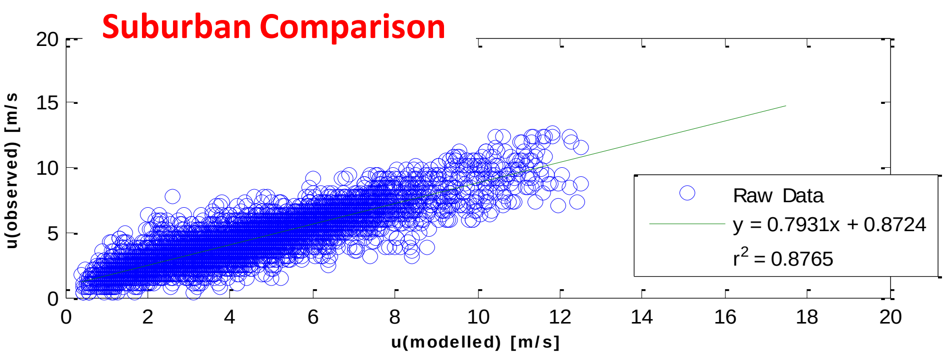
	C_H				S_H			
	Observed	***Wieranga Model***	***Bottema Model***	***Log-Model***	***Observed***	***Wieranga Model***	***Bottema Model***	***Log-Model***
Roughness length (z_0)	--	1.15	1.15	0.8713	--	0.55	0.55	0.5171
Friction velocity ratio	--	1.0	1.3312	1.7022	--	1.0	1.2636	1.5512
u_M [m/s]	4.5992	4.9728	3.2281	4.6165	4.4401	4.9804	3.5795	4.3940
u_S [m/s]	2.1288	2.2497	1.4604	2.0885	2.1712	2.2269	1.6005	1.9647
MAE [m/s]	--	0.7113	1.4248	0.6133	--	0.9392	1.0635	0.7594
RMSE[m/s]	--	0.9790	1.6878	0.8651	--	1.2202	1.3873	1.0479

Urban Observations & Modelling

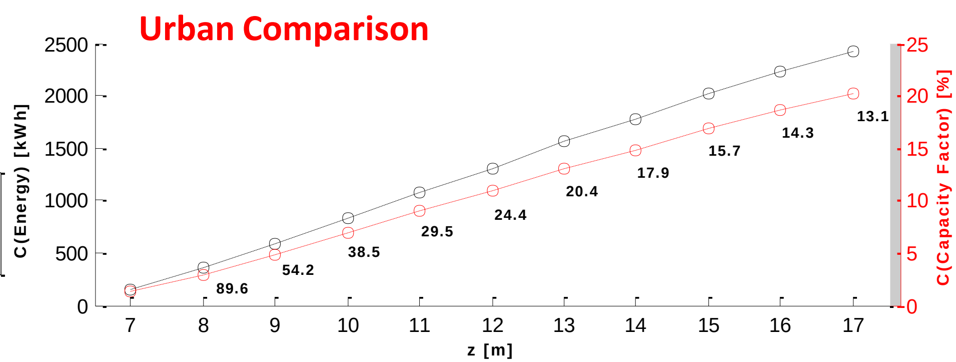
Observation vs. Modelling

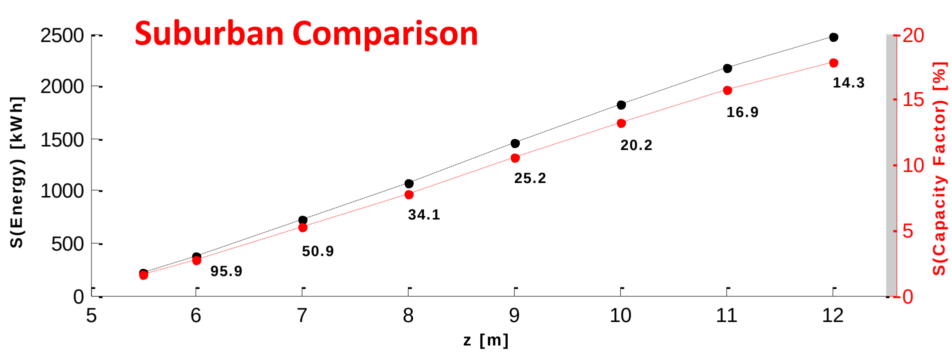
Scattergram comparison of high-platform observed and modelled wind speeds (Nov. 2010 –*to*– Jan 2011)





Energy implications with respect to height variation for a wind generator at both sites (Nov. 2010 –*to*– Jan 2011)

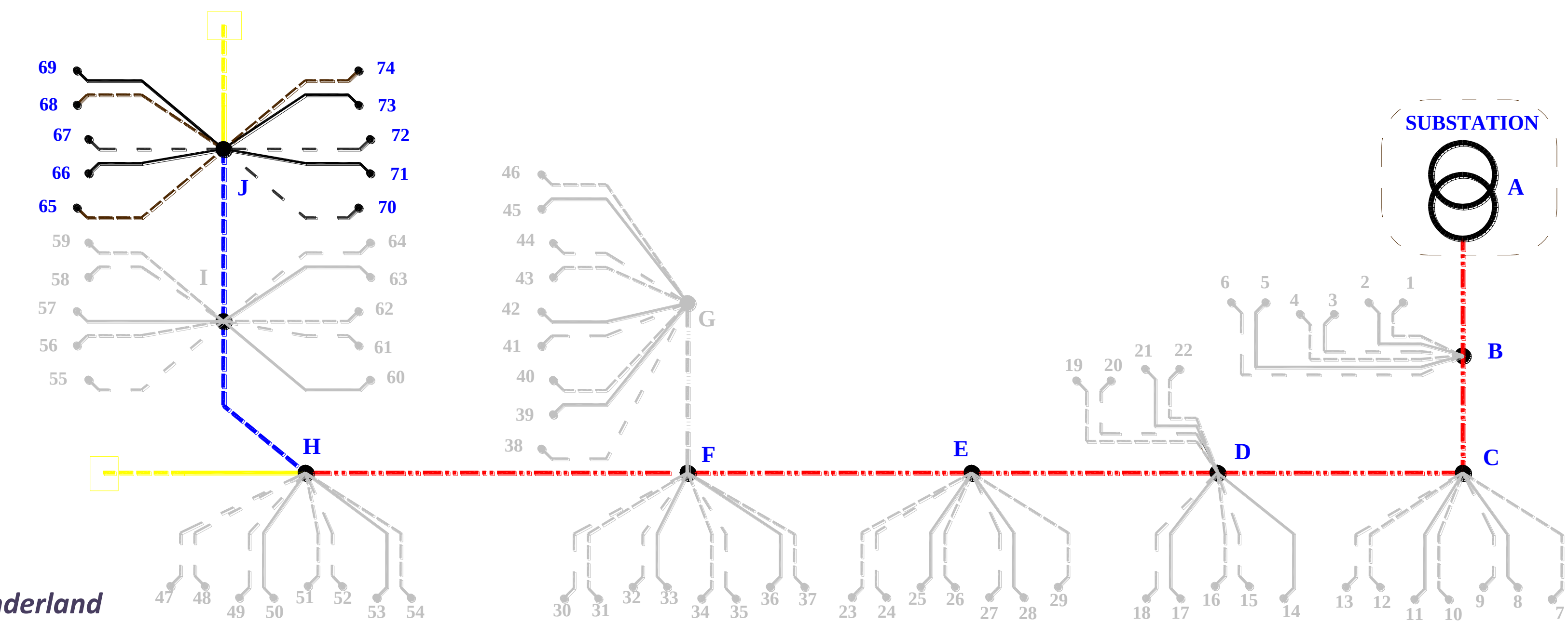




Distribution Network Reaction

Typical Mean Year of Wind Speed (Markov Chain)

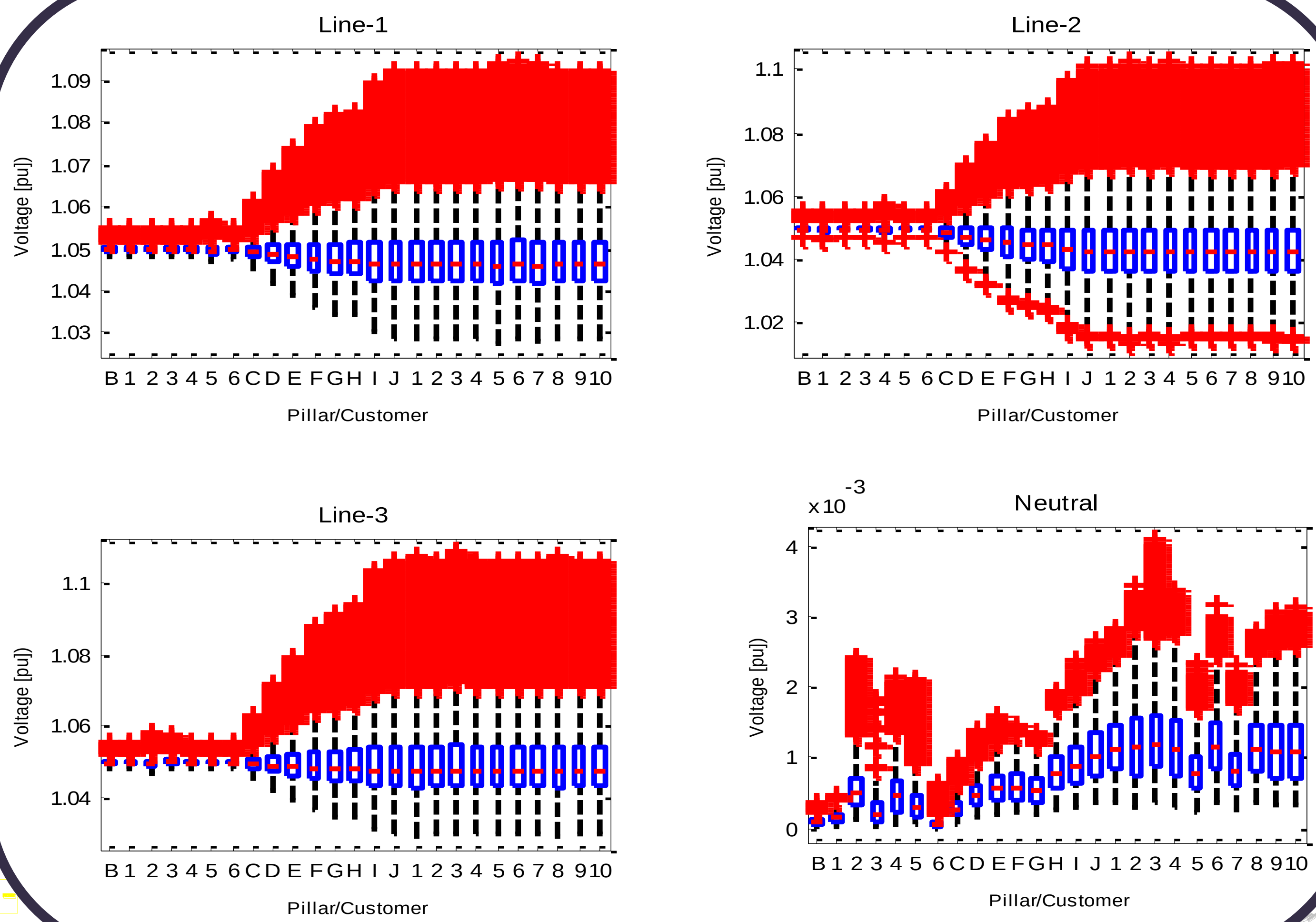
Statistical Comparison	*Urban Modelled Wind Speed (C_H)*		*Suburban Modelled Wind Speed (S_H)*	
	Modelled Wind Data (4789 Hrs)	Markov chain Extended Data set (8760hrs)	Modelled Wind Data (5556 Hrs)	Markov chain Extended Data set (8760hrs)
u_{Mean}	4.62	4.58	4.39	4.33
u_{STD}	2.09	2.18	1.96	2.05



SCHOOL OF ELECTRICAL AND ELECTRONIC ENGINEERING

Results & Findings

Distribution Network Reaction



Overview

- Aims and Objectives
- Research Context/ Motivation
- Methodology
- Findings
- **Future Work**
- Conclusions

Future Work

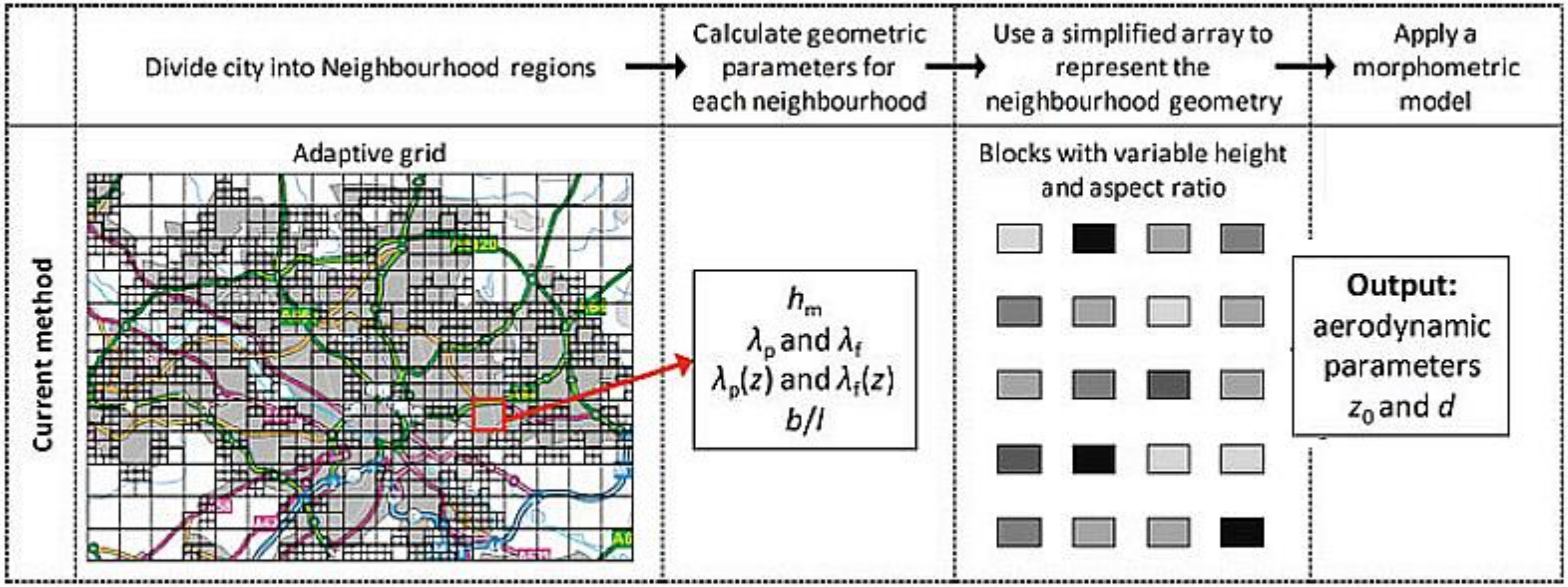
$$U(z) = \frac{u_*}{k} \ln\left[\frac{z-d}{z_0}\right]$$

To be applicable from the ISL into the RSL, neighbourhoods of homogeneity need to be identified – distinctly different surfaces can be considered separately

J. T. Millward-Hopkins, *et al.*, "Estimating Aerodynamic Parameters of Urban-Like Surfaces with Heterogeneous Building Heights," *Boundary-Layer Meteorology,* vol. 141, pp. 443-465, 2011/12/01 2011.

J. T. Millward-Hopkins, *et al.*, "Aerodynamic Parameters of a UK City Derived from Morphological Data," *Boundary-Layer Meteorology,* vol. 146, pp. 447-468, 2013/03/01 2013

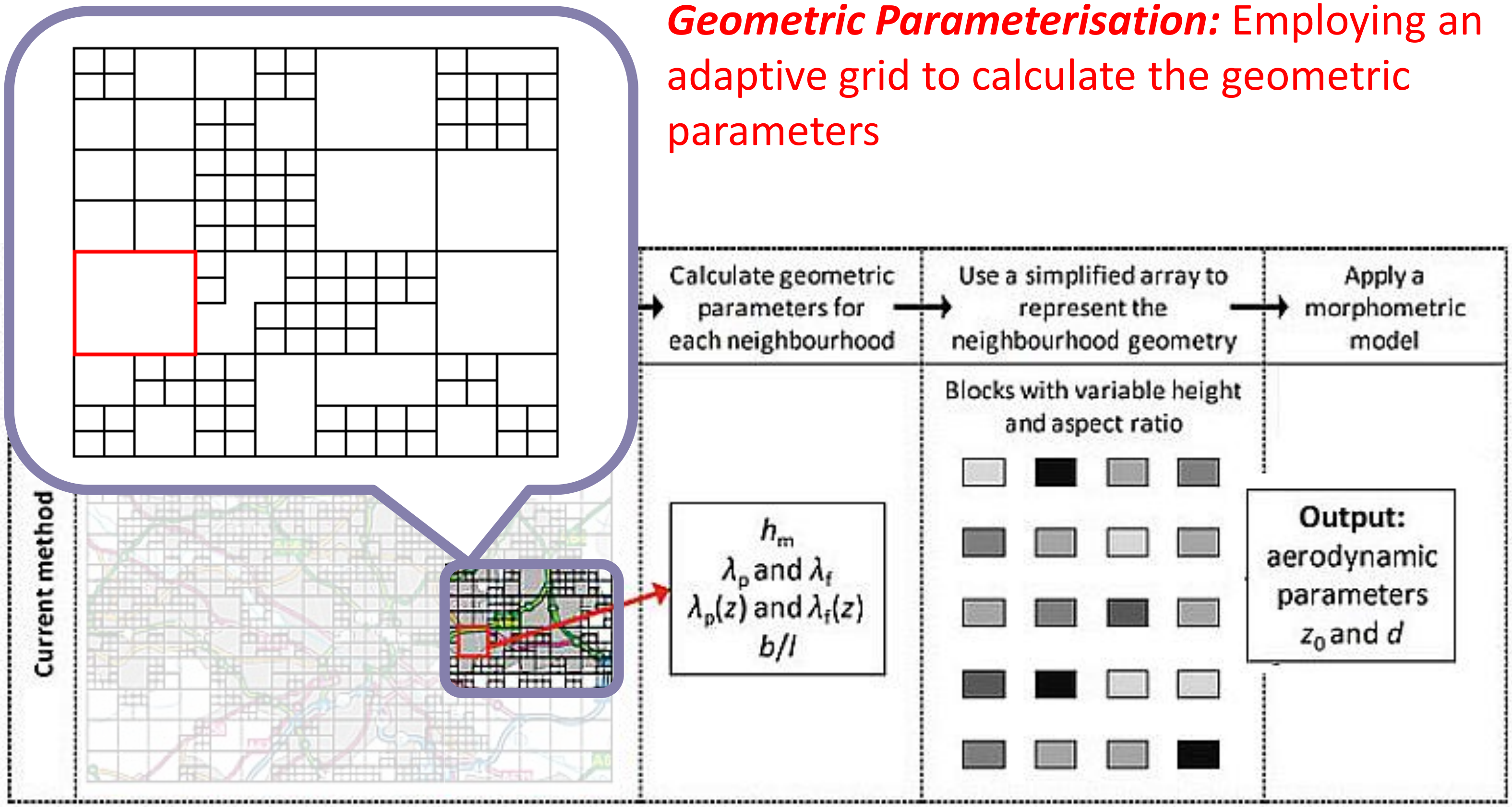
UNIVERSITY OF LEEDS



Future Work

- Rastered Digital Elevation Model (DEM) - - *building footprints (Dublin)*
- Divide the city into distinct neighbourhood regions – **Adaptive Grid**

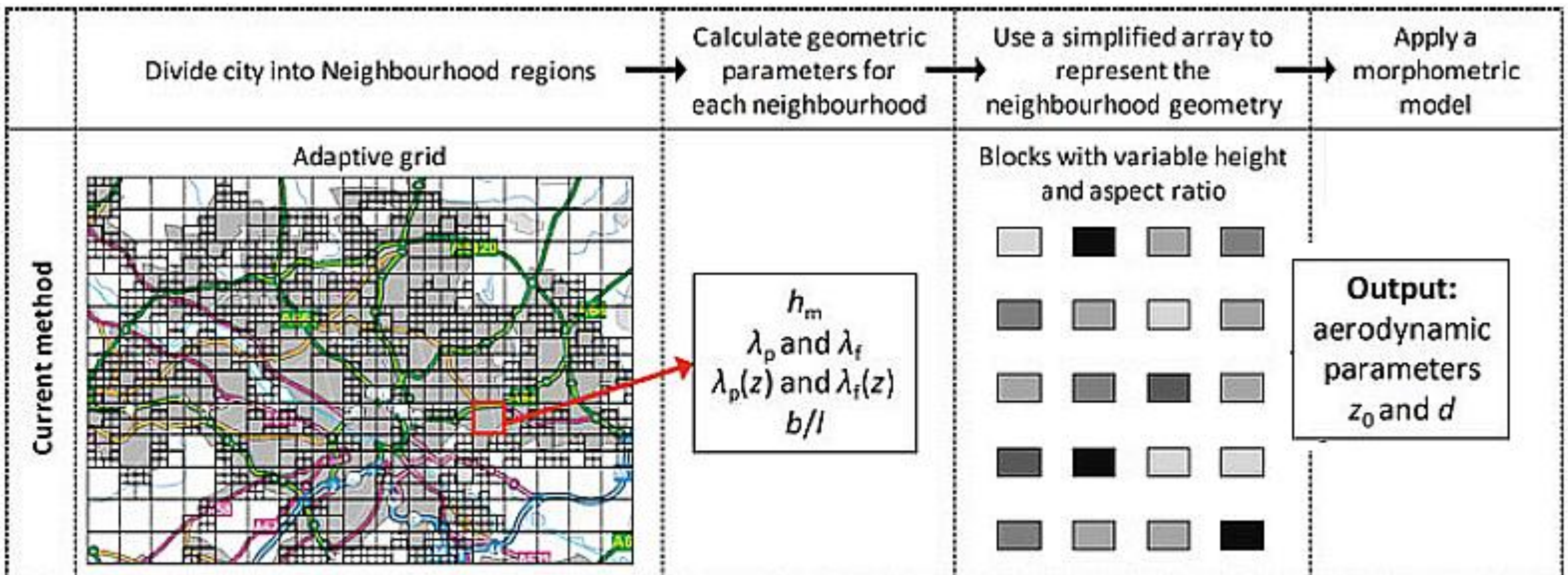
Geometric Parameterisation: Employing an adaptive grid to calculate the geometric parameters



Future Work

- Rastered Digital Elevation Model (DEM) - - building footprints (Dublin)
- Divide the city into distinct neighbourhood regions – **Adaptive Grid**
- Geometric Parameterisation
- Morphemetric Model

$$d = \int_{0}^{h_{max}} f_d\left(\lambda_p(z)\right) dz, \Longrightarrow \frac{d}{h_m} = f_d(\lambda_p) = \begin{cases} \dfrac{19.2\lambda_p - 1 + \exp(-19.2\lambda_p)}{19.2\lambda_p\left[1 - \exp(-19.2\lambda_p)\right]}, & (\text{for } \lambda_p \geq 0.19) \\ \dfrac{117\lambda_p + \left(187.2\lambda_p^3 - 6.1\right)\left[1 - \exp(-19.2\lambda_p)\right]}{\left(1 + 114\lambda_p + 187\lambda_p^3\right)\left[1 - \exp(-19.2\lambda_p)\right]} & (\text{for } \lambda_p < 0.19) \end{cases} \Longrightarrow z_0$$



Overview

- Aims and Objectives
- Research Context/ Motivation
- Methodology
- Findings
- Future Work
- **Conclusions**

SCHOOL OF ELECTRICAL AND ELECTRONIC ENGINEERING

Conclusions

- In the context of smart cities and smarter (electricity) grids, this type of research is essential if renewable energy is to facilitate a cultural shift towards an era of *prosumers*.
- In terms of the limits available to wind energy extraction in an urban context., the analyses illustrated limited opportunities below a height 2 → 4 x z_{Hm}
- By linking urban wind observations to a background reference, an empirical logarithmically matched profile was possible. (Analytical linkages to observations within the canopy suggested that knowledge of the background resource in this regard is of limited value)
- Analyses of a fully described 4-wire unbalanced section of Dublin city network, in respect of increasing levels of prosumer (with a grid-tied commercially available DwG), illustrated that for exemplar consumer load and a typical mean year of wind speed, voltage tolerance breaches are unlikely and of marginal concern (<2% of occasions)
- Future work will focus on validating the emperical logarithmic extrapolation models through moprphemtric means of deriving the Dublin city urban aerodynamic parameters

Thank you

e: keith.sunderland@dit.ie

SCHOOL OF ELECTRICAL AND ELECTRONIC ENGINEERING