Emmanuel, R., Aarrevaara, E., Duenas, J., Thomson, C. & Gallagher, C. (eds.)

MUrCS Proceedings 2020

Master in Urban Climate & Sustainability (MUrCS)

The Publication Series of LAB University of Applied Sciences, Part 15

LAB University of Applied Sciences

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MUrCS
Master in Urban Climate & Sustainability

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Editorial

The European Master programme in Urban Climate and Sustainability (MUrCS) project (www.murcs.eu) is pleased to bring out this "summary for practitioners" publications arising from the students' thesis work. Rapid anthropogenic climate change in an increasingly urbanised world urgently requires new professionals with a scientific understanding of urban climate and ability to work within the planning system to manage and lead sustainable change. In the present volume we highlight the fruition of our approach to these 'new professionals' by integrating the three thematic streams of MUrCS, namely; Science, Planning and Management.

The ecological crisis brought about by anthropogenic actions have diminished human ability to respond to climate change (Kalnay & Cai, 2003). The role of cities in both contributing to the problem as well as to act as engines of change are only now gaining traction (Hebbert & Jankovic, 2013), and the need to achieve such changes in an equitable, sustainable and effective manner is now more widely recognised (UN, 2010).

Furthermore, urban action to tackle the climate and sustainability challenges need to take account of the contextual specificities of cities – rapid urban growth and sprawl in many developing regions, as well as the consequences of urban decline in the post-industrial developed world (Satterthwaite, 2008). In the EU, the key challenge is to retrofit cities to adapt to changing climate in the short term, while contributing to the mitigation of climate change in a sustainable manner in the long-term (EU, 2012).

This first volume highlights these varied needs of cities from across the world, in the face of both local and regional climate change.

Given our focus on urban climate, a majority of papers focus on aspects of urban heat island mitigation. Apsunde considers the triadic relation of urban form, air quality and the wind environment at street level in the dense setting of the City of London to account for local air quality variations. On the other hand, Ibitolu employs the Local Weather Type (LWT) classification approach to conduct a spatio-temporal wind analysis of Toulouse, France. Given the paucity of UHI studies in the rapidly urbanising global South, Khan performed a UHI study in Karachi, and demonstrates the cooling implications of mixed local climate zones (LCZs) that may offer urban planning approaches to manage the increasing UHI effects in future.

On the policy side, Presser de Santana investigates what we know of the influence of urban factors on city climate, with a view to determining the most influential factors pertinent to London according to the opinion of experts and how/where these factors could be embedded within existing urban legislation.

Three other papers focus on Green Space approaches in different cities. Stepani develops a protocol for green area target setting in a developing city (Jakarta, Indonesia) and demonstrates the futility of uniform target setting that does not take into consideration the local climate variations found within cities.

Similarly, Torres-Limache demonstrates Green Area Ratio as a planning tool for sustainable green infrastructure in a densely built arid environment like the one in Lima, Peru. Focussing more on the social vulnerability and the design options to mitigate these, Zala develops a 'Greendex' that bring together social and environmental vulnerability parameters into a unified index for Glasgow that could act as a planning tool to both identify hotspots and opportunities for mitigatory actions.

A third theme that runs through the present collection addresses the so-called circular economy. Nazir shows initial developments of a conceptual framework for a bio-based circular economy with a specific focus on bio-waste management of Bahar Colony in Lahore, Pakistan. Whereas Soto-Nieto contextualises the alignment of the circular economy to socio-spatial issues by mapping and leveraging the discussions on the implications of circularity in cities as a climate-sensitive approach to urban planning and design, demonstrating the utility of bringing both dimensions together in our quest for urban sustainability.

Another theme developed by our graduates in this first batch, explores the ecosystem services and bio-based approaches to urban sustainability. In 're-valuing canals' Al Dwairi highlights the different roles canals can play in cities by mapping the provision of Ecosystem Services (ES) provided by the Smart Canal project in the north of Glasgow city. On the other hand, Chowdhury highlights biomimicry approaches to mitigate UHI by way of specify guidelines, which describe the components of neighbourhood consideration such as: vegetation and hydrological courses, existing built structures, vehicular accessibility, heat stress and wind analysis, and height of the building, providing a useful link between UHI mitigation, green infrastructure and ecosystem services.

Ultimately, human factors remain a key variable in the success or otherwise of sustainability actions. Two papers highlight the behavioural aspects in energy efficiency. Glowacki demonstrates that improvements to the stakeholder engagement process in policy design, reflected in the energy efficiency roadmaps, are an entry point for transformative changes. Taking a more micro view, Carlo highlights several case studies and expert interviews, to draw out generalisations of the relationship between humans and touchpoints that are relevant to the use of behavioural insights for energy conservation policies in the residential sector.

We hope these outputs provide evidence for the successful embedding of the MUrCS approach to creating 'new professionals.' Given the policy and practice relevance of several of these papers, we further hope practitioners may find actionable knowledge even as we contribute to the creation of international urban thinkers able to understand, manage and lead transformative change to address urban climate change in a sustainable manner.

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GCU Glasgow Caledonian University

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Kiran Ashok Apsunde, Civil Engineer and Environmental Planner

He is a Civil Engineer with Masters in Climate Change and Sustainable Development from CEPT University, India. Kiran worked as an environmental planner and climate consultant with national and international organisations in India. He has also been a visiting faculty of GIS and has presented four research papers in various international conferences. His MUrCS thesis explored the interaction between urban form and air quality at the street level. Having completed the programme with a distinction, he has commenced working as a PhD Research Scholar on the EU H2020 GoGreen Routes project at Trinity College Dublin.

Mahmudul Islam Chowdhury, Architect

Trained as an Architect (BArch) at the BRAC University, Dhaka. For the past three years before joining MUrCS he worked in architectural design and also as a research associate at the Bengal Institute of Architecture, Landscape and Settlements, a leading architectural research institute in Bangladesh. He has worked with data leveraging on sound pollution of the mega city of Dhaka. His master thesis explored the bio-based design techniques to mitigate urban heat islands and was developed in collaboration with the CNRS in Toulousse, France. Mahmud is interested in emerging cities which require strategic designs to accommodate future demands and research on sustainable cities.

Marina Khan, Architect and Urbanist

Born and raised in Pakistan, she obtained her BArch from the National College of Arts, and she joined a top architectural firm in Karachi where the foci of her practice were building and urban design vis-à-vis green building interventions, adaptive reuse and social urban resilience. Her MUrCS thesis surrounds these topics in dense and vulnerable areas. She has recently collaborated with Ramboll Finland and the World Green Building Council in projects related to sustainable urban regeneration, net-zero transitions, health and wellbeing in cities. Marina's future research aspirations lie in the decarbonization of cities, buildings, and climate-sensitive policy in developing cities of South Asia.

Megi Zala, Architect and Urban Planner

Having graduated from Albanian Univesity with a Master in Architecture, she has five years of experience in the public and private sector in Albania working with planning policy, architectural and interior design. In her MUrCS thesis she developed strategies based on vulnerability assessment for spatial and micro-climate analysis for improving green infrastructure in cities. Megi served as a research assistant at Glasgow Caledonian University, in the Connecting Nature project with Glasgow City Council and COSMA project (Sri Lanka). She is now a research fellow at Politecnico de Milano (Italy) and is interested in combining cross-disciplinary aspects in the interaction between the built environment, people and climate.

Oliver Carlo, Engineer
He obtained a BEng in Mechanical Engineering from PES University, Bengaluru and then he worked as a sustainability consultant in Mumbai (India) for more than four years. Oliver has strong expertise in green building development for the residential and the commercial sector, with know-how on sustainable architectural design development, building energy modelling and lighting design amongst others fields. His master's thesis explored how demand-side energy policies could be strengthened through the application of behavioural insights. He shall further be continuing his PhD in exploring passive methods for urban ventilation and air pollution mitigation.

Paula Presser, Architect and Urban Planner
She graduated with a Bachelor in Architecture and Urbanism from Universidade Federal do Rio Gande do Sul, Brazil. Paula has worked in projects in Brazil and Ireland, being responsible for the design of neighbourhoods, parks and squares, environmental licensing in different cities of Brazil and large-scale urban infrastruture for the 2014 World Cup. She attended trainings in Germany, Spain, and joined MUrCS afterwards. Paula completed her thesis analysing microclimate policies in London. Her main research focus is urban climate legislation, green spaces and the impact of design on microclimate.

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Thais Glowacki, Transdisciplinary Architect
She has a transdisciplinary background, graduated in Social Sciences from Universidade Federal do Parana and later with a BArch in Architecture and Urbanism from Pontifícia Universidade Católica do Parana in Brazil. She worked with sustainable urban development in Angola, Africa. During MUrCS she further developed knowledge on how the urban built environment impacts on people and the local ecosystem. Her thesis discussed how stakeholder collaboration/co-creation could be enhanced in the policy design for decarbonising the buildings sector. Now, better equipped, she wants to focus her work on climate adaptation in cities while being part of the urban transition makers' network.

URBAN HEAT ISLAND (UHI)

Exploring the triadic relation of urban form, wind and air quality at street level

A case study of City of London, United Kingdom

Kiran Ashok Apsunde

Abstract

The triadic relation on urban form, air quality and the wind environment at street level in a dense setting of the City of London is investigated through detailed characterisation of the urban form, wind simulation and statistical analysis in conjunction with AQ data. The study has taken a detailed approach towards identifying the street level metrics that influence the urban wind environment and ambient air quality. Besides using some of the existing metrics, the study has introduced new parameters that may further aid in understanding the triadic relation. For 826 canyons mapped in the study area, the study has analysed about 42 urban form metrics to understand the influence on the wind environment. Additionally, for 63 canyons with AQ observations, 64 wind and urban form metrics are analysed for their statistical significance as predictors using the exploratory regression approach. Out of the 42 metrics used to investigate the influence of urban form on wind pattern, 22 are found to have a statistical significance of greater than 50%. Moreover, out of the 64 variables used towards investigating the role of wind and urban form metrics on AQ, 10 are found to exhibit a statistical significance of greater than 50%.

1. Introduction

If managed well, urbanisation can contribute to sustainable and climate-resilient growth. However, the rate and scale of urbanisation present cities with a plethora of physical, socio-economic and environmental challenges. Exacerbation of heat stress due to UHI alongside air, water, land and noise pollution are already posing severe risks to human health and wellbeing in urban settings. With changing climate and increasing inequality in socioeconomic conditions within the cities, the vulnerability of the urban population is anticipated to increase significantly. Recognising this, a great emphasis has been laid on sustainable urban development in recent years. The United Nations Sustainable Development Goal (SDG) 11 aims specifically at making cities and human settlements safe, resilient and sustainable (United Nations 2015). Over the last two decades, the significance of urban form in the quest for sustainable urban development has seen a gradual recognition globally (Marquez & Smith 1999). Owing to some positive influences on thermal comfort and energy consumption, there appears to be a consensus towards 'compact' urban form as a key to urban sustainability (Emmanuel & Steemers 2018). However, studies indicate that compact cities tend to have poor air quality with high pollutant concentration (Cárdenas Rodríguez et al. 2016). Thus, there are significant shortcomings and oversights in terms of impacts and consequences of compact form on local microclimates and what this means for energy demand, thermal comfort, air quality and health and wellbeing (Emmanuel & Steemers 2018). Extensive research has been done on the effects of urban form on local climate, thermal comfort and energy consumption over the past five decades. However, despite its recognition among researchers, there is dearth of research examining the dynamic relationship between built forms and overlying climate on air quality. While a number of studies analysing cities at a broad scale have emerged in the recent years, the degree to which urban form impacts air quality at street level; and urban form metrics that are pivotal in altering the ambient air quality and the wind environment are yet to gain wider attention. Acknowledging this, the proposed study aims at characterising the urban setting using a set of parameters and demonstrating the role of urban form in modifying the wind environment and the background air quality. The overarching goal of the study is to further the understanding on the subject and identify urban form metrics that may potentially inform the development of a broad planning framework that incorporates 'Built Form' driven effects on public realm while guiding urban development in a climate-sensitive manner.

2. Background

Several studies have used a set of urban geometry parameters to understand the corresponding implications on thermal comfort and energy consumption (For instance, see Chatzipoulka & Nikolopoulou 2018). Although this study did not explore the link between urban form and air quality, some of the metrics used are widely adopted for air pollution studies in urban areas. In 2014, Edussuriya et al. highlighted that street-level pollution is a multidimensional problem and deals with a large number of complex variables other than its source. The study analysed about 21 variables, of which only nine variables were found significant. This study, however, lacked wind simulation and was based only on statistical correlations between the urban form metrics and air quality. To fully understand the phenomena, it is essential to identify the critical parameters in action in an urban environment that affect air dispersion (Edussuriya et al. 2011). Since then, several studies have emerged; however, most of these studies are limited to isolated cuboids and do not reflect the real-world urban environment. Therefore, this study is the first attempt to investigate the street-level triadic relationship of a real-world case thoroughly. The dense nature of the built form and rising air quality concerns make the City of London an appropriate case study.

3. Method

Literature suggests that there appears to be a correlation between the urban form, wind environment and air pollution. While the different form may trigger changes in wind metrics, certain wind velocities, and turbulence conditions may contribute to the removal of pollutants (Yang et al. 2020). Thus, a framework based on this understanding has been considered for this study (Figure 1). In a broad sense, the study involves a detailed characterisation of the urban setting at street level and statistically exploring its influence on the simulated wind environment and observed air quality.

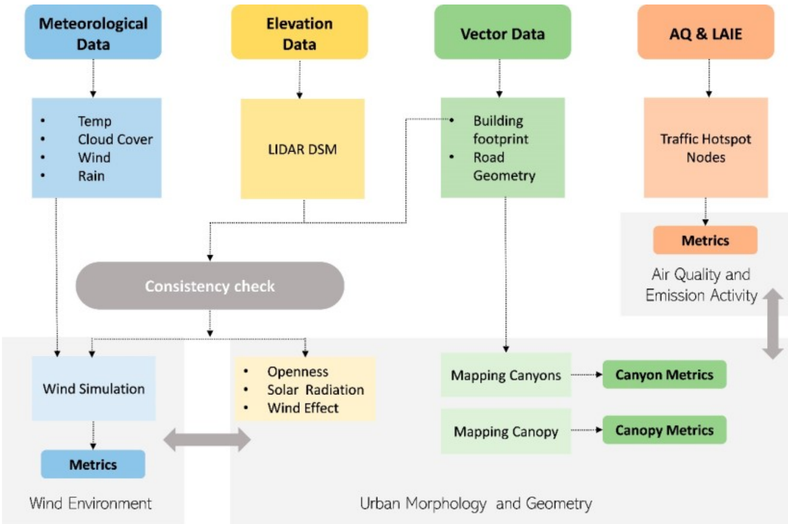


Figure 1. Methodological framework and approach adopted (Apsunde 2020)

3.1 Study area delineation, data collection and preparation

An Urban Climate Walking tour was availed with the help of Dr.J. Futcher, to explore the influence of building forms on the various urban climate effects and further its influence on the dispersion of heat and pollution. The walk along its route entails a network of air quality monitoring points (Futcher & Mills, 2020) - data from which has been used for this study. Thus, a radius of 900m from the centre of the climate walk route, covering all monitoring points, has been demarcated as the study area or the core analysis area for this exercise (Figure 2). For certain modelling tasks, an additional 20%, i.e. 360m buffer, has been considered to avoid computational errors along the periphery.

The data used for this study was obtained from primary and secondary data. For Elevation, roads and buildings from EDINA Digimap (Ordnance Survey), Meteorological Data from CEDA (MIDAS UK) and Accuweather Archives and Air Quality from Futcher & Mills (2020) and London Atmospheric Emissions Inventory (LAEI).

Table 1 offers a summary of the preparatory steps taken towards overcoming data gaps and preparing the data for subsequent steps.

Table 1. Data preparation steps (Apsunde 2020)

Data	***Summary of Preparatory Steps***	***Rationale***
Air Quality Observations	• Identified period with the least data gaps i.e. June to December 2018; • Out of the 82 Nitrogen Dioxide (NO_2) observation points across the study area; only those with temporal data coverage equal to or greater than (≥) 80% of the time-frame have been retained. • To fill the remnant data gaps, a combinatorial approach entailing cluster wise correlation matrix and geographical proximity has been deployed. In other words, observation points within the respective clusters are cross-correlated, and the observation points exhibiting high correlation and geographic proximity are used as predictors for data filling using linear regression model.	• Spanning over 08 clusters in the City of London area, the acquired AQ monitoring data comprises of significant temporal gaps. The rationale behind this approach is to overcome the effects of missing data while avoiding excessive data filling and retaining the representativeness of the field observations.
Building Footprint and Height & Lidar Digital Surface Model (Elevation)	• Using satellite images on the Google Earth Pro (GEP) platform in conjunction with the New London Architecture (NLA) database on new constructions, the building footprint & height data has been validated prior to its application in the study. Using ArcGIS 10.8 and GEP, new buildings are included while the demolished ones are excluded. • The Lidar DSM data has been validated and rectified using the updated Building Footprint and Height data as references. Towards this end, tools like Create a Constant Raster, Raster Calculator, Conditional Function, and Mosaic to New Raster available in the ArcGIS environment are applied in combination.	• The building footprint and height data is a crucial input towards computing the urban morphological parameters, thus it is essential to ensure that the building data corresponds to the state of built form during the identified AQ monitoring time-frame. • Representing elements like trees, buildings, bridges, etc. the surface data obtained in the form of 1 km x 1 km Lidar Digital Surface Model (Lidar DSM) images of 0.5m resolution, corresponds to the acquisition period 2009-2015. Considering the fine resolution of the surface data, it has been preferred for the wind and solar simulations discussed in later parts of this report. However, prior to use, it is ensured that the data corresponds to the surface characteristics of the study timeline.
Meteorological Data		
Wind	• Identified three UK Met Office observation stations close to the study area. • Computed seasonal and overall wind characteristics like wind direction and speed at 33 m height.	• Apart from serving as key inputs towards executing wind simulation exercises, the computed parameters on wind, temperature and cloud cover allow for a better understanding of the study area meteorological profile.
Temperature	• The monthly, seasonal and overall values of parameters such as maximum temperature (Tmax), minimum temperature (Tmin), rainfall, and the number of Rainy days are computed.	
Cloud Cover	• Cloud cover has been estimated using the sunshine hours and the possible daily sunshine hour for the respective month	• Data on cloud cover was not available. However, studies have found sunshine based estimation of cloud cover considerably reliable observations *(Hoyt, 1977)*.

3.2 Characterisation of urban form

Despite the heterogeneity of the urban canopy in almost any real city, it is useful to describe the built form and the spaces in between in terms of quantifiable measures that express its properties that influence the micro-scale climate (Erell et al. 2015). For this study, the urban form has been primarily described using geometrical parameters pertaining to street canyons and urban canopy. Tools like the GIS based Street Canyon and Urban Canopy Tools by CERC in combination with road network, building geometry and height data have been used to compute urban canyon and canopy primary descriptors such as Canyon Heights (Maximum, Minimum, and Average), Canyon Width, Canyon Length, and Built Length, Plan Area Density (PAD), Frontal Area Density (FAD), and Canopy Height. Additional parameters based on these descriptors have been developed (Table 2).

Table 2. Computed descriptive metrics/parameters

Metric Name	***Definition***	***Formula***
Height-Width Ratio (HWR) <u>OR</u> Aspect Ratio ***[Left Side, Right Side and Average]***	Ration between the average height of adjacent vertical elements (facades) and the average width of the space between them. (Evyatar Erell, Pearlmutter and Williamson, 2015)	$\boldsymbol{HWR} = \frac{Canyon\ Height_{Left,Right,Avg}}{Canyon\ Width}$
HWR Difference (HWR_Δ) – Left to Right	Arithmetic difference between the left-side aspect ratio and the right-side aspect ratio.	$\boldsymbol{HWR_\Delta} = HWR_{Left} - HWR_{Right}$
Length-Width Ratio (LWR)	Ratio between the average length of the mapped canyons and the average width of the space between the adjacent vertical elements. (Evyatar Erell, Pearlmutter and Williamson, 2015)	$\boldsymbol{LWR} = \frac{Canyon\ Length_{Average}}{Canyon\ Width}$
Canyon Coverage (CC)	Ratio between the average length of vertical elements (Built Length) on either sides and the length of mapped canyons.	$\boldsymbol{CC} = \frac{Built\ Length_{Average}}{Canyon\ Length_{Average}}$
Built Length-Width Ratio (BLWR)	Product of CC and LWR. May also be interpreted as effective LWR.	$\boldsymbol{BLWR} = CC\ x\ LWR$
Height Difference – *Left side to Right* side (HDLR)	Arithmetic difference between the average height of vertical elements on the left and right sides of the canyons.	$\boldsymbol{HDLR} = Avg.Height_{Left} - Avg.Height_{Right}$
Height Difference (HD)	Arithmetic difference between mean maximum height of the vertical elements and the average height of vertical elements in canyons. (Yang et al., 2020)	$\boldsymbol{HD} = Max.Height_{Avg.} - Avg.Height$
Canyon Normality (CN)	A measure which is a function of both canyon and wind orientations with respect to North. With values ranging from 0 to 1, the purpose of CN is to indicate the degree of normality between the longitudinal canyon axis and the incident wind flow.	$\boldsymbol{CN} = \left\lvert \sin[\theta_{wind} - \theta_{Canyon}] \right\rvert$ *Here,* θ_wind = Wind Orientation w.r.t North; θ_Canyon = Canyon Orientation or Street Bearing w.r.t North.
Built Volume (B_Vol)	This metric is a measure of the total building volume within a grid cell.	**B_Vol** $= \boldsymbol{PAD\ x\ Avg.Canopy\ Height\ (H)}$

In this study, a new metric, Effective Frontal Area, has been adopted. It is a function of the frontal area density in a specified wind direction and frontal advantage. It is expressed as:

$$Eff.\lambda_{Frontal.} = \{\lambda_{F.Adv.}\} + \{\lambda_{Frontal.}\}$$

Here, λF.adv. = Frontal Advantage; λFrontal = Frontal Area observed within the grid cell of interest.

Frontal Advantage is a measure based on the frontal area of grid cells surrounding the cell of interest in all 8 directions. Frontal advantage uses the FAD values of neighbouring cells and identifies whether a grid cell is advantaged or disadvantaged due to its position. Frontal advantage is negative when the mean FAD value on the upwind side is higher than the downwind side, and vice-versa.[1]

The study also incorporates metrics based on terrain and climatic factors. Using surface elevation data in GIS, parameters like Topographic Openness (TO), a multi-directional measure expressing the degree of dominance or enclosure of a location on an irregular surface (Yokoyama et al. 2002); Wind Effect (WE), a dimensionless index (Boehner & Antonic 2009) wherein values below 1 indicate wind shadowed area while values above 1 indicate wind-exposed areas; and Global Solar Radiation have been computed.

3.3 Traffic hotspot analysis and node exposure

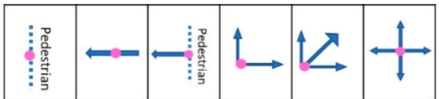
Owing to temporally non-uniform traffic data, the LAEI data (2016) has been considered for identifying the activity-based hotspots in the study area. Using the LAEI-NO_2 dataset in conjunction with incident (sample) points spaces 10 m apart along the road network, statistically significant hot and cold spots were identified by executing the Getis-Ord Gi* statistics based Hot-spot Analysis tool in ArcGIS. The tool assigns a Z-score value to all the incident points, indicating their respective standard deviation. Based on the Z-score ranges (Table 3), the incident points are classified into Hot Spots and Cold Spots at varying confidence level.

The way traffic functions around nodes (junctions), high accumulation and slow movement ,often creates pockets of higher pollution concentrations the locations of which may shift owing to the traffic dynamics and airflows around junctions (Gokhale 2011). Several AQ observation points are located on nodes of some form.

Table 3. Z-score ranges (Apsunde 2020)

z-score (Standard Deviations)	p-value (Probability)	Confidence level
< -1.65 or > +1.65	< 0.10	90%
< -1.96 or > +1.96	< 0.05	95%
< -2.58 or > +2.58	< 0.01	99%

Table 4. Node exposure score (Apsunde 2020)



0	1	1	2	3	4

Thus, in order to capture the influence of nodes on AQ observations, a simplistic approach wherein all the observation points are given a 'node exposure score' depending on the type of node and number of road segments they are exposed to (Table 4).

[1] Given the limited scope of this article, conceptual explanation on Effective Frontal Area has been significantly curtailed. For further information please contact the author at kiran.aps01@gmail.com

3.4 Wind simulation and metrics

The built environment's heterogeneity in form and the consequent surface roughness greatly influences the urban wind environment. Towards this end, wind simulation exercises based on the principles of Computational Fluid Dynamics (CFD) help in deepening our understanding of the wind behaviour in urban areas while further facilitating in deciphering the urban form factors or metrics that act as strong manipulators of wind flow.

For this study, wind simulation i.e. computation of spatially varying wind field, is performed using WindNinja, a computer program that is specifically designed to simulate the effect of terrain on wind flow. WindNinja uses elevation data in conjunction with the domain mean meteorological parameters to simulate wind behaviour. Spatially distributed wind vectors of varying speed and direction are the key output of the simulation exercise. Two runs, at 6m and 12m height from the ground level, have been undertaken to arrive at the wind speed and direction pattern across the study area at 3m spatial resolution.

Any change in the wind metrics along the horizontal and vertical plane may indicate the state of pollution dispersion i.e. higher the deviation in wind metrics larger is the influence on the gas or pollution concentration (Eddy Flux principle). Thus, additional metrics on vertical and horizontal fluctuations in wind behaviour have been computed (Table 5).

Table 5. Wind metrics (Apsunde 2020)

Wind Metric	Plane	Description	Calculation method
Turbulence Intensity (@ 6m and 12m)	Horizontal	Turbulence intensity is defined as the ratio of standard deviation of fluctuating wind velocity to the mean wind speed, and it represents the intensity of wind velocity fluctuation.	$TI = \frac{\sigma_u}{\bar{u}}$
Wind Speed Flux	Vertical	Change in wind speed per meter height	$Flux = \frac{x_6 - x_{12}}{6}$ Here, X6 = Value at 6m; X12 = Value at 12m.
Wind Direction Flux	Vertical	Change in wind direction per meter height.	
SD Speed Flux	Vertical	Change in SD of wind speed per meter height.	
SD Direction Flux	Vertical	Change in SD of wind direction per meter height.	
Turbulence Intensity Flux	Vertical	Change in Turbulence Intensity per meter height.	

3.5 Exploratory regression analysis and correlation matrix

At this stage, the triadic relationship between urban form, wind flow, and air quality at street level has been explored statistically**.** Using exploratory regression method, the significant variables and the nature of relationship with dependent (response) variables such as wind flow and air quality has been identified. Later, using Pearson's correlation matrix the strength of the relationship, i.e. the degree of influence of the independent (predictor) variables have been presented. Exploratory Regression & Correlation analysis has been performed twice in this study.

*3.5.1 Urban form and the wind environment***:** Firstly, the analysis is conducted to understand the influence of urban form on wind speed (dependent variable) across all the canyons in the study area. At this stage, altogether 42 explanatory variables have been deployed.

3.5.2 Air quality, urban form and the wind environment: Since the AQ observation point does not cover the entire spatial extent of the study area, only canyons with AQ observations are considered for exploring the triadic interaction. Here, AQ is treated as the dependent variable, while variables pertaining to the wind and urban form are considered as explanatory variables. At this stage, about 64 explanatory variables have been deployed.

4. Results

4.1 Air quality and meteorological profile

The study period extends over two seasons viz. Summer (June to September) and Autumn (September to December). The air quality trend in the study area indicates that as the study area progresses from Summer to Autumn, the overall air quality worsens, i.e. NO_2 concentration values increase (Table 6). While two clusters (6 & 7a) witness enhanced air quality in Autumn, there is an overall increase of 5.62% in NO_2 concentration across the monitoring network. Among the clusters witnessing an increase in NO_2 concentration, clusters 4,6,7a and 10 are the most affected. These clusters also exceed the overall study area mean concentration of 59.29 ug/m^3. All clusters, except for cluster 7 in Summer, have mean concentration values exceeding the UK and EU limit of 40 ug/m^3.

Table 6. Seasonal AQ – Nitrogen Dioxide (Apsunde 2020)

Cluster Name	Summer	Autumn	Overall	% Change - Seasonal
2	49.22	55.58	52.40	12.92
4	59.20	65.22	62.21	10.16
6	78.10	69.98	74.04	-10.39
7	39.25	44.88	42.07	14.34
7a	87.04	74.70	80.87	-14.18
8	40.72	46.64	43.68	14.55
9	52.23	54.55	53.39	4.45
10	66.33	71.86	69.10	8.33
ALL	**57.66**	**60.91**	**59.29**	**5.62**
Unit: ug/cu.m				

While the Summer values of NO_2 are considerably low, it is observed that the variation in concentration i.e. the standard deviation of NO_2 in Summer (19.67) across the study area is significantly higher than in Autumn (15.5). This holds true even at the cluster level, where high variability in concentration is witnessed during summer (Table 7). Spatial distribution of air quality indicates that the NO_2 concentration spikes around street nodes and junctions, especially around Bank of England (A) area and the intersection between Camomile Street and Bishopgate Street (B) (Figure 2). Clusters with pedestrian streets or the ones located away from busy roads, exhibit lower NO_2 concentration values. For example, see cluster 2 in the North-West; and clusters 7, 8 and 9 in the East and South.

Table 7. Cluster-wise AQ descriptive statistics (Apsunde 2020)

Cluster Name	Observation Points	Timeframe	NO_2 Concentration (ug/cu.m)				
			Minimum	Maximum	Range	Mean	Standard Deviation
2	14	Summer	35.49	78.91	43.42	49.22	12.98
		Autumn	44.53	82.28	37.75	55.58	11.81
		Overall	**40.01**	**80.51**	**40.50**	**52.40**	**12.29**
4	8	Summer	37.85	90.25	52.40	59.20	16.99
		Autumn	45.62	82.77	37.15	65.22	12.07
		Overall	**41.74**	**86.51**	**44.78**	**62.21**	**14.32**
6	3	Summer	69.73	94.22	24.49	78.10	11.40
		Autumn	64.38	81.00	16.62	69.98	7.79
		Overall	**67.15**	**87.61**	**20.46**	**74.04**	**9.59**
7	6	Summer	32.27	50.08	17.81	39.25	6.52
		Autumn	40.91	46.60	5.69	44.88	1.92
		Overall	**38.51**	**47.73**	**9.22**	**42.07**	**3.56**
7a	6	Summer	70.52	95.54	25.02	87.04	8.81
		Autumn	63.50	84.73	21.23	74.70	7.87
		Overall	**67.01**	**89.66**	**22.65**	**80.87**	**7.70**
8	7	Summer	34.88	44.60	9.72	40.72	3.71
		Autumn	39.25	55.06	15.81	46.64	5.64
		Overall	**37.71**	**49.04**	**11.33**	**43.68**	**3.97**
9	6	Summer	33.58	77.18	43.60	52.23	15.72
		Autumn	41.82	69.64	27.83	54.55	10.22
		Overall	**38.55**	**73.41**	**34.86**	**53.39**	**12.92**
10	15	Summer	38.39	116.54	78.14	66.33	18.22
		Autumn	43.20	115.31	72.11	71.86	16.50
		Overall	**40.80**	**115.92**	**75.13**	**69.10**	**16.85**

The observations across the study region indicate that the autumn months witness a higher wind velocity in comparison to the summer months (Figure 2). Across the entire study period, the mean velocity has been observed to be about 13.48 km/h. The mean incident direction calculated based on hourly wind observations from June to December 2018 is 193.66° with respect to North. The same tends to lean more towards south-southwest in Summer (195.85°), and towards South (191.47°) in Autumn.

Figure 2. Study area, air quality and meteorological profile (Apsunde 2020)

4.2 Urban form characteristics

4.2.1 Building height distribution: A standard deviation-based height distribution indicates that about 82.4% (3684) buildings in the study area are lower than 45.2m in their height. Buildings with the height ranging from 27.3m to 45.2m (n=2441) constitute the largest share of buildings (54.6%) in the study area. There are about 100 towers in the study area that are taller than 80m. Most of these towers (shown in red) are in close proximity to each other, especially near the study area centre, and are clustered along the Bishopgate Street (indicated with a purple dotted line in the Map) (Figure 3a). Buildings ranging in height from 45.2 to 63 m constitute only 13.38% (n=598) of the total number of buildings in the study area. However, despite the low share in numbers, owing to their large size, they have significant spatial coverage across the study area (see buildings shown in orange colour).

4.2.2 Urban canyon metrics: Results (Table 8) indicate that the average canyon height across the study area is 45.22m, while the mean canyon length is about 52.95m. The mean HWR in the study area is 3.34, and the canyon coverage is 0.95 on an average (Figure 3f). Besides indicating that the canyons throughout the study area remain heavily sheltered from the wind and natural light, this also suggests that the urban form surrounding the canyons is dense and of a complex nature. The mean Length-width ratio for the study area is about 4.26. In general, high LWR values are observed in narrow internal streets that are surrounded by large buildings (Figure 3e). There is significant variability in the vertical elements along the mapped canyons. The deviation of the average maximum canyon height from the mean height is 8.73m, which is considerably high (Figure 3d). In general, the right side of the canyon is taller than the left side by 0.78m (Figure 3c). However, the standard deviation value indicates that there is a massive variability in the elevation differences between the two sides. Much of these variations in building heights root from the clusters of tall towers near the study area centre.

4.2.3 Canyon normality: The canyon normality assessment shows that the study area is mostly composed of canyons that either highly or mildly (low) normal to the incident wind direction. Out of the 826 identified canyons, 334 (40.44%) exhibit high normality (Angle range: 60-90), while 322 (38.92%) exhibit low normality (Angle range: 0-30). Moderately normal canyons (Angle range: 30-60) which are about 170 in number (20.58%) are a minority (Figure 3b). The seasonal variations in the wind direction have a slight influence on the canyon normality values. Across the study region, there is an overall decline in the CN values. This indicates that canyon normality, in general, is slightly higher in summer than in Autumn. In other words, wind flow in Summer observes more surface roughness or dissipation or potential wind deflection than in Autumn (Table 9).

Table 8. Summary of canyon metrics (Apsunde 2020)

Descriptor	Left		Right		Overall	
	Mean	Std.Dev	Mean	Std.Dev	Mean	Std.Dev
Width	-				18.17	11.80
Avg. Height	44.83	21.09	45.61	22.00	45.22	21.55
Min. Height	34.08	18.34	33.73	16.65	33.90	17.49
Max. Height	48.83	24.93	50.33	27.84	49.58	26.39
Length	52.98	38.34	52.93	37.84	52.95	38.09
Built Length	49.21	34.90	49.20	34.50	49.21	34.70
CC	-				0.95	0.09
HWR	3.30	2.20	3.39	2.41	3.34	2.05
HWR Difference	-				-0.09	2.09
LWR	-				4.26	3.98
BLWR	-				4.02	3.77
HDLR	-				-0.78	25.93
HD	-				8.73	16.50

Table 9. Summary of canyon normality metrics (Apsunde 2020)

Normality Class	Timeframe	Canyon Normality (CN)					
		Minimum	Maximum	Range	Mean	Std. Deviation	% Change in Mean CN *(Summer to Autumn)*
High	Summer	0.853	1.000	0.147	0.968	0.035	0.380
	Autumn	0.848	1.000	0.152	0.972	0.033	
	Overall	0.868	1.000	0.132	0.971	0.033	
Medium	Summer	0.472	0.882	0.411	0.708	0.105	0.190
	Autumn	0.468	0.884	0.416	0.710	0.111	
	Overall	0.502	0.866	0.364	0.709	0.105	
Low	Summer	0.002	0.531	0.529	0.184	0.138	-2.679
	Autumn	0.002	0.523	0.521	0.179	0.131	
	Overall	0.002	0.498	0.496	0.179	0.133	

4.2.4 Urban canopy metrics: Results (Table 10) indicate that across the study area, the Plan Area Density is about 0.54 i.e. 54% of the land area is covered by buildings. The same along the canyons is about 0.446. PAD values are high in pockets where the streets are narrow, and buildings are either densely packed or have high ground coverage (Figure 3k). The Frontal Area Density (FAD) value is 2.653 across the study area at canopy grid level (25 x 25m), while the same along the canyons is about 2.423. FAD values are higher in areas where tall buildings are present (Figure 3i). Since FAD is a function of wind direction, the value changes as the study area progress from Summer to Autumn. A similar pattern, as observed for canyon normality in the preceding section, is observed in the case of FAD values. The values at both canopy grid and canyon levels, witness a decline of 2% on an average. This substantiates the understanding that surface roughness or flow dissipation or wind deflection is potentially higher in Summer than in Autumn.

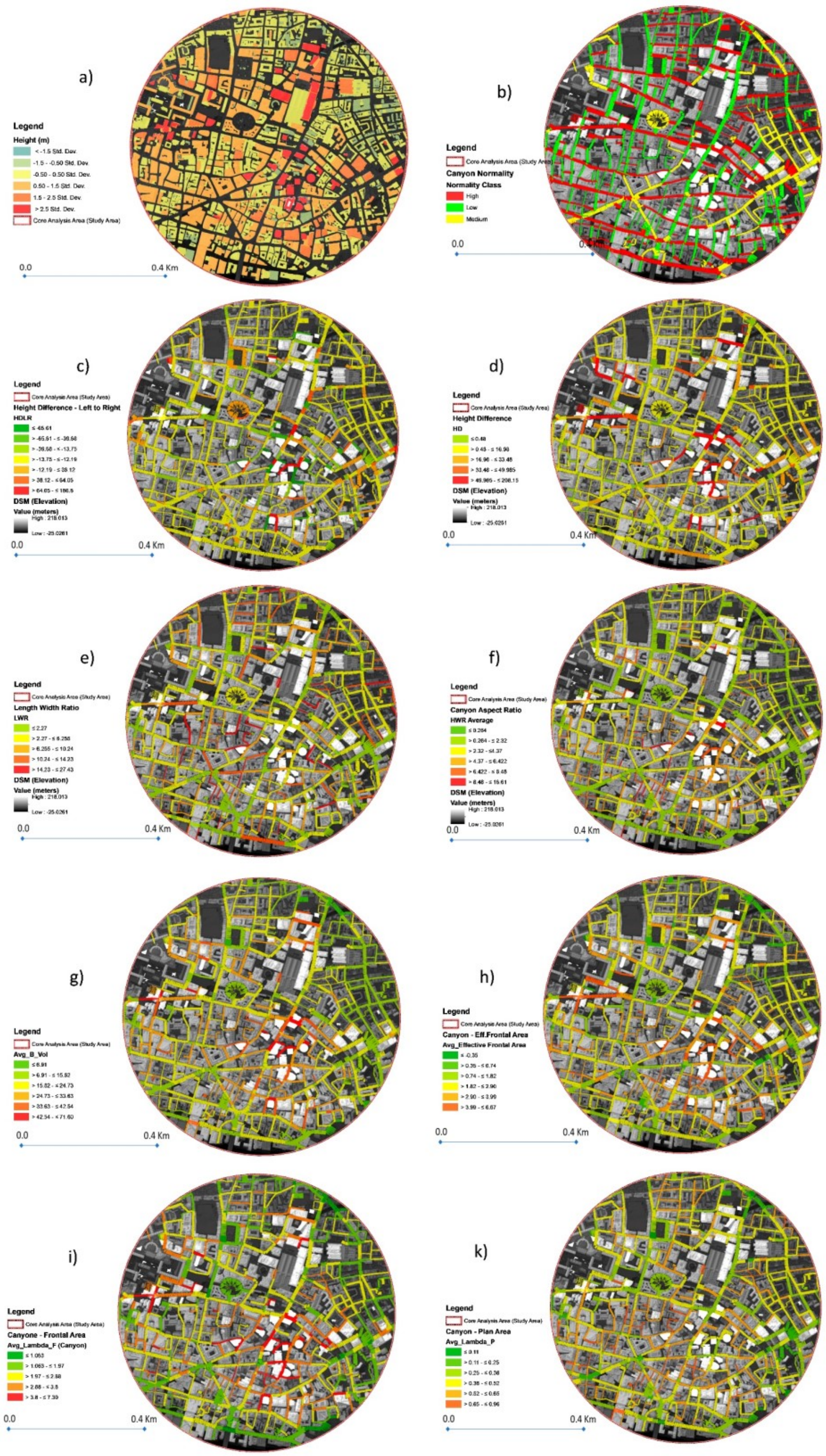


Figure 3. Urban form metrics (Apsunde 2020)

Table 10. Statistical Urban canopy metrics (grid and canopy level) (Apsunde 2020)

Descriptor	Canopy Values - Study Area		Canyon Values	
	Mean	Std.Dev	Mean	Std.Dev
PAD	0.54	0.30	0.446	0.135
FAD - Summer (25m)	2.680	1.73	2.446	0.910
FAD - Autumn (25m)	2.626	1.71	2.400	0.904
FAD - Overall Timeframe (25m)	2.653	1.72	2.423	0.907
FAD - Overall Timeframe (50m)	2.646	1.308	2.563	0.895
FAD - Overall Timeframe (75m)	2.652	1.080	2.604	0.806
Built Volume	26.04	21.07	20.271	8.907
Effective FAD (Overall @25m)	2.672	2.130	2.360	1.082
FAD - Overall North (25m)	2.663	1.718	2.417	0.876
FAD - Overall Northwest (25m)	2.666	1.717	2.677	0.996
FAD - Overall West (25m)	2.653	1.723	2.646	0.992
FAD - Overall Southwest (25m)	2.637	1.734	2.628	1.033
FAD - Overall South (25m)	2.640	1.731	2.554	1.106
FAD - Overall Southeast (25m)	2.641	1.731	2.803	1.285
FAD - Overall East (25m)	2.655	1.724	2.682	1.126
FAD - Overall Northeast (25m)	2.664	1.720	2.602	0.994
Avg. Canopy Height	44.915	24.013	43.489	14.594

The Effective FAD, which takes into consideration the difference between upwind and downwind frontal areas, is 2.36 at the canyon level across the study area. Since, Effective FAD takes, frontal advantage into consideration, the spatial distribution across the site (Figure 3h) is more discrete in comparison to the FAD distribution.

The Built Volume Density, which is a function of PAD and canopy height, is 26.04 m^3/m^2 across the study area. While the same at the canopy level is about 20.28 m^3/m^2. Like the spatial trend observed in FAD, canopy grids with tall buildings exhibit very high built volume density values, especially in clusters 6, 7a, 7, 8 and 4 (Figure 3g).

4.2.5 Terrain and climate related metrics: Results (Table 11) indicate that canyons grouped under medium normality class, have higher openness values, while the ones with low normality have relatively low openness value. In general, narrow streets and spaces between buildings, i.e. enclosed spaces have lower openness values, and building roofs, wide roads, and open spaces have higher TO values (Figure 4a).

Table 10. Statistical summary of the terrain and climate-related metrics (Apsunde 2020)

Canyon Descriptors	Normality Class	Statistical Parameters		
		Range	Mean	Std. Dev.
Openness	High	12036.76	36.04	8.93
	Medium	6671.99	39.25	8.27
	Low	11123.56	34.55	9.51
	ALL	**81.54**	**36.12**	**9.20**
Solar Radiations (KWH/sq.m)	High	67134.30	201.00	86.03
	Medium	40809.52	240.06	80.38
	Low	67766.85	210.46	80.93
	ALL	**546.32**	**212.72**	**84.18**
Wind Effect (Direct)	High	292.26	0.88	0.04
	Medium	151.53	0.89	0.03
	Low	289.94	0.90	0.06
	ALL	**1.17**	**0.89**	**0.05**

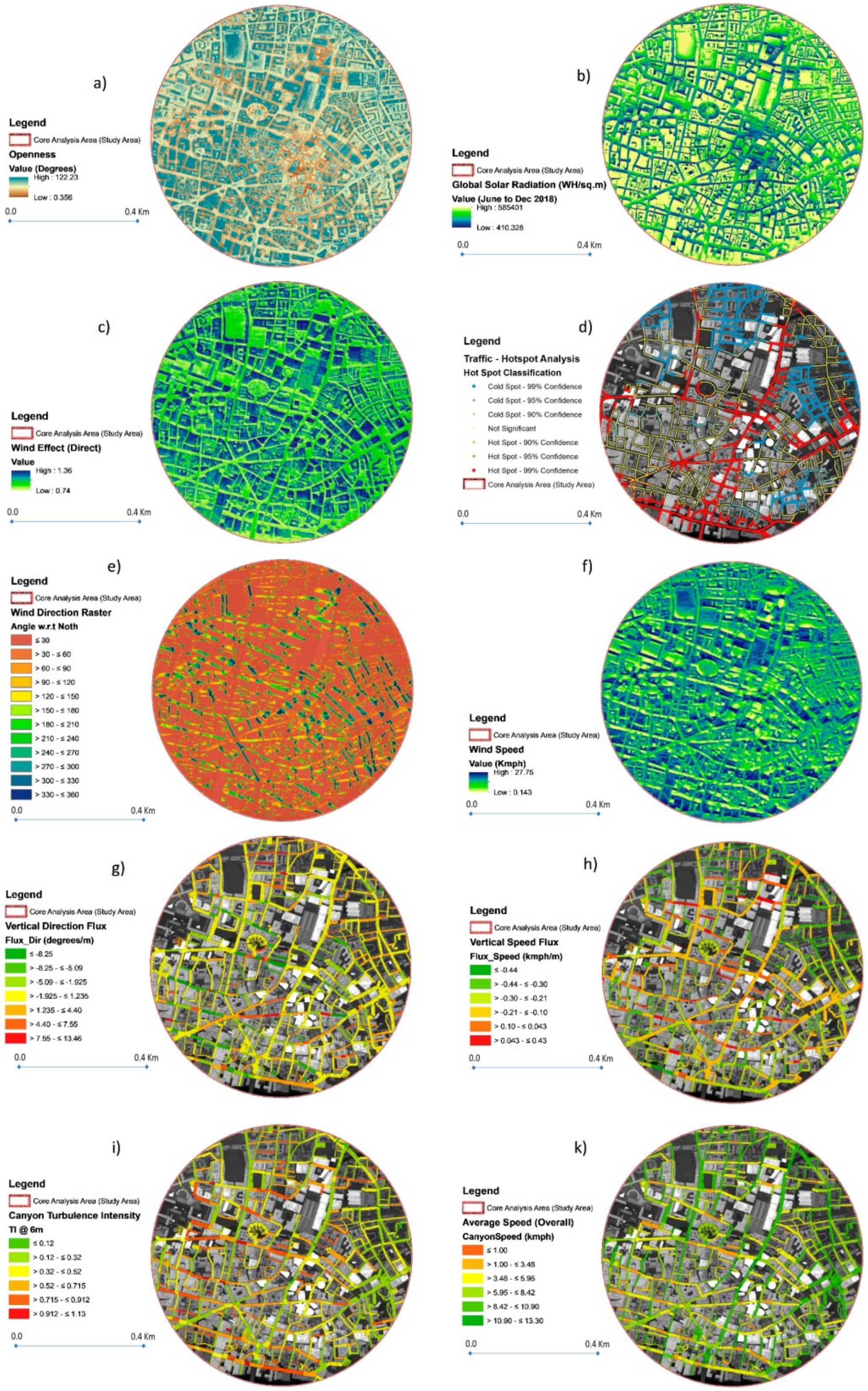


Figure 4. Terrain, climate, traffic and wind metrics (Apsunde 2020)

Canyons grouped under moderate normality receive more solar radiations in comparison to other normality classes. Overall, canyons shadowed by tall towers in the study area exhibit poor solar insolation (Figure 4b). Across all the normality groups, highly normal canyons are more most deprived of solar insolation, and the mean insolation value is about 20% lower than that of moderately normal canyons.

The spatial distribution of Wind Effect across the study area indicates that building roofs are more exposed than the street canyons. Vertically, the value of WE tends to rise with the rise in building heights while on the horizontal plane the WE value is higher for streets or canyons that are most aligned with the dominant wind direction which in this case is 193.66 degrees from North (Figure 4c).

4.3 Traffic hotspot and emissions intensity

The traffic hotspot analysis indicates that across the study area, junctions are prominent hotspots (Figure 4d). It can be inferred from the hotspot analysis that clusters 6,7a, 9, 4, and 10 of the air quality monitoring campaign, have most of their points in pockets classified as hotspots. This broadly substantiates for the high concentration values observed in these pockets of the cities. On the other hand, clusters 2, 7, and 8 have most of their observation points in pockets that are either classified as cold spots or non-significant with regards to the emission intensity activity.

4.4 Wind simulation and metrics

Across all the canyons in the study area, the mean wind speed is about 7.19 kmph. Canyons with high normality exhibit the lowest mean speed (5.3 kmph) while canyons with low normality have the highest mean wind speed (9.04 kmph). On the other hand, the wind speed deviation is higher in canyons that are highly normal to the wind flow while the same for moderately or mildly normal canyons remain relatively low (Table 11).

Along the vertical plane (Table 12), the least changes are observed in the canyons of high normality in comparison to the other two classes. This indicates that along the vertical plane, the wind environment remains relatively more consistent in canyons that are highly normal.

Table 11. Wind metrics for 6m height (Apsunde 2020)

Descriptors @ 6m	Normality Class	Statistical Parameters		
		Range	Mean	Std. Dev.
Wind Speed	High	11.77	5.30	1.86
	Medium	12.83	7.38	1.84
	Low	13.30	9.04	1.78
	ALL	**13.30**	**7.19**	**2.47**
Wind Direction	High	309.54	188.48	48.24
	Medium	265.02	195.12	33.96
	Low	231.16	192.06	19.33
	ALL	**309.54**	**191.24**	**36.48**
SD Speed	High	5.11	2.73	0.72
	Medium	5.43	2.49	0.82
	Low	6.17	2.59	0.80
	ALL	**6.17**	**2.63**	**0.78**
SD Direction	High	145.49	59.70	35.46
	Medium	133.04	27.25	22.07
	Low	110.78	16.06	13.58
	ALL	**145.49**	**36.01**	**32.84**
Turbulence Intensity	High	1.13	0.56	0.19
	Medium	0.84	0.36	0.15
	Low	0.92	0.30	0.13
	ALL	**1.13**	**0.42**	**0.20**
Wind Effect (Direct+Indirect)	High	0.44	0.93	0.06
	Medium	0.35	0.94	0.07
	Low	1.21	0.94	0.09
	ALL	**1.25**	**0.93**	**0.07**

Table 12. Wind metrics for 12m to 6m height (Apsunde 2020)

Flux Descriptors (Vertical Gradient: 12m to 6m)	Normality Class	Statistical Parameters		
		Range	Mean	Std. Dev.
Wind Speed Flux	High	1.136	-0.207	0.176
	Medium	0.802	-0.238	0.107
	Low	0.652	-0.238	0.087
	ALL	**1.136**	**-0.225**	**0.134**
Wind Direction Flux	High	28.613	-0.779	4.562
	Medium	18.966	0.074	2.392
	Low	8.714	-0.115	0.815
	ALL	**28.613**	**-0.345**	**3.160**
SD Speed Flux	High	0.682	0.027	0.108
	Medium	0.495	0.067	0.069
	Low	0.357	0.080	0.054
	ALL	**0.682**	**0.056**	**0.086**
SD Direction Flux	High	24.053	5.431	4.623
	Medium	19.711	2.155	2.466
	Low	13.007	1.101	1.429
	ALL	**24.053**	**3.069**	**3.824**
Turbulence Intensity Flux	High	0.242	0.018	0.032
	Medium	0.099	0.017	0.013
	Low	0.100	0.015	0.009
	ALL	**0.242**	**0.017**	**0.022**

As expected, the change in wind direction along the horizontal plane is higher in highly normal canyons while the same remains relatively low in mildly normal canyons. A similar pattern is observed in the wind direction deviation along the vertical plane. In comparison to the other canyon classes, highly normal canyons observe more directional deviation, indicating the formation of vortex, eddies or rotating cells.

The turbulence intensity along the horizontal plane is high in canyons that are highly normal to the wind flow while the same remains low for canyons with low normality. A similar pattern has been observed along the vertical plane. Vertically, the value of Wind effect tends to rise with the rise in building heights, while on the horizontal plane the WE value is higher for streets or canyons that are most aligned with the dominant wind direction which in this case is 193.66 degrees from North. Refer Figure 4e to 4k.

4.5 Exploratory regression and correlation analysis

4.5.1 Urban form and the wind environment: The variables in the illustrations above are presented in accordance to their significance as predictors of Wind velocity. Figure 5A represents the consistency of the variable relationship while Figure 5B indicates the overall significance and strength of relationship using Pearson's correlation (R). out of the 42 variables deployed for this analysis, 22 were found to have a statistical significance of greater than 50%.

The newly incorporated metrics like Canyon Normality, Global Solar Radiation, Topographic Openness and Wind Effect, are found amongst the strongest predictors. Additionally, the use of surrounding FAD values (@25m) confirms that they strongly influence the wind environment of the point they enclose. In this case, FAD-N (North), FAD-S (South), and FAD-SW (South-West) were found amongst the stronger predictors. Further, this also suggests that the nature of the relationship with surround FAD values need not be consistent across, i.e. while some surrounding FAD values may show a positive relationship with the dependent variable, others may differ.

FAD values for the study area have been computed at 25m resolution, however, in order to understand their representativity, they have been additionally aggregated to 50m and 75m resolutions. Out of these three resolutions, FAD-50m is found to exhibit a better relationship in comparison. Thus, for an intra-city comparison on urban form and wind speed, FAD values at 50m may be used.

PAD shows a strong negative influence on the wind environment. This indicates that an increase in PAD increases the surface roughness and canyon enclosure, thus dissipating the wind flow.

4.5.2 Air Quality, urban form and the wind environment: The illustrations Figure 5C & 5D correspond to the exploratory regression analysis undertaken using 64 explanatory variables to explore the triadic relationship between air quality, the wind environment and the urban form. This analysis, which is performed for 63 canyons with AQ observations, shows that out of the 64 variables deployed, 10 are found to have a statistical significance of greater than 50%. Some of the newly incorporated metrics feature amongst these top 10 predictors.

As anticipated, the proximity of the AQ observation points to emission intensity hotspots, expressed using Z-score and Node exposure (JN), has a strong positive influence on the AQ observations, i.e. AQ worsens. Likewise, exposure to wind, expressed using WEDI and Std. Deviation of WEDI shows a strong negative influence on air quality, i.e. AQ improves with enhanced exposure to wind. Amongst neighbouring FAD metrics, FAD-Northwest and FAD-North have a strong negative influence on air quality. The Effective FAD, intended to capture the influence of surrounding frontal areas, is one of the most significant predictors and exhibits a strong negative influence on air quality.

Although of relatively low significance, the wind metrics obtained at 12 m such as Turbulence Intensity and Std. Deviation of speed are better predictors of AQ than those obtained at 6m height.

The HWR of the right-side of canyons, which in most cases faces the windward direction, is one of the strongest predictors with a strong negative influence on AQ. This implies that the air quality may get better in areas where the HWR is high, thus indicating the plausible positive consequences of tall buildings on local AQ.

Although of statistically low significance, metrics like Topographic Openness and Global Solar Radiations that exhibit a strong positive influence on wind speed, indicate a negative relationship with air quality, i.e. AQ worsens with the increase in TO and GSR values. This can be attributed to the positive relationship of these parameters with Road width which in turn is strongly related to heightened traffic activity.

In Figure 5: graphs A and C correspond to Variable relationship consistency; B and D correspond to variable statistical significance and correlation.

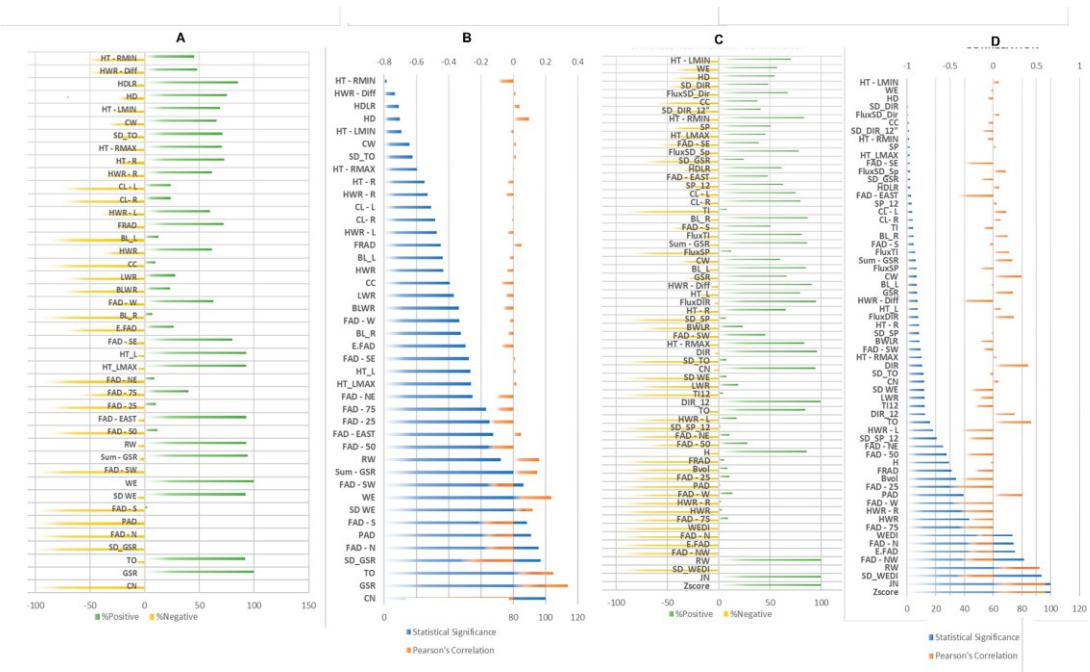


Figure 5. Exploratory Regression and Pearson's Correlation (Apsunde 2020)

5. Implications and Conclusions

The study has undertaken a detailed characterisation of the urban form within the study area and thus has paved a solid foundation for further studies to investigate the subject in detail. Out of the 42 metrics used to investigate the influence of urban form on wind pattern, 22 are found to have a statistical significance of greater than 50%. Moreover, out of the 64 variables used towards investigating the role of wind and urban form metrics on AQ, 10 are found to exhibit a statistical significance of greater than 50%. Amongst the newly introduced parameters Canyon Normality, Topographic Openness, Global solar Radiation, Effective Frontal Area, Wind Effect, Node Exposure and traffic Z-score are identified as statically significant predictors with a strong influence on the wind environment and consequently, the ambient air quality. The study reiterates the significance of incorporating traffic dynamics in studies pertaining to the interaction between urban form, wind environment and air pollution. Further, the high concentration of air pollutants around nodes invites planning authorities to be more vigilant about the proposed urban form around nodes, especially with regards to FAD or Effective FAD (EFAD). Traffic being the primary source of pollution, the metric on traffic shows a highly significant positive correlation with AQ. This implies that traffic management is still key to urban air quality management.

The outcomes of this study can be used towards undertaking the following studies:

1.	Comprehensive Urban Ventilation Index	This study has demonstrated that Topographic Openness, Solar Insolation, Wind Effect and Proximity to Traffic hotspots are significant predictors of air quality and wind behaviour in the study area. Thus, a comprehensive ventilation index based on the IPCC Exposure (Traffic), Sensitivity (Lack of Openness) and Adaptive Capacity (Wind Effect) Framework is proposed for further evaluation.
2.	Simulation-based sensitivity analysis of urban form	Based on the existing characterisation of the urban form, some key canyons or neighbourhoods may be identified for scenario-based simulations exploring the changing interaction between urban form, solar insolation and wind, and their consequent implications on the ambient air quality.
3.	Logistic regression-based hotspot mapping	A logistic regression-based hotspot prediction model may be developed. Towards this end, the urban geometrical and morphological metrics developed in this study may be deployed in conjunction with the field-based AQ observations, and thus a probabilistic model that may be applied towards identifying air pollution hotspots in the city with regards to either existing or proposed urban developments.
4.	Role of edge and corner density	This study has used metrics like turbulence intensity and flux to capture the eddy-like behavioural pattern of wind. However, built form metrics like edge and corner density may be worth exploring.
5.	In-depth study exploring the seasonal variations	This study broadly argues that change in seasonal wind directions changes the way urban form interacts with it, and thus this may have some implications on pollution dispersion. Towards this end, a simulation-based study exploring the pollution concentration distribution with changing wind directions would facilitate in fostering this understanding.

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Assessment of wind characteristics and Urban Heat Island dynamics for urban planning

A case study of City of Toulouse, France

Henry Adeniyi Ibitolu

Abstract

To build resilient and climate responsive cities, city planners must understand the local complexities of the urban environments. This study employed the Local Weather Type (LWT) classification approach to conduct a spatio-temporal wind analysis of Toulouse. Using the urban database and the Meso-NH simulation data at 250m x 250m horizontal resolution, the Local Climate Zones (LCZ) and nocturnal Urban Heat Island (UHI) was analysed. To quantify the wind characteristics, a mean and frequency statistical approaches was evaluated. Results revealed that the mean analysis overestimated the wind intensity by 1-2 m/s during daytime. At night-time, both methods show similar pattern from East-to-West with LWT-9 underestimating the wind by 2 m/s around the airport for the frequency analysis. Analysis of the nocturnal UHI in relation to wind intensity showed that a decrease of 0.20m/s in diurnal average wind intensity in the city centre resulted in a night-time UHI of 2.57OC, while an increase of 0.47 m/s in the sparsely built LCZ-9 was observed to have resulted in a UHI of 0.32OC. Consequently, the anticyclonic urban-breeze circulation on 4th July 2004 was visualized. Finally, the results showed that the higher the building volume density, the lower the pedestrian velocity ratio.

1. Introduction

The urban population of the world has grown rapidly from 751million in 1950 to 4.2 billion in 2018, and over 68% of the world population is projected to live in urban areas by 2050 (United Nations 2019). This rapid urbanization has significantly turned cities into dense urban areas with less greenery, more pollution sources, and impervious surfaces. The presence of artificial materials in buildings and public spaces increases the heat storage in the ground layer and building fabrics and contributes to the higher level of air and surface temperature in urban areas compared to their surrounding rural areas (Oke 1987). This phenomenon is known as "Urban Heat Island" (UHI).

Consequently, cities are becoming more and more densely built-up with compact and high rise buildings composed mostly in the city centres and other Central Business District (CBD) where a vast majority of the population spend their entire day working. Hence, UHI has become a rising concern to the quality of life within the built urban environments (Wong & Yu 2005). Meanwhile, countries in southern Europe and the Mediterranean basin are particularly vulnerable to a rise in climate change extreme events. No event made this more apparent in France, than the 2019 summer heatwave, which saw the southern commune of Gallargues-le-Montueux recording France's highest ever temperature of 45.9^{O}C breaking the previous 2003 record of 44.1^{O}C. Not surprising, more than 50 French cities exceeded their previous high temperature records in the 2019 heat wave (WMO 2019).

Significant progress has been made to associate the morphology of urban surfaces to the atmosphere. Despite this, it is generally recognized that the outstanding issue for urban climate science is the need for knowledge transfer from urban research into urban decision-making (MAPUCE 2016). Unfortunately, most urban planners do not have the required knowledge to quantify the effect that different urban morphology scenarios could have on UHI intensity. For instance, a survey to which 25 French urban planning agencies answered showed two major limitations that inhibit the adoption of climate sensitive building topics to be considered in the everyday planning strategies; the first limit is linked to the lack of knowledge of these actors on these important topics, while the second is the lack of pertinent data (MAPUCE 2019).

Hence, it is important that necessary climate analysis is made available to assist urban planners, thus informing the development of a broad climate-sensitive planning framework. However, for this case study based on the city of Toulouse, attempts were made to push these limits back by analysing the wind regimes on the city scale.

1.1 Aim and Objectives

Wind flow in urban centres are generally warmer with weaker speed than in the rural/suburban due to the blockage of high-rise buildings and the surface roughness (Yim et al. 2009). The UHI mitigation strategies suggested by Santamouris & Kolokotsa (2016) includes using cool materials with higher albedo on buildings & pavements, the use of green systems such as trees, hedges, shrubs and grasses in cities, and the introduction of water bodies, such as lakes, fountains and ponds. However, wind ventilation corridor is a viable approach to introduce cooler wind into built areas, which can help reduce urban temperature and mitigate the urban heat island effect. The overall goal of this research is to explore how and to what extent the wind dynamics can exert effects on modulating the city-wide UHI intensity in Toulouse, France. This analysis was implemented in the open-source QGIS to make it easily available to researchers working within urban studies as well as city planners. The Meso-NH simulation model data and the Local Weather Types (LWT) classification approach were used to achieve the following objectives:

- Identification and characterization of wind pattern in the city.
- Analysis and visualization of the daytime urban breeze circulation (Hidalgo, Masson & Pigeon 2008) from the Meso-NH model output.
- Assessment of the relationship between wind intensity and nocturnal UHI characteristics across various urban morphology in the city.
- Visualization and Cartographic representation of the wind pattern in the city.

2. Background

Recent urban climate literatures have been composed of studies aimed at understanding and modelling the thermal characteristics of the UHI phenomenon. The UHI effects poses significant challenges to urban livelihood and ecosystems services. However, cities are significantly warmer than the surrounding rural areas since the urban morphology and their artificial surfaces have varying radiative and aerodynamic characteristics, which modifies the surface energy balance and interact with the local circulation pattern. The diverse structures of urban morphology in cities has been attributed as an explanation for variations of urban climate (Adolphe 2001). It is important to clearly describe interactions between urban morphology and climatic conditions (Wang et al. 2017). For instance, Adolphe (2001) developed a spatial model to standardize the complexity of urban morphology and the variety of climatic conditions. While for urban temperature, Stewart and Oke (2012) defined the local climate zones (LCZ) to differentiate generic temperature patterns over city fabrics.

2.1 Wind flow pattern and UHI

Wind velocity is an important parameter in urban environment influencing the air quality, health, outdoor/indoor comfort and the energy consumption of buildings (Memon & Leung 2010, Yang & Li 2011). Wind provides cooling effects that helps to mitigate the adverse effects of heat island on the environment and human thermal comfort. For example, within the tropics, a wind velocity of 1–1.5 m/s can create cooling effect which is equivalent to a 2^{O}C drop in temperature (Erell et al. 2011). With appropriate wind induced airflows air pollution in cities can be dissipated (Kato & Huang 2009). Wind pattern is affected by building height and orientation (Rajagopalan et al. 2014).

Several studies have investigated the role of urban geometry on microclimate. Investigations by Shashua-Bar et al. (2004) revealed that areas with shallow open spaces and wider spacing recorded temperatures 4.7°C higher than measurements taken from a meteorological reference. Also, in a research investigating the relationship between thermal performance and urban morphology, Golany (1996) noted that the configuration of a city can assist wind circulation and affects wind velocity which in turn influences the temperature variations. He made clear that morphology of a city directly affects the movement of wind, depending on its design, shape, and orientation of the roads within it. Furthermore, in a study by Morris et al. (2001) it was found that an increase of wind speed by 1 m/s causes a 0.14°C reduction in the intensity of heat island. It was also revealed that, by increasing the cloud cover by 1 okta, UHI decreases by about 0.12°C.

2.2 Local Weather Types (LWT) classification approach

This study uses the Local Weather Types (LWT) classification approach proposed by Hidalgo et al. (2014) and further studied by Hidalgo & Jougla (2018), which is critical for identifying the plurality of weather situations representative of a place. According to Hidalgo & Jougla (2018), a local weather type refers to the description of the atmospheric situation directly stemming from the analysis of climatic data from the atmospheric boundary layer. LWT classification is useful because it allows for shifting from a mean climate conditions typically driven by long-term climatic variables to a shorter meteorological time-scales which is a more realistic representation of the daily cycle of the atmosphere and thus have immediate impact on human comfort level.

Cantat (2004) explored the extent of the UHI in the city of Paris according to the weather types intensity, frequency, duration and shape. In that paper, statistical analysis was used to highlight the essential influence of cloud cover and wind on the formation of the UHI and how the corresponding weather types could cause the urban-rural temperature difference to go from 0 to over 10°C. However, based on data from the CAPITOUL experiment (Feb 2004 and Mar 2005) as detailed in Masson et al. (2008), Hidalgo et al. (2014) and Hidalgo & Jougla (2018) concluded that 11 clusters were enough to adequately describe the local weather conditions in Toulouse in terms of the diurnal temperature ranges, precipitation, wind regimes and humidity amplitude. A review of literatures available in the field of urban microclimate and urban forms highlights few investigations relating UHI to urban planning and morphology on a city scale (Taleb & Abu-Hijleh 2013). Many studies provide strong evidence and findings which are limited to building-to-building relationships, defined as different ratios (Abreu-Harbich et al. 2014).

3. Method

3.1 Overview of dataset

The dataset used in this study is categorized into 2 different types i.e. the atmospheric dataset and the surface/urban dataset.

3.1.1 Atmospheric data: The atmospheric weather data used included the U and V (i.e. the zonal and meridional) wind components at 10m together with the wind velocity ratio (VRat) at 2m pedestrian level derived from the MésoNH-SURFEX atmospheric model output. The simulation output was each calculated as hourly wind data from 01-03-2004 to 28-02-2005. In this study, only the summer season (June to August 2004) was investigated. Meanwhile, the simulation data was sub-classified into Constant and Time-Dependent fields. The constant fields included data that stay the same all through the entire simulation process, such as LONS-Longitude, LATS-Latitude, HEIG-Elevation above sea level[m]. The time-dependent wind variables were extracted from two numerical simulation scenarios- Reference (REFER) and Urban Increment (URBINC) situations.

The reference (REFER) numerical simulation scenario was performed such that, the MésoNH-SURFEX model was coupled with the surface scheme - Town Energy Balance (TEB) to simulate the urbanised areas (Masson 2000) and with the Interaction between Soil, Biosphere, and Atmosphere (ISBA) scheme to simulate natural covers. Consequently, the "urban increment" (URBINC) scenario was also run to estimate the current impact of the blue and green belt within the mixing layer by comparison with the REFER simulation. For this scenario, the natural features were removed (i.e. the vegetated and watered grid box in the ISBA and TEB schemes were replaced with the characteristics of the most common urban land use category in the zone). The grid resolution of the atmospheric data is 250m x 250m horizontal scale within a horizontal domain of 30km x 30km covering the entire communes in Toulouse.

Furthermore, the simulation output data were stored in binary R files with each day of simulation contained in a folder, while the local weather type situation for each day (01-03-2004 to 28-02-2005) was stored in a text (.txt) file. However, for this study, only the summertime (June-July-August) weather situations was analysed. According to Hidalgo & Jougla, (2018), LWT - 7, 8 and 9 are the most persistent weather situation during summertime. They represent 85% of summer days in the simulation with a frequency of 24 days (26%), 37 days (40%) and 18 days (20%) respectively.

3.1.2 Surface/urban dataset: The surface data was acquired from the MApUCE project urban database which includes the urban data in GIS shapefile (.shp) format and the Digital Elevation Map (geotiff format) in 25m x 25m resolution. The urban data include the LCZ maps which shows the different local climate zones across the city landscape and the UHI maps showing the night-time temperature as compared to the previous daytime temperature.

Table 1: Summary of all the dataset used in the research (Ibitolu 2020)

Atmospheric Data	Time-dependent fields	REFER & URBINC Simulation	U-Wind component V-Wind component VRat - Velocity Ratio	250m x 250m	01-03-2004 to 28-02-2005 Hourly Summer data was analysed
	Constant fields	LONS, LATS, HEIG			
Surface (Urban) Data	Local Climate Zone Map	The map with the local climate zones across the metropolitan area including the urban and natural surfaces			
	Urban Heat Island Map	For each Local Weather Type situation in the study period [LWT 7, 8, 9]			
	Topography Map	25m x 25m			
	Toulouse Urban Database	- At individual building scale - At the Reference Spatial Unit- RSU scale			

The Toulouse building information dataset used in the study was provided in 2 different scales, namely the "building scale" and the "Reference Spatial Unit -RSU". The RSU is the aggregation of buildings into blocks while, a block is an aggregation of individual buildings that intersect each other with at least one point in common. In this study, the building attributes used include building height (i_H) and building volume (i_vol).

3.2 Description of methods

The method involved statistical evaluation of the Meso-NH data and GIS post-analysis.

3.2.1 Statistical Evaluation: The methodology for the statistical evaluation was carried out in two phases: Wind Preparation Phase and Wind Main Analysis Phase. For the Wind Preparation Phase, an R script was written to read-in the hourly wind data (VRat, U and V components), identify the days that each local weather types (7,8,9) occurs in summer from the LWT (.txt) file and then combine these two subroutines to extract the hourly summertime Velocity Ratio and the U-V components for LWT 7, 8, 9.

Meanwhile, in the Wind Main Analysis Phase, two distinct procedures were implemented i.e. mean analysis and frequency analysis approach. The step-by-step procedure is summarized in Table 2.

Table 2: Summary of the step-by-step procedure for the wind main analysis (Ibitolu 2020)

Steps		Description
I	Reading in the data into a variable	The first step is to read in the hourly wind data derived from phase one. This is stored in a variable "data_temp"
II	Extracting the required time interval	This step extracts the required time-interval for day & night: 15h -18h GMT (i.e.17h - 20h local time)-> to represent day, 01h -04hGMT (i.e. 03h – 06h local time)-> to represent night
III	Calculating the Mean or Frequency	The mean wind characteristics (VRat, U-V components) and the most frequent wind characteristics within the time interval for each LWT was calculated.
IV	Converting the U-V components into wind speed and direction	The U-V components from previous step was converted into the wind speed (FF) and wind direction (DD) using an R function written for that purpose
V	Wind Threshold Classification	For cartographic visualization, the wind speed (FF) and wind direction (DD) was combined based on the Beaufort scale wind threshold classification (See Table 4)
VI	Conversion to Shapefile (.shp)	The final step is the conversion into shapefile format (.shp), which is the required format needed to carry out further analysis and visualization in the GIS environment.

Table 3: Adapted Beaufort scale wind classification (Ibitolu 2020)

Beaufort Scale	Wind Speed (m/s) at 10m above ground	Wind Category
Calm / Light air	< 1.5	Very Weak
Light Breeze	1.51 – 3.3	Weak
Gentle Breeze	3.31 – 5.4	Intermediate
Moderate/Fresh	>5.4	Strong

3.2.2 GIS Analysis: The shapefile (.shp) output from the statistical evaluation served as input data for the GIS visualization. These input datasets were combined with the urban/surface dataset acquired from the MApUCE database (MAPUCE 2016). Clipping, overlay, masking, aggregation, and resampling of data are some of the GIS operation executed. Building density is a key concept that must be considered in the description of a city's urban spatial structure. Hence, from the urban information dataset described Table 2, the Building Volume Density (BVD) map was created using rasterization and raster calculator toolset. Furthermore, to understand the variation in wind intensity (ΔWind(m/s)) and the Nocturnal UHI intensity (ΔUHI(°C)) across the different LCZ in Toulouse, the modelled wind velocity data at 250-m horizontal grid and the UHI map were overlaid onto the LCZ map in ArcGIS. Using the "Extract Values to Point" toolset, each grid of the wind intensity and UHI data point is matched with its underlying LCZ.

4. Results

4.1 Mean wind analysis versus most frequent wind analysis

The mean approach simply averages the hourly wind velocity and direction for each grid of the LWT for the required time interval, while the frequency approach evaluates the most frequent wind velocity and direction. The result of these analysis is presented.

Figure 1 clearly shows that the frequency approach tends to show more details as compared to the mean analysis. Hence, to quantitatively assess how both approaches perform in relation to estimating the wind variables on the city scale, the east-west wind profile was analysed and the results are presented in Figure 2 below.

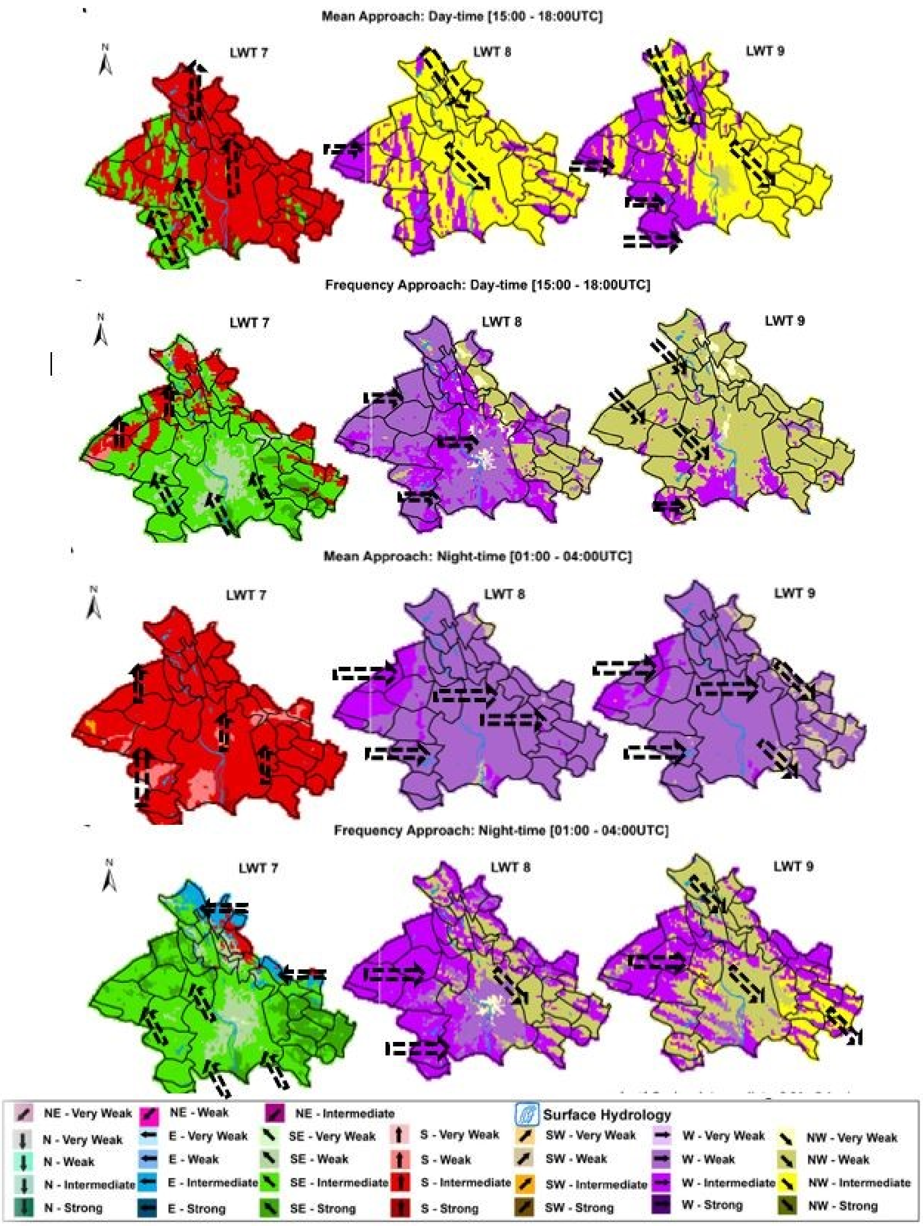

Figure 1: Summer wind characteristics for mean vs frequency analysis for Toulouse (Ibitolu 2020)

Figure 1 clearly shows that the frequency approach tends to show more details as compared to the mean analysis. Hence, to quantitatively assess how both approaches perform in relation to estimating the wind variables on the city scale, the east-west wind profile was analysed and the results are presented in Figure 2 below.

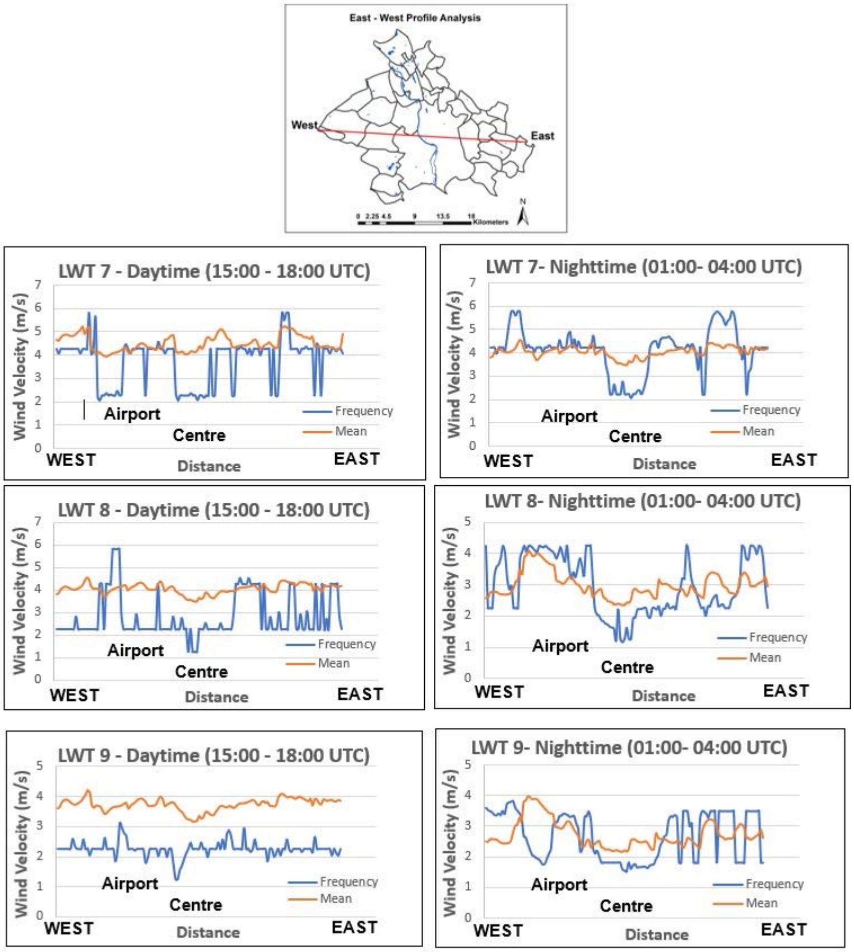

Figure 2: Comparison of the East–West Profile of wind velocity for the mean and frequency methods for each LWT 7,8,9 during daytime and night-time (Ibitolu 2020)

The most persistent summer wind characteristics for LWT 7 is the south-easterly wind with stronger velocity(>5.4m/s) along the fringes of the Eastern part of the city, and the wind speed slows down towards the core of the city centre. While for LWT 8 & 9, the predominant wind is the westerly and north-westerly wind. This result is consistent with previous findings (Hidalgo et al 2008; Hidalgo & Jougla 2018). The graph in Figure 2 quantifies to what extent both methods either overestimated or underestimated the wind velocity in Toulouse.

At first look, it is evident that the mean approach tends to overestimate the wind velocity by 1-2m/s during the daytime for all weather types. While at night, the case is different with both methods showing almost similar wind intensity from East to West, with occasional spikes in the frequency method. Furthermore, observed temporal similarities between the mean and frequency East-West profile is that they both show the distinct presence of the urban centre with a drop in the wind speed across all local weather types irrespective of the time of day. This is due to the dense built-up which slows down the wind speed as it approaches the centre (Santamouris et al. 2008).

4.2 Relationship between wind intensity and nocturnal UHI intensity across Local Climate Zones (LCZs) in Toulouse

The analysis of LCZ map of Toulouse generated at the building block scale as well as, the change in wind intensity from daytime to night-time across all weather types is presented in Figure 3.

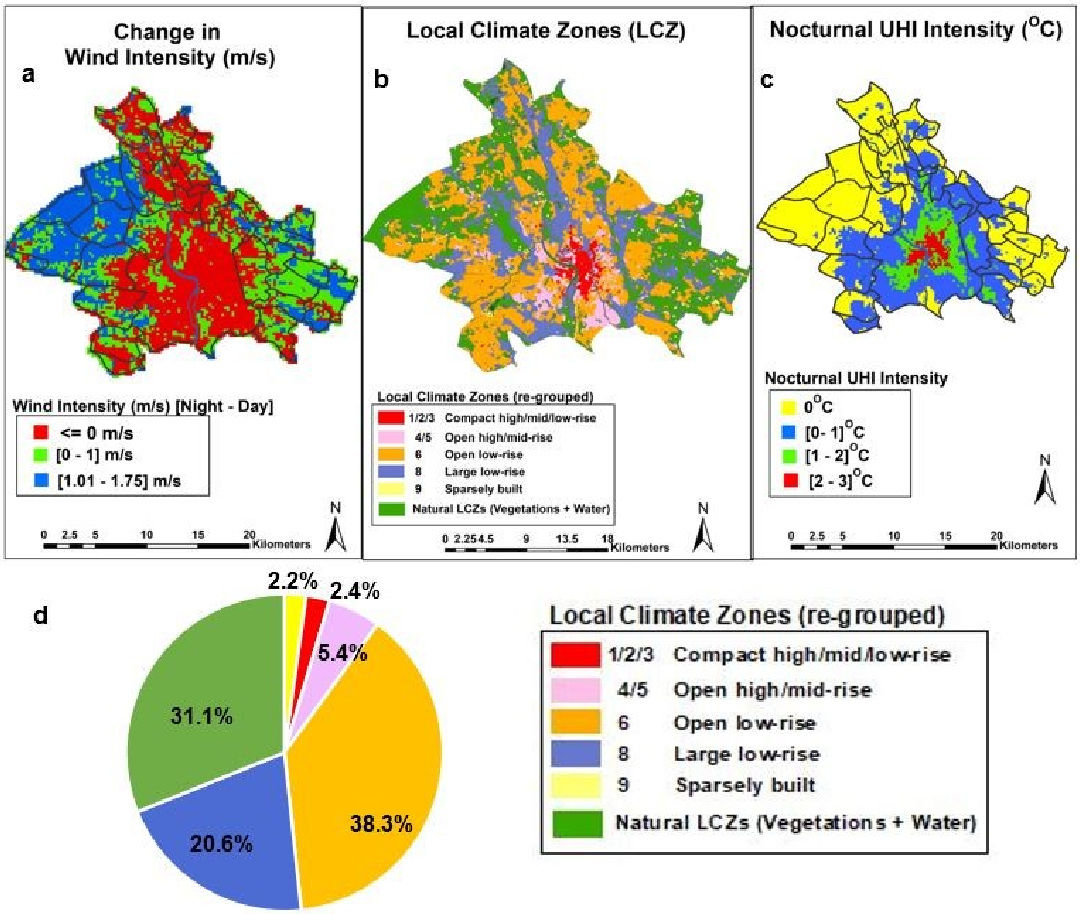

Figure 3: Comparison of (a) change map in wind intensity from day-time to night-time, (b) LCZ re-grouped, (c) the Nocturnal UHI Intensity (d) pie-chart distribution of LCZ (Ibitolu 2020)

A visual inspection of Figure 3 reveals that the natural LCZ (i.e. all vegetation types and water) occupies 31.1% of the land area. Meanwhile, the most common built LCZ in Toulouse is the open low-rise (LCZ 6) category thus reflecting the city's low built density. Furthermore, the Nocturnal UHI map (Figure 3c) reveals the aggregated warming pattern of the city at night as compared to the previous daytime. It is evident that the city centre (in red) has a UHI intensity of between [2-3] °C, while the next urban regions surrounding the core of the city-centre (green and blue) has UHI intensity between [1-2]°C and [0-1]°C.

The nocturnal UHI has a distinct decreasing pattern as one moves away from the densely built urban core towards the sparse suburban. This result is consistent with previous findings (Kwok et al. 2019), where the same decreasing pattern was observed for both air temperature and the mean radiant temperature in Toulouse.

Table 4: Summary of UHI Intensity and Wind Intensity across the LCZs (Ibitolu 2020)

LOCAL CLIMATE ZONEs (re-grouped)		Urban/Rural Nocturnal Heat Island Intensity (Δ°C)		Change in Wind Intensity (Night-time - Daytime) (m/s)		
Zone	Zone Title	Average	Max	Min	Average	Max
1/2/3	Compact Zones (High/mid/low-rise)	2.57	3	-0.82	-0.20	0.52
4/5	Open High/mid-rise	1.52	3	-1.40	-0.13	1.72
6	Open low-rise	0.76	3	-1.48	0.20	1.75
8	Large low-rise	0.64	3	-1.39	0.14	1.70
9	Sparsely built	0.32	2	-0.82	0.47	1.75

Nonetheless, areas with LCZ-1/2/3 can be seen to have the highest average nocturnal UHI intensity of 2.57°C. Consequently, LCZ-1/2/3 recorded the highest decrease in the wind intensity (-0.20m/s) from daytime to night-time. This is expected since the urban-rural thermal gradient is at the highest at night-time because of the thermal properties of urban materials which tends to conserve the daytime heat which is later released at night-time. Further analysis revealed that an increase in wind intensity of 0.20m/s and 0.14m/s is observed for LCZ-6 and LCZ-8 respectively. This could be due to their spatial heterogeneity in urban form because of their locations at urban–rural boundaries, or perhaps because of the larger area covered by the LCZs. Also, Table 4 showed that LCZ-6 has the largest wind intensity range, which is consistent with previous findings on larger intra-LCZ variabilities in cities at night (Skarbit et al. 2017).

4.3 Visualizing urban breeze circulation in Toulouse

The differential rate of heating between the built urban centres and the surrounding countryside is the main cause for the urban breeze circulation. The atmospheric conditions favouring the formation of this phenomenon is a strong insulation day coupled with low surface wind velocity and a deep boundary layer. Luckily, these atmospheric conditions were observed by Hidalgo et al., (2008) across Toulouse and surrounding countryside during the Intensive Observation Period number 5 (IOP5, 3rd and 4th July 2004) of the CAPITOUL experiment (Feb. 2004 to Feb. 2005).

To visualize the existence of this phenomenon, the wind characteristics on the 4th of July 2004 in the Meso-NH simulation was analysed such that the average wind pattern between 12:00–15:00UTC and 15:00–18:00UTC was evaluated.

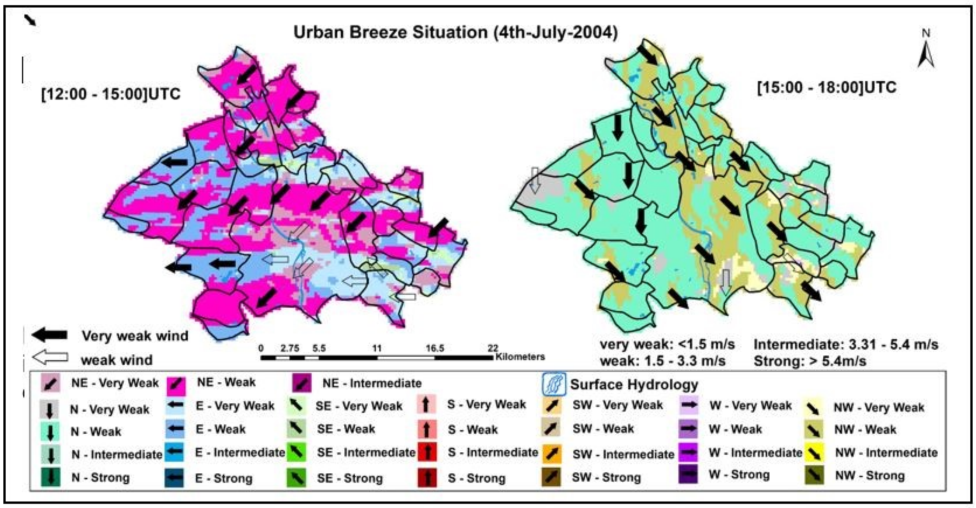

Figure 4: Urban Breeze Situation at 10m in Toulouse Metropole on 4th/July/2004 (Ibitolu 2020)

On 4th-July-2004, between 12:00-15:00UTC, the dominant wind system at 10m was weak E-NE pattern. This is expected since according to the weather clustering by Hidalgo & Jougla (2018), the most persistent weather type on that day is LWT-7 which is a typical sunny-summer day with persistent but weak south-easterly wind. Thus, this extreme urban-rural horizontal temperature gradient which must have begun to develop from the previous day and the early morning, together with the weak wind intensity allows a more turbulent boundary layer to build up. That is why between 15:00–18:00 UTC, the wind system had switched to a NW-SE pattern, such that there is a near-surface wind advection from the less built-up northern part of the city, towards the urban centre. This result corroborates the previous aircraft measurement by Hidalgo et al. (2008a) where it was noted that the urban-breeze grew in intensity from 2 m/s at 12:00UTC to 5-6m/s at 18:00UTC. Similar results were also recorded by Lemonsu and Masson (2002) in the city of Paris and its surrounding in July 1994.

4.4 Wind velocity ratio analysis

The wind velocity ratio is a unitless quantity defined as the ratio of wind speed measured at pedestrian level (Vp) to that at the reference point -Vref. To understand how wind is characterized across different urban built-up scenarios in the city, the VRat is compared with the building volume density across 3 case study areas such that; Case A [Urban-Core] is representative of the densely built city-centre, Case B [Airport Area] represents the suburban, and Case C [Rural Area] is representative of rural areas, but greatly influenced by high elevation.

From Figure 5, strong velocity ratio values can be seen around the airport area and towards the eastern part of the city where there are more open spaces. At night, this ratio had decreased such that very weak velocity ratio could be observed in the city centre due to the less turbulence in the atmosphere which in turn lowers the speed. Consequently, the characteristics difference in the building volume density map derived from the building-unit scale and the RSU scale is shown in Figure 5. The more detailed building-unit scale helps to identify areas with no buildings which could serve as the ventilation corridor to allow wind flowing into the city.

Likewise, scattered high BVD are observed in the airport areas and other large commercial complexes around the city. This demonstrate the applicability of built-up volume as triggers of local heat island phenomena and their influence on local wind systems (Harlan et al. 2006). Table 5 reveal that CaseB:(Airport) recorded the maximum BVD(100%) per unit area. This is due to the presence of largebodied buildings at the airport terminals. CaseA: (Urban Core) had the highest mean BVD of 13% because of the tall and closely packed dense nature of the buildings in the centre. Meanwhile CaseC: (Rural) recorded the maximum value of wind velocity ratio both during the daytime and night-time. This is expected since the surface wind velocity is accelerated because of less obstructions from fewer buildings in the rural vicinity. Further, the highest mean value of the velocity-ratio was recorded at the airport area.

These findings are similar to previous work by Kubot and Miura et al (2000) in Japan and Malaysia, where they analysed the variation of gross building ratio in relation to the velocity ratio. Hence, this result has illustrated that irrespective of time of day, the relationship between BVD and VRatio tends to behave in a similar pattern with higher VRat in daytime, thus, demonstrating how the urban surface morphology and small-scale orography could influence the wind field.

Table 5: Summary of the relationship between building volume density and mean of the unitless velocity ratio during the day and night (Ibitolu 2020)

	Building Volume Density (%)		Velocity Ratio			
			Daytime		Night-time	
	Mean	Max	Mean	Max	Mean	Max
Case A	13	86	0.384	0.562	0.355	0.495
Case B	9	100	0.529	0.732	0.454	0.699
Case C	2	15	0.429	0.790	0.374	0.749

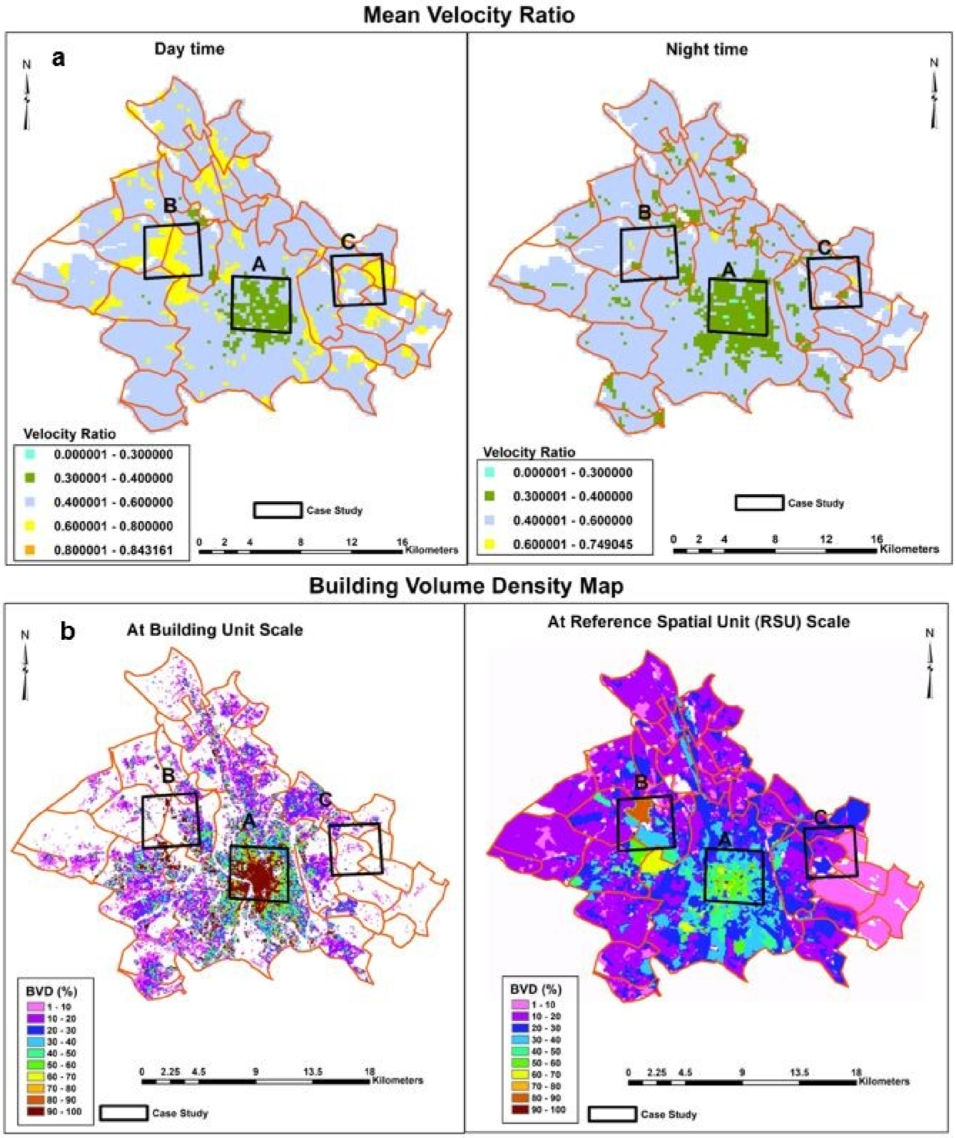

Figure 5: (a) Mean velocity ratio across all weather types, (b) Building Volume Density Map at building and RSU scale with the marked case study areas (Ibitolu 2020)

5. Implications and Conclusions

This study has demonstrated that urban morphology and the wind characteristics has a great impact on the extent and intensity of the summertime UHI. Thus, the urban planning agency of Toulouse can leverage on the results of this study to design resilient and climate-sensitive urban neighborhoods.

Furthermore, whilst the synoptic scenario on 4th-July-2004 was favourable to the development of an urban-breeze which could be considered to be a positive feedback, since the advection of fresh breeze from the rural outskirt could bring in much needed cooler air into the warm city-centre, it is important to note that, urban breeze can also accentuate the diffusion of pollution from the industrial campuses in the suburban into the city-centre. Therefore, this knowledge can assist the environmental agency in the prediction of peak pollution perturbation pattern and the evaluation of air quality policy in the city. Hence, since this study only focus on the summertime UHI, it is recommendation that future research should evaluate other seasons, to understand the inter-seasonal UHI dynamics.

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Assessment of intra-city urban heat island effect in relation to vulnerable stakeholders via LCZ classification, LST Analysis and Transverse Surveys

A case study of Karachi, Pakistan

Marina Khan

Abstract

The UHI phenomenon and its impacts are gaining momentum as a major research focus in South Asian urban climate literature. However, Karachi, despite recurring heatwaves and increasing temperatures in parallel with sustainability challenges of urbanization, governance and high-density vulnerable population lacks in-depth investigations. Hence, this thesis attempts to explore the UHI effect and urban variables in Karachi. The methodology employs the LCZ classification, remote sensing data and traverse/stationary surveys and establishes the intra-urban temperature disparities along with temporal UHI intensity, hotspots, and heat sinks. The LCZ mapping identified a disproportionate mix of compact built-up classes in the city's urban core along with a terrible lack of blue-green infrastructure, while the mobile surveys identified the nocturnal UHI magnitude to be much higher than that of the daytime with the maximum night-time magnitude of 3,0°C and 1,5°C during the daytime. Particularly, the high-rise buildings offered conflicting temperature patterns, serving as the heatsinks in the day and the hotspots at night-time. However, in combination with other LCZs, they enhanced the cooling effects in different LCZ classes during the day. This study also attempted the extrapolation of future trends and anticipated intense densification in future which may exaggerate the UHI effect, insinuating a likeliness for worse climatic impacts. The critical zones thus identified were quantified in terms of air temperature and MRT values in ENVI-met. Whereby, the compact midrise densifications seemed like a stable middle ground among density enhancement and climatic repercussions. Alternatively, the cooling implications of mixed LCZs may also offer opportunities for policies in urban planning to manage the increasing UHI effects in future and may suit the practical realities of the heterogeneous developing cities.

1. Introduction

Despite struggling with sustainability issues for decades, Pakistan continues to face exacerbating climate change challenges and ranks among the top ten most affected countries in the Global Climate Risk Index (GERMANWATCH 2018), bearing setbacks of billions of dollars to its economy (ADB 2017) and losing millions in human resource (DAWN 2019). Meanwhile, Pakistan's economic capital 'Karachi' is massively beset by a crisis of governance visible in the destitute state of service delivery, unplanned and unsustainable urbanisation trends and intensified climatic strain on the local population (Hasan et al. 2017). In the recent years, the heatwave events have persisted in Karachi where during such an episode in 2015, thousands of people died and suffered heat-related illnesses (BBC 2015). These deaths were disproportionately spread across the city which identifies a variance in susceptibility and preparedness to the climatic effects.

The IPCC warns that the growing cities of countries like Pakistan have been escorted by intense growth of highly vulnerable informal groups who most likely end up on risky lands of extreme weather (Field & Barros 2014) and are disproportionately susceptible to the effects of climate change (IPCC 2018). Unfortunately, Karachi is one such example where the statistics project a huge population residing in squatter settlements in intensely densified inner city, along the beds of rivers/drainage channels as well as in the growing urban sprawl (Hasan & Mohib 2003). In this context, the exacerbating climatic challenges are a severely urgent issue, most importantly for the vulnerable stakeholders living in underserviced poorly constructed informal settlements (Hasan et al. 2017). By far, Karachi presents little to no scientific exploration and hence, implores investigation to establish mitigation strategies for the resiliency of the stakeholders.

1.1 Aims and objectives

This study aims to assess the impact of urbanisation in strengthening the UHI effect in Karachi by evaluating the prominent drivers and identifying the critical areas. The objectives are:

- To document the variation of intra-city UHI and locate the microscale hotspots and cold spots present in the heterogeneous urban fabric at various times.
- To explore the drivers in UHI development such as land use, urban morphology, building density, population, etc.
- To extrapolate how future growth may impact the warming patterns and to explore mitigation strategies for the critical zones

2. Background

The UHI effect has been well and widely explored (Arnfield 2003), and with the persistency of heatwaves in the last decades and its potential threats, its domain has expanded to thousands of cities across the world (Zhou et al. 2017). The subject is particularly apt for regions with a UHI presence throughout the year (Jonnson 2004), including several south Asian cities. Furthermore, given that the climate change and its unmitigated cum unprecedented effects are presenting a serious risk in South Asia (Im et al. 2017), the UHI research focus has gained momentum in the region. Yet, the research scope shows quite a narrow capacity i.e., only limited to quantifying the phenomenon and lack of in-depth explorations (Kotharkar et al., 2018).

While Pakistan despite being home to few of the most populous cities lags far behind in UHI investigations (Kotharkar et al., 2018). It must be noted that globally, there is substantial development made in surface UHI mapping for humid and temperate regions, however, these studies are still quite limited in arid and semi-arid areas (Rasul et al. 2017). And even though the south Asian studies seem to be leaning towards tropical studies, there's still a lack of focus on the urban thermal comfort. Therefore, for Karachi as an arid south Asian city, the literature review identifies global methodologies, and then particularly locates these practices in the context of South Asia and Pakistan. This establishes a relative as well as general understanding of UHI approaches to allow comparative references along with finding possibilities for appropriation.

3. Method

This study employs a hybrid methodology for mapping, data collection, analysis and mitigations. Mainly, the Local Climate Zone (LCZ) classification is adopted to analyse the urban morphology, while the intracity UHI magnitude and temperature difference assessment is carried through Land Surface Temperature (LST) datasets in GIS substantiated with data collected through field (fixed and traverse) surveys during January and February 2020. The mean LST is graphically compared to find the highest and lowest temperature impacts while the temperature data obtained in traverse surveys is translated into route-wise temperature profiles. This leads to the identification of relative thermal anomalies among LCZs, the diurnal behaviours and the minimum and maximum temperature thresholds, thereby, identifying the UHI magnitude. Further assessments include the study of future trends and their heating impact via comparative analysis between 2009 to 2019 LCZ maps and extrapolation of temperatures in the tentative LCZ change. Eventually, the literature guided mitigations are explored for the critical areas through micro-modelling using ENVI-met. The software tools/devices employed for the data collection and analysis include WUDAPT Saga, Google Earth Pro, ArcGIS, ENVI-met, Leonardo, MS Excel, Tinytag Plus 2 (TGP-4500), Tiny Tag explorer, etc.

3.1 Context

Karachi as a coastal South Asian city has an area of 3530 sq. km and is home to over 16 million people (Pakistan Bureau of Statistics 2018). Climatically, the Köppen-Geiger system classifies it with BWh, i.e., hot desert climate conditions with the worst summers characterised by very low annual precipitation.

3.2 Sources of Data- LCZ mapping, LST retrieval and the Traverse Surveys

The World Urban Database and Access Portal Tools (WUDAPT) mapping method was opted to facilitate the LCZ classification. As explained by Bechtel et al. (2015), daytime Landsat 8 imagery with less than 10% cloud cover was downloaded for June 2019 from the USGS Earth Explorer site. The algorithm to generate the LCZ classification involves training data using google earth where these samples must cover homogeneous areas at least the minimum size of an LCZ. The classification was carried out based on land cover types identified by Stewart & Oke (2012), where the main identification of training sites was informed by field campaigns and photos along with secondary data from the historical/ recent urban maps from the urban planners' archives. Subsequently, the WUDAPT level 0 map at a resolution of 100m was generated. Based on a qualitative inspection using Google Earth for any poor classifications, further training areas were added and the classification was rerun.

Similarly, another map is generated for 2009. However, Landsat 5 dataset was used instead for 2009 (as recommended by http://www.wudapt.org/prepfeat_overview/path2step3a/). As opposed to LULC studies, both these maps facilitate an area/percentage-based assessment of LCZ change (LCZC) to detail out the climate-based changes.

Additionally, again Landsat 8 datasets are used to determine the LST in °C with a procedure defined by Avdan & Jovanovska (2016). The acquired LST map is overlaid on LCZ map and independent LST pixels for each LCZ class are extracted. Given the overall accuracy of these LCZ classification maps may range from 50-90% (Bechtel 2019; Ren et al. 2019), a buffer is applied where the smaller areas inequivalent to the minimum LCZ area were disregarded. The mean LSTs thus calculated for each class (averaged over 2 days i.e., April 22 and June 09, 2019) identified the overall differences in mean LST and the comparative degree of warmness among LCZs.

Furthermore, mobile measurement campaigns in parallel with a fixed measurement station were conducted to investigate the intra-urban spatial distribution of air temperature. Seven winter surveys on five routes were carried out between the last week of January and the first week of February 2020 under similar dry weather conditions. Two specific times were selected i.e., between 2:00 to 4:30 p.m. and 7:00 to10:00 p.m. and in total, 2 cars facilitated the campaigns with the device Tinytag Plus 2 (TGP-4500) mounted approx. 2 m high on a PVC pipe over the car roof. A similar fixed station setup was established on an apartment building rooftop. During the day, the loggers were placed inside a ventilated and insulated cardboard box to prevent direct sunlight. The traverse surveys follow an exploratory methodology as instead of conventional repeated runs on the same routes, this study has focused on maximizing the extent of the samples and number of routes to be representative of the larger city area. Also, there is an attempt to explore elements beyond the predefined LCZ types, such as combinations and edges of various LCZs i.e., a point, a road, or a junction between two LCZs. Such as approach allows qualitative inspection into the relative temperature patterns in the heterogeneous city as a result of mixing of LCZs. The device response time required a stop of 2.5 minutes at each pre-identified spot on the routes to determine the final temperature reading whereby the GIS location and time stamps were manually collated during the survey. The air temperature (T_{Air}) difference and the inter-LCZ UHI (IUHI) magnitude are measured using the formulas:

$$T_{Air}\ difference\ (\Delta T) = T_{Fixed\ station} - T_{LCZ}$$

Where the $T_{Fixed\ station}$ is the air temperature at the fixed station and T_{LCZ} is the air temperature at the respective LCZ on the mobile route. Note that the negative ΔT values indicate fixed station observed higher air temperature during the traverse than that of the mobile route.

$$IUHI\ magnitude = \Delta T_{LCZ\ max} - \Delta T_{LCZ\ min}$$

Where, $\Delta T_{LCZ\ max}$ is the air temperature of LCZ having the highest ΔT value & $\Delta T_{LCZ\ min}$ is the air temperature of LCZ having the lowest ΔT value compared to the fixed station.

3.3 ENVI-met Simulations

Lastly, to quantify the effects of the mitigations, simulations are carried out to derive mean radiant temperature (MRT) along with T_{Air} for the hottest summer day of 2019 for the identified critical area. In this case, the selected area is a highly dense low-rise (LCZ3) informal residential neighbourhood. The built fabric is mostly characterized by wall-to-wall buildings with extremely narrow streets and scarce vegetation. The ENVI-met model is directly traced from the building outlines in the Google maps (Figure 1) while the detailed initial input parameters are shown in Table 1.

Table 1: Input details for ENVI-met simulations (Khan 2020)

Model Parameters			
Parameter	**Definition**		**Value**
Main Data	Domain Size		70m x 70m x 35m
	Cell Size		1m x 1m x 1m
Simulation Time	Start Date		12 June 2019
	Start Time		18:00
	Simulation Time		30 hrs
Meteorological Conditions	Wind Speed		2.05 m/s
	Wind Direction		180.00
	Min and max. T_{Air}(°C)		Min= 30.50, Max= 41.00
	Min and max. RH		Min= 39.00, Max=82.00
Case Parameters			
Scenarios	Urban Geometry	Green cover	Surface properties
Base Case	3- 11m	None/sparse	4" Concrete block walls, 6" Cast concrete roof
High Albedo	Same as Base	Same as Base	All walls and roofs to be painted white, Street to be light concrete.
Green roofs	Same as Base	Green roofs for buildings	Same as Base
Medium Density	24m	Same as Base	Same as Base

The three simulated cases other than the existing case are,

- 'High albedo case'-all building surfaces painted white
- 'Green Case'- with green roofs
- 'Medium Density (Height enhancement) case'-all buildings to be mid-rise

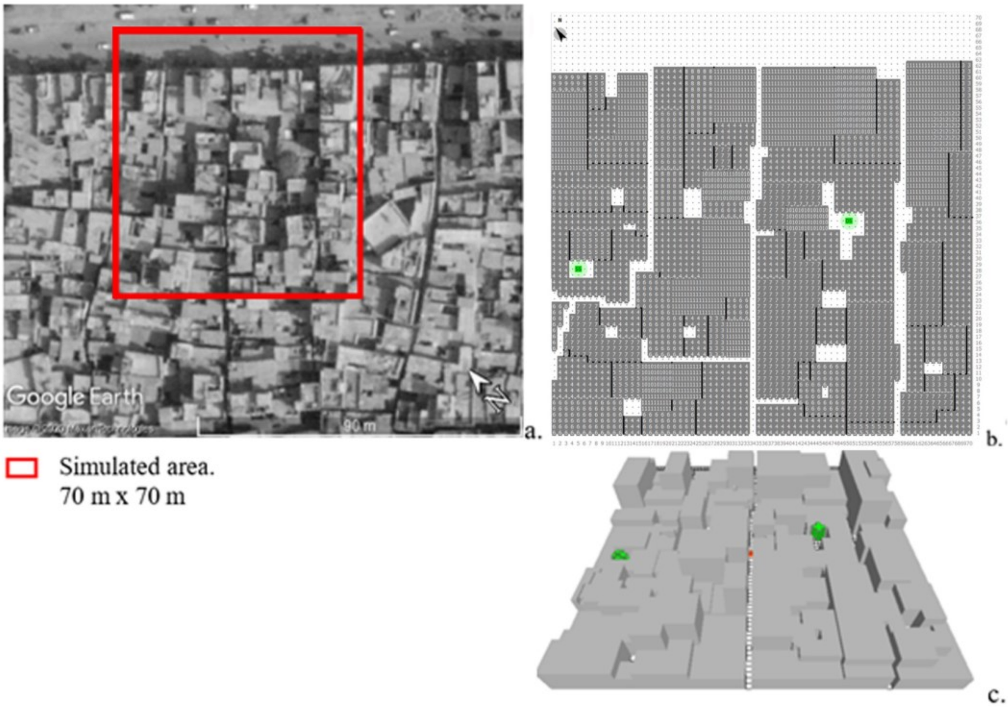

Figure 1: The case study; Moosa colony (a) Building footprint (Google Earth), (b) ENVI-met representation- Grid cells 1×1m, (c) 3D view of the ENVI-met model (Khan 2020)

4. Results

4.1 LCZ mapping

The LCZ mapping highlighted the presence of all 17 disproportionately distributed LCZ classes in the peri-urban Karachi area (Figure 2). The built-up area (LCZ1-10), mostly near the city core, constituted one third of the total area which is predominantly surrounded by barren land-LCZF (48%). Generally, the built-up areas show extreme scarcity of green-blue LCZ classes where the green covers (LCZA-D) collectively and water-LCZG only formed 14% and 2.7% of the area, respectively.

Focusing specifically on the built-up area, it was identified that although Karachi is majorly dominated by industrial areas-LCZ10 (24%) and the abundance of low-rise zones i.e., Compact lowrise-LCZ3(15%) and open lowrise-LCZ6 (15%), LCZ3 often intersects with compact midrise-LCZ2 (3.5%) followed by the LCZ7-lightweight low rise (4%). The dominant LCZ3 and LCZ6 may correspond to the extensive residential land use in the city and insinuate a dichotomy of extremes in terms of density as well as social classes. It is noted that LCZ3 covered a wide range of aspect ratios and including both, the informal and formally planned areas, and often intersected with the lightweight lowrise-LCZ7 elements. Similarly, the LCZ7 inclined towards sub-classes in combination with LCZ3. Since the mix is organic in nature, the boundaries are hard to distinguish. Further, the multiyear change analysis verifies that the built-up areas have been expanding intensively overtime as the built cover increases from 690,10 km^2 to 1022,82 km^2 from 2009 to 2019.

The comparisons recognize that generally significant areas remain low-rise (LCZ3 and LCZ6) in both the years, however, LCZ6 is the only as well as massively decreasing LCZ class observed in terms of area, while LCZ3 and LCZ2 are hugely increasing. This implies the identification of vertical and/or horizontal expansion among the low-rise and/or less dense LCZ types. Meanwhile, major roads are witnessing an infusion of mid-rise and high-rise blocks (a change from LCZ6 to LCZ1, 4 and 2). However, the change towards high-rises is quite insignificant to other LCZs, albeit it shows strong anticipation in future. Also, the huge increase in sparsely built areas-LCZ9 affirm to the growing urban sprawl. Meanwhile, the hugely diminishing green areas with the significant reduction in LCZA-D (14%) and water resources (1%) along with the substantial increase in barren land (3,8%) attest to unbalanced decrease in the blue-green infrastructure and recognize the challenges to UHI, i.e., unplanned densification, urban sprawl and the shrinking green areas.

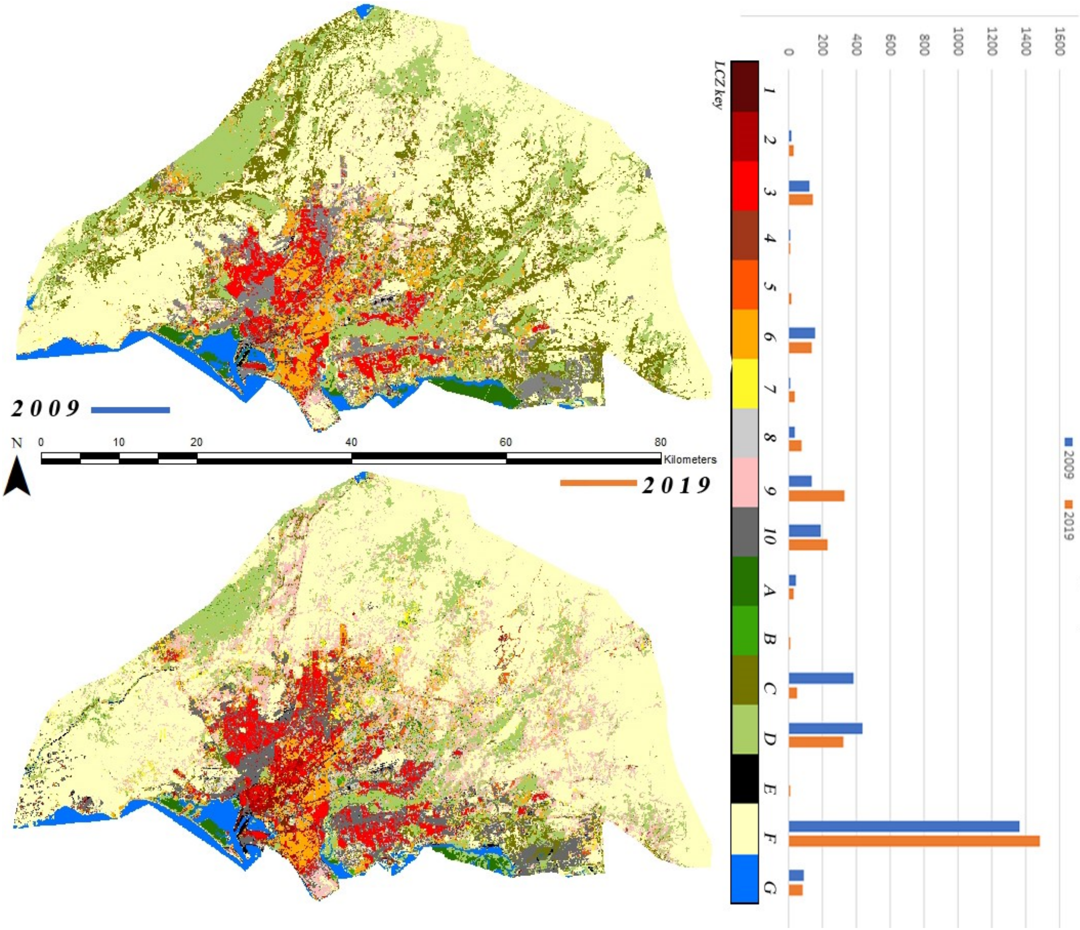

Figure 2: LCZ maps of peri-urban Karachi, 2009 & 2019 (Khan 2020)

4.2 LST Results

As shown in figure 3, the LST maps identified the Surface UHI(SUHI) differences among various LCZ classes forming the summer SUHI magnitude of approximately 15 °C across the city. The highest LST values were observed in the non-urban barren land-LCZG followed by the sparsely built-up areas with less/no vegetation. While the coolest LST was correspondent with the water body-LCZG followed by dense trees-LCZA. In addition, among the built classes LCZ 1-6, the compact lowrises-LCZ3 and open midrises-LCZ5 were the warmest. Contrarily, the LCZs that were higher vertically (both, open and compact) except for LCZ5, exhibited lower LST than others. Meaning that during the day, LCZ1, LCZ4 and LCZ2 are almost 1°C cooler in comparison to LCZ3.

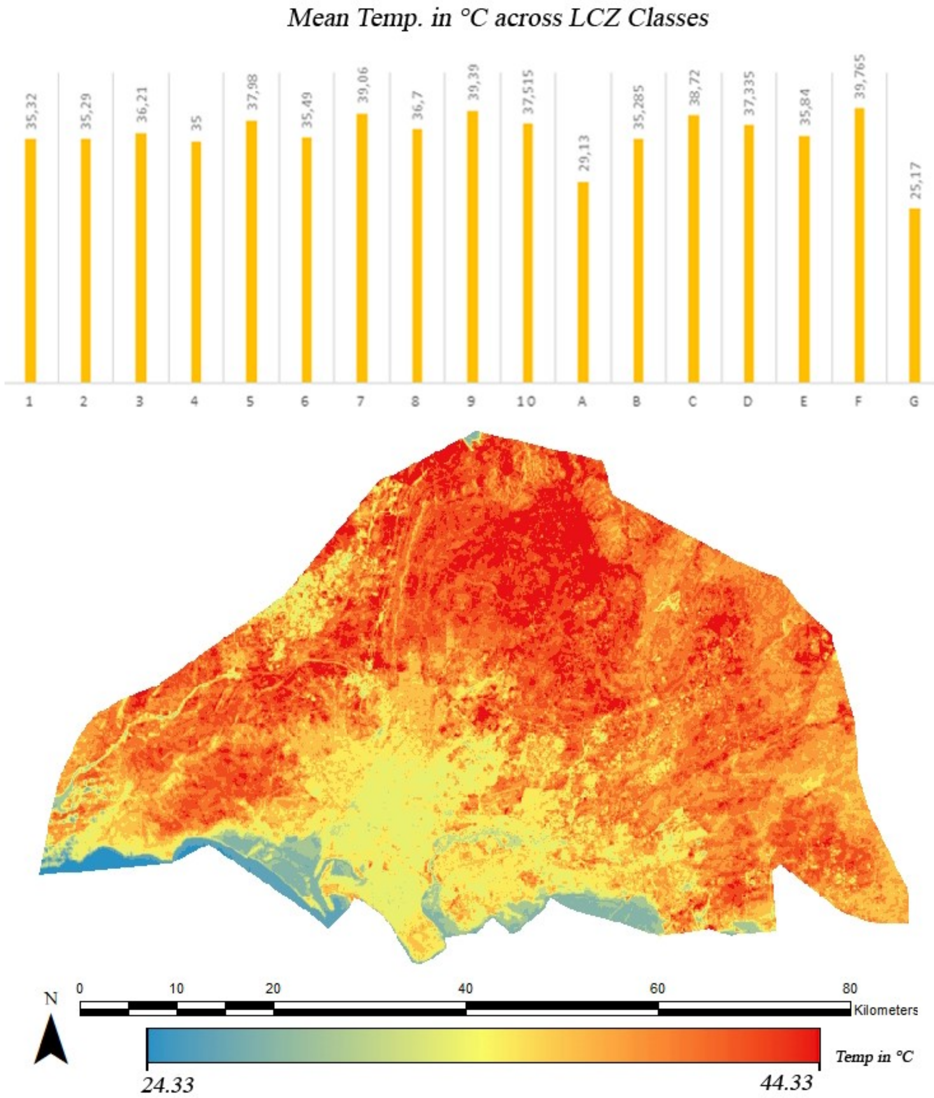

Figure 3: LST map for Karachi, June 2019 (Khan 2020)

<u>4.3 Traverse surveys</u>

Table 2. identifies the UHI magnitude observed on each route during the winter 2020 traverse surveys. The overall UHI magnitude observed is between 0.99-3.00°C where the daytime UHI intensity was weaker than that of night-time. During the day, the coolest LCZs were found to be high-rises i.e., LCZ1 and LCZ4, followed by compact midrises-LCZ2. Alternatively, at night, open low-rise i.e., LCZ8 and LCZ6, were found to be the coolest. While the warmest LCZs during the daytime were open midrise-LCZ5 and compact low-rise mixed with lightweight lowrise-LCZ3[7]. Both these LCZs also remained consistently warm at the night-time. Meanwhile, the high-rises (LCZ4 and LCZ1) showed contradictory effects at night-time with significantly high temperatures. Comparing the temperatures difference, the maximum night-time UHI magnitude of 3,0°C and 1,5°C during the daytime was observed. Based on comparisons, it was roughly noted that the higher the building height, the lesser the temperature during the day. Consequently, the high-rises even in combination with other LCZs, such as LCZ3/1 on route 1 and LCZ6/1 on route 4 exhibited lesser temperatures as

compared to standard LCZ classes on the same routes during the day, refer to figure 4 and Table 3.

Such observations also extended towards combinations of other open LCZs and green covers often serving as relative cold spots among the dense and compact LCZs. Such as LCZ 6/B on route 1 and LCZ 6/B route 2, along with LCZ 2/D and 2/8 on route 3 exhibited lesser temperatures as compared to standard LCZ 6 and 2 respectively on the same routes. Thereby, identifying correlations between the juxtaposition of LCZs with high-rise buildings, open forms, and green covers in subduing the heat intensity in comparison to standard LCZ zones.

Table 2: UHI magnitude on various routes (°C) (Khan 2020)

Route	Dis. Km	Date	Time	Lowest ΔT	Lowest ΔT LCZ	Highest ΔT	Highest ΔT LCZ	UHI Mag.
Route 01	18	31/01/2020	14:10-16:50	-0,115	LCZ6/B	0.88	LCZ5	0.995
Route 02	12	01/02/2020	13:50-15:20	-0,978	LCZ2	0,276	LCZ5	1.254
Route 02 (Night)	12	04/02/2020	19:00-21:10	0,449	LCZ6	1,674	LCZ5	1.225
Route 03	12	02/02/2020	15.20-16.50	-1,484	LCZ1	-0,222	LCZ2	1.262
Route 04	25	02/02/2020	14.35-16.35	-0,531	LCZ4	0,937	$LCZ3_7$	1.468
Route 05 (Night)	36	03/02/2020	20:05-21:55	-1,448	LCZ8	1,55	LCZ1	3.000

Table 3: UHI magnitude on various routes (°C) (Khan 2020)

Route 1, 31 January 2020										
Time	LCZ 5 FBA	LCZ F SG	LCZ 3- For DG	LCZ 3/1 GS	LCZ 3_7 KAL	LCZ 6 13D	LCZ 8 AKUH	LCZ 6 KDA	LCZ 6/B QM	IUHI Mag.
Day	0,88	0,75	0,573	0,239	0,45	0,353	0,066	0,052	-0,115	0,995
Temperature pattern- Day: LCZ5 > LCZF > LCZ3-Formal> $LCZ3_7$ > LCZ6 > LCZ3/1> LCZ8 > LCZ6 > LCZ6/B										
Route 2, 01-Feb & 04-Feb 2020										
Time	LCZ 5 FBA	LCZ 3-For MC	LCZ 2 KC	LCZ 3-Inf MC	LCZ 6 FCA	LCZ 3-For LK	LCZ 3/6 MQ	LCZ 6/B QM	-	IUHI Mag.
Day	0,276	-0,323	-0,978	-0,526	-0,393*	-0,345	-0,197	-0,58	-	1,254
Night	1,674	0,986	0,779	1,302	0,449*	1,285	1,383	1,03	-	1,225
Temperature pattern- Day: LCZ5> LCZ3/6 > LCZ3 Formal> LCZ3 Formal> LCZ6 > LCZ3-Infomal > LCZ6/B > LCZ2										
Temperature pattern- Night: LCZ5> LCZ3/6> LCZ3-Infomal > LCZ 3-Formal > LCZ6/B> LCZ3- Formal > LCZ2 > LCZ6										
Route 3, 02-Feb 2020										
Time	LCZ 2 SB	LCZ 2 PM	LCZ 2 SD	LCZ 2/D AB	LCZ 2/8 NED	LCZ 4 HBL I.I.	LCZ 4 I.I. CR	LCZ 1 FTC	LCZ4 AM	IUHI Mag.
Day	-0,698	-0,222	-0,372	-0,631	-0,8	-0,938	-1,246	-1,484	-1,296	1,262
Temperature patter - Night: LCZ2> LCZ2> LCZ2/D> LCZ2 > LCZ 2/8 > LCZ4> LCZ4 > LCZ4 > LCZ1										
Route 4, 02-Feb 2020										
Time	LCZ 37 MC	LCZ 10 WW	LCZ 10 WWR	LCZ 2 KH	LCZ A/F MF	LCZ D BQP	LCZ 4 DM	LCZ 6 DH	LCZ 1/6 DA	IUHI Mag.
Day	0,937	0,06	0,115	-0,244	-0,005	-0,244	-0,531	-0,005	-0,161	1,468
Temperature pattern- Day: LCZ37 > LCZ10 > LCZ1/6> LCZ A/F≈LCZ6 > LCZ2 ≈LCZD > LCZ4										
Route 5, 03-Feb 2020										
Time	LCZ 8 AKUH	LCZ 2 BB	LCZ 1 BB	LCZ 4 BB	LCZ 8 JPMC	LCZ 4 SHF	LCZ 6 KDA	LCZ 6 KUR	LCZ 8 KU1	IUHI Mag.
Night	0,781	0,826	1,374	1,239	0,744*	1,552	1,139*	-0,805	-1,448	3,00
Temperature pattern- Night: LCZ4 > LCZ1 > LCZ4 > LCZ8 > LCZ6* >LCZ2 > LCZ8										

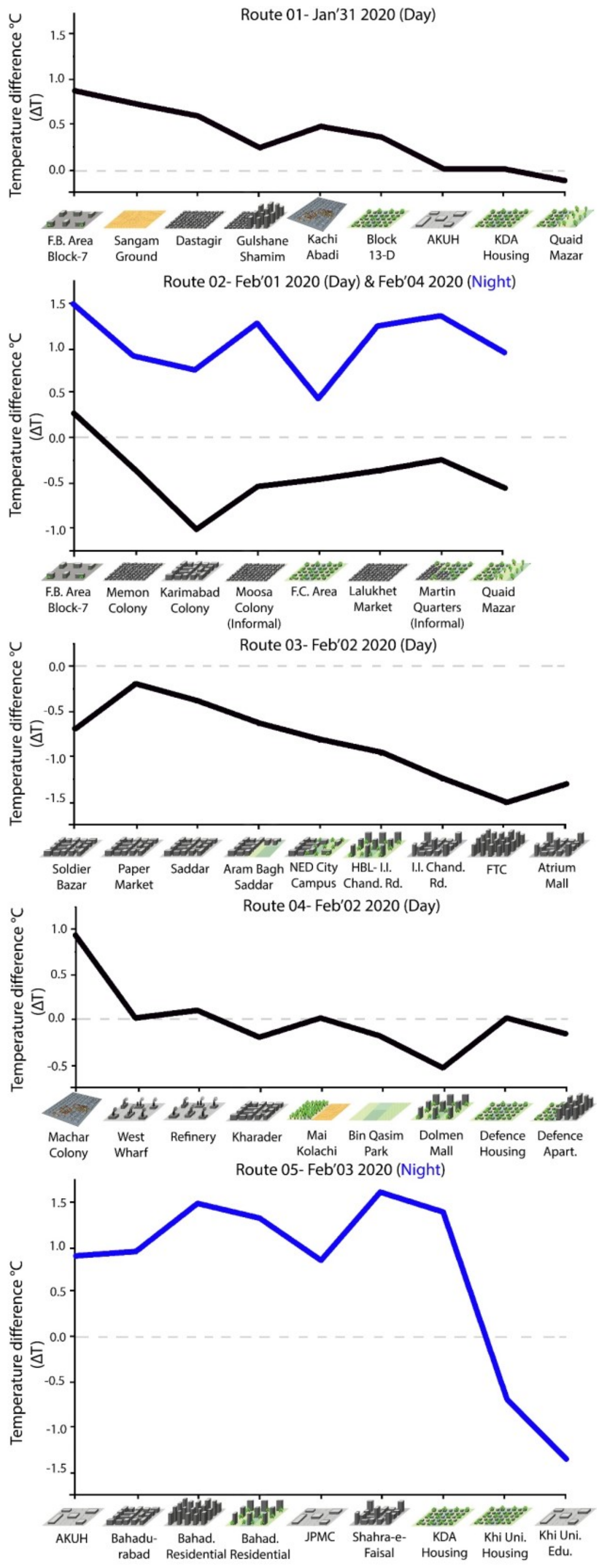

Figure 4: Temperature difference(°C) profiles during traverse surveys (Khan 2020)

4.4 Extrapolation in future scenarios

y appropriating Perera & Emmanuel's (2018) strategy, with the extrapolation of possible temperature changes in future scenarios, as shown in Table 4, its projected that all LCZ intensifications (assuming LCZ6 and LCZ8 as the base case) lead to cooling effects except for open midrise-LCZ5 during the peak daytime. This effect strengthens as the LCZs go higher.

Table 4: Projected day-time temperature differences (Khan 2020)

Existing LCZ		Projected LCZ								
LCZ	Title	1	2	3-For	3-Inf	4	5	6	7	8
1	Compact High-rise	-1.48								
2	Compact Mid-rise	-1.48	-0,97							
3	Compact Low-rise	-1.48	-0,97	-0,33	-0,52					
4	Open High-rise	-1.48	-0,97	-0,33	-0,52	-1.12				
5	Open Mid-rise	-1.48	-0,97	-0,33	-0,52	-1.12	0,88			
6	Open Low-rise	-1.48	-0,97	-0,33	-0,52	-1.12	0,88	-0,393		
7	Light weight low-rise	-1.48	-0,97	-0,33	-0,52	-1.12	0,88	-0,393	x	
8	Large Low-rise	-1.48	-0,97	-0,33	-0,52	-1.12	0,88	-0,393	x	0,06

However, the same association to building heights at night-time leads to extreme warming, as shown in Table 5. The night-time UHI is pertinent due to the high susceptibility of outdoor temperatures impacting indoors for free-running buildings (Jacobs, et al. 2019). Further, under the pretext that open lowrises-LCZ6 is drastically being transformed in to taller and dense LCZs, all the tentative intensifications cause extreme local warming at night-time except for compact mid-rises-LCZ2. Given these repercussions, the growing numbers of high-rises may instigate extreme climatic consequences at the city scale if unregulated.

Meanwhile, horizontal densification of open low-rise towards a more compact form i.e., LCZ6 to LCZ3 also induces night-time heating. Since LCZ3 is already dominant in the city, more additions may have a disproportionate temperature impact on the overall city heating. Meanwhile, the vertical transition of LCZ3 towards LCZ2 seems to be the most stable and least harmful change from a diurnal perspective.

Table 5: Projected night-time temperature differences (Khan 2020)

Existing LCZ		Projected LCZ								
LCZ	Title	1	2	3-For	3-Inf	4	5	6	7	8
1	Compact High-rise	1,37								
2	Compact Mid-rise	1.37	0,82							
3	Compact Low-rise	1,37	0,82	0,98	1,30					
4	Open High-rise	1,37	0,82	0,98	1,30	1,55				
5	Open Mid-rise	1,37	0,82	0,98	1,30	1,55	1,67			
6	Open Low-rise	1,37	0,82	0,98	1,30	1,55	1,67	-0,80		
7	Light weight low-rise	1,37	0,82	0,98	1,30	1,55	1,67	-0,80	x	
8	Large Low-rise	1,37	0,82	0,98	1,30	1,55	1,67	-0,80	x	-1,44

4.5 Discussions

Karachi, despite being considered a high-density city is majorly dominated by low-rise LCZs, and yet exhibits a considerable UHI magnitude. This identifies that the connotation of high-density does not translate into high-rise buildings in Karachi as LCZ classes vertically high featuring higher aspect ratio may not be equivalent to high population density given the disparity in formal/informal growth pattern and dominance of highly dense compact low and mid-rise informal developments in Karachi (Hasan & Mohib 2003). Meanwhile, the high-rise buildings have been identified with contradictory heating patterns in a diurnal cycle and may construe positive or negative implications based on usage.

Literature guides that in hot regions, the alignment of timing of use and shading provided by deeper forms is reciprocally beneficial for both, the outdoor as a 'solar umbrella' (Emmanuel 1993) and indoors by decreasing the energy demand, such as for areas with dominated commercial buildings with peak daytime functions (Futcher et al. 2013). Hence, the so appearing dichotomy of high-rise buildings may suit the commercial high-rises in Karachi. However, this limited daytime phenomena of 'cool island' effect (Pearlmutter & Berliner 1999) may contrarily lead to greater UHI intensity at night. Hence, dis-serve other building typologies with diurnal functional cycles and may even be disastrous for Karachi.

Furthermore, the anticipation towards more high-rise buildings and the intensification of the already high population density are both critical for UHI formation (Kotharkar & Surawar 2016) and causing/increasing vulnerability towards heat health risks. The consideration of vulnerability is essential in developing cities given the massive volume of vulnerable populations forming a majorly ignored stakeholder. Hence, these observations not only entail a comprehensive understanding of the complex interplay between the temporal and spatial phenomena but also implore a recognition of the qualitative and quantitative attentions for bespoke identification of drivers to UHI and mitigation capacities.

Bearing in mind these discussions, the informal developments which may potentially be a major part of LCZ3 thus, not only are densely populated but the current dominance in the city scale, likeliness towards further growth and extreme temperature patterns in parallel with vulnerable populations unanimously distinguish it as the most critical LCZ. Therefore, further mitigations are explored specific to this LCZ class.

4.6 ENVI-met Simulations

Based on the comparisons to the existing conditions as observed in Figure 5, the simulations highlighted that the greatest day and night time T_{Air} decrease occurs with the density manipulations followed by high-albedo strategies. Although, a more pronounced change was observed in terms of MRT with the lowest spread observed again in the 'Medium Density' scenario.

While during the daytime, the 'high-albedo' scenario strikingly accentuated the effect of MRT greater than that of any other case, causing worst thermal comfort implications. This study endorses that the approaches that lead to better T_{Air} may not act synonymously for the thermal comfort (Emmanuel & Fernando 2007). Thus, evaluating these indicators, it appears that mid-density enhancement has a positive mitigating effect, although more pronounced on MRT than T_{Air}. and with this implication for lower thermal discomfort in the heavily built sections of the city and given the likeliness towards mid-density future trends, it might prove as a viable mitigation choice.

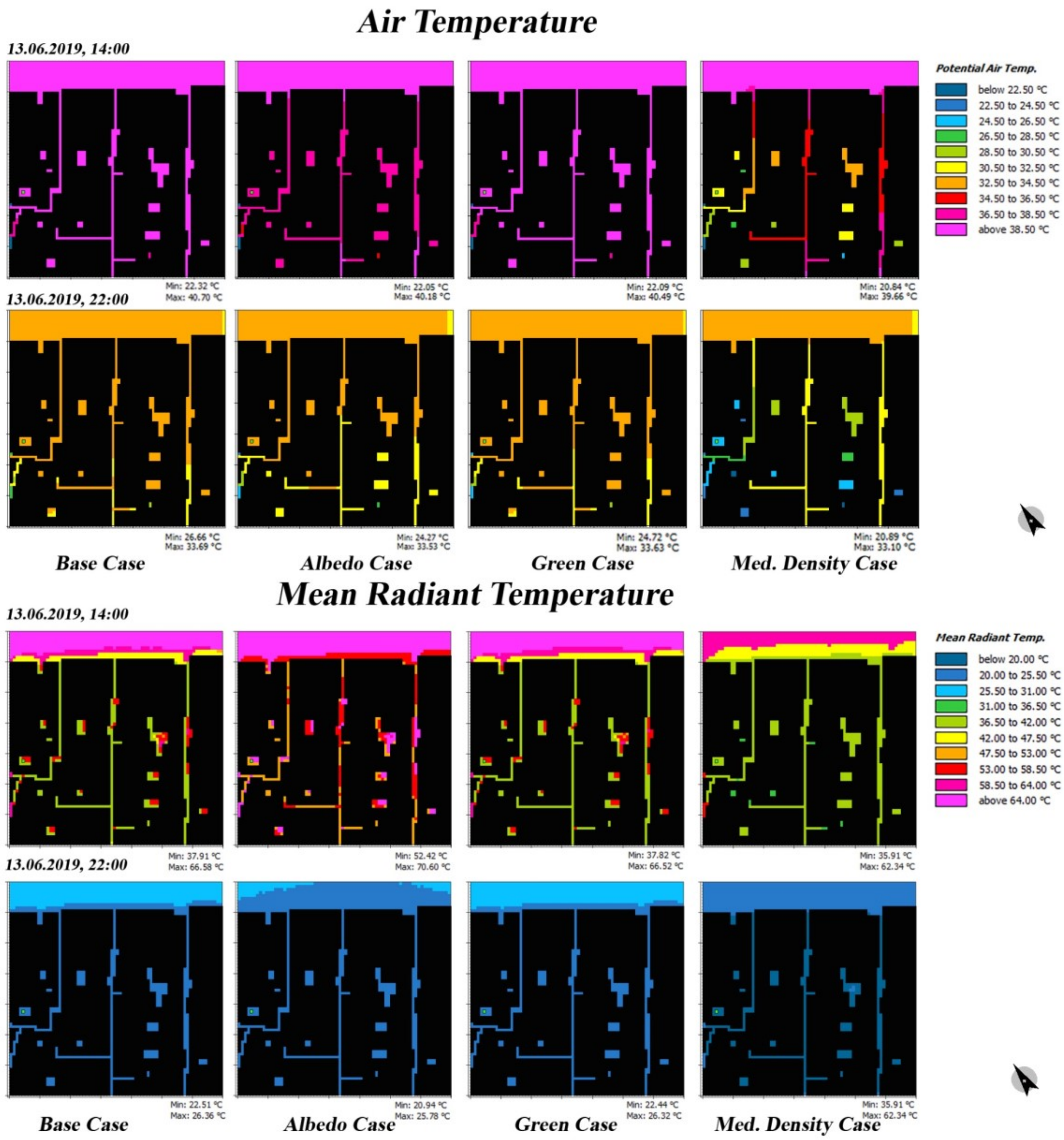

Figure 5: Air Temperature an MRT patterns (at 1.5 m above street surface) (Khan 2020)

5. Implications and Conclusions

The scope UHI investigations is nascent in Karachi. As a pioneer study, this study delivers a multidimensional process within a complex urban fabric to study the UHI effects to facilitate climate-sensitive urban planning.

For LCZ classification, although the WUDAPT method offered a simple process, it yet established an accuracy of 68% in the data-scarce developing context of Karachi. For future studies, customization / sub-classification is proposed to fit to the local realities which could enhance the assessment.

The LCZ mapping clearly identified a disproportionate mix of compact built-up classes in the city's urban core along with a terrible lack of blue-green infrastructure, while the LST maps recognized the SUHI differences among various LCZ classes forming the summer SUHI magnitude of approximately 15 °C at daytime. The small winter dataset of traverse surveys, in coherence with the LST, not only established the temporal effect of standard LCZ classes on the street level, but also provided an introspection into unique combinations /subclasses of these in creating cooler spots and vice versa. This is a relevant consideration bearing in mind the formal/informal nature as well as mixed built typologies of Karachi's development and may offer better practical utility as opposed to examining standard LCZ classes. However, a bigger dataset along with a comprehensive understanding of these mixtures would be vital in facilitating future research.

In both the methods, the intra-zone UHI differences relate well with previous studies attesting to the common drivers such as spatial arrangement / land cover, building density, green cover and vegetation, among others. The LST maps identified compact low-rise(LCZ3) and open mid-rise (LCZ5) as the warmest among the built-up classes (1-6) for the daytime, while the traverses detected a more accentuated role of the high-rises (LCZ1 and LCZ4) as cold spots on the street level during the day. However, for night-time, the high-rises (LCZ1 and LCZ4) served the opposite role. Generally, the temperatures contrasts between zones with large differences in surface morphology and land cover was established such as the high-rises (LCZ1 and LCZ4) in contrast with open low-rise and large buildings (LCZ6 and 8), creating the maximum night-time UHI magnitude of 3 °C. On the contrary, the maximum daytime UHI magnitude was relatively lesser with 1,5 °C between compact low-rise infused with lightweight low-rise ($LCZ3_7$) and open high-rises (LCZ4). Further, the LCZ maps' comparisons between 2009 and 2019 show a continuous increase in more built-up areas, particularly the intense densification of the city core with the infusion of compact low, mid-rise and high-rise blocks. This trend towards vertical expansion as well as horizontal densification is shown to push the UHI effect up and insinuates a likeliness for worse climatic impacts for the coming years.

And albeit its suggested to avoid the construction of dense, airless, overpopulated communities altogether (Toy & Yilmaz 2010), the practical utility of such suggestions in the given context is almost impossible to ensure. However, the daytime advantages such as shading may allow potential and opportunities for appropriation towards positive energy management (Futcher et al. 2013). On the other hand, the way forward must also offer inclusive UHI mitigation strategies to the unprivileged and disproportionately affected, implying the need for interventions which align with the social and economic realities of the low-income settlements (Hasan & Mohib 2003). Aiding this observation, one design implications of this study is that height enhancement i.e., the densification towards compact mid-rises (LCZ2) is the least harmful among all LCZ classes validated via ENVI-met simulations and temperature extrapolation in future scenarios, and may be a viable UHI mitigation option. However, the wind flow dynamics is a relevant research area for future studies to derive holistic recommendations.

Moreover, propositions also require careful consideration as they may not have synonymous effects towards reducing air temperature and offering better thermal comfort. Alternatively, the cooling implications of mixed LCZs may offer opportunities for policies in urban planning for new developments advocating the idea of tall irregularly positioned building with varied heights and freed up open space (Chatzipoulka & Nikolopoulou 2018), thereby, encouraging airflow and vegetation channels. And hence, seem like a stable middle ground for practical density requirements and local climate, energy consumption and comfort effects.

Through this process, two main perspectives are identified. Firstly, a deeper climate-based change classification for the rapidly growing developing cities. This implies that the currently dominant LULC practice may be elaborated into LCZ change (LCZC) classification to understand heating behaviors associated with urban growth patterns. Such a method not only quantifies change in land densification by going beyond the traditionally simplistic descriptors of rural/urban but also specifies precise thermal trends associated with specific land typologies to facilitate future planning. Additionally, it offers identification of actual urban growth as opposed to planned growth and hence, vital for city planning and policy making, explicitly for developing cities pertaining to extreme poverty (Millington et al. 2018). Secondly, the distinction of density-based assumptions in the LCZ classification and mitigation seem to be context specific and not identical in all situations. More precisely, the informal developments in Karachi, often exhibit a combination of vertical and horizontal building densities juxtaposed with high population density and hence, require bespoke assessment and interventions. Thereby, the insufficiency of LCZ framework to rightly address population density needs to be alternatively addressed. Meanwhile, UHI mitigation in response to the perspectives of disaster/risk origins being embedded in the physical environment versus the societal conditions and vulnerabilities puts the spatial planning at a vital point in sustaining a balance between these two standpoints and may enhance the capacity towards disaster risk reduction (Rafiq & Blaschke 2012). Both the above-mentioned perspectives aid the recognition of these debates. Hence, such an approach may be useful for contexts like Karachi with a huge chunk of illegal informal settlements for documentation as well as identification of the scale of mitigation.

In general, Karachi, as one of the most-dense cities of the world requires an urgency-instinct approach for UHI mitigation and yet offers great mitigative potential to manage the climatic challenges based on expected trends.

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Between Buildings: An Evaluation of London's Microclimate Policy

Paula Presser

Abstract

Urban centres play a crucial role in climate change. Therefore, it is necessary to think about urban planning's role in these changes. This thesis aims to investigate what we know about how urban factors influence the city's climate, within these factors which would be the most influential in London according to the opinion of experts and how these factors appear in the London's climate simulations. Furthermore, how this knowledge can be added within the existing urban legislation. For this, a mixed methodology was used between literature review, questionnaire and focus group. From the results obtained by the focus group, we saw that the main factors that we still do not know about urban climate are urban form and modelling, about how we can tackle: regulations and modelling. In the questionnaire, we saw that the main factor that must be considered in London is anthropogenic heat and that the current urban policies in London are unsatisfactory by most of the participants. Through the work, it can be concluded that an evaluation methodology is needed that focuses on the interrelation between urban factors, the formation of evaluation committees of the planning structure for the implementation of new climatic practices.

1. Introduction

The future scenarios of the climate crisis show a severe increase in the global average temperature, according to the International Panel of Climate Change (Ng et al. 2016). Thus, it is necessary to find ways to reduce city emission, as they account for 80% of total greenhouse gas (GHG) (Chakraborty and Allred 2015). Urban constructions are the first forms of anthropogenic climate change, afterwards, they are ways of adapting the external environment to human requirements according to the needs of each location - cold, heat, humidity, etc. (Hebbert and Jankovic 2013). Today some solutions help to reduce energy consumption for buildings and assessment tools that facilitate quantifying these expenditures. However, these strategies need to relate to urban planning and consider not only buildings in isolation but them as a group (Bourdic and Salat 2012). Therefore, the urban regulation policies need to work at different scales to achieve their goals.

A study with more than 32 architects and design practitioners found out that building regulations are the main driver for energy changes (Heaphy 2017). So this work will highlight the urban planning power to take cities to an eco-friendlier level and climate responsible future, so it is in an urgent way that we must study the possible strategies to be taken by cities in this aspect.

This work aims to investigate how the knowledge acquired in previous research on the influence of urban factors can effectively help in reducing the urban impact on the climate crisis and how can this be translated in urban governance. To this end, we will go through a literature review where we analyse the main climatic factors and how they affect urban space. What anthropogenic changes occur in the urban space and how they affect the climate in that area, so we look for some examples of how cities in different climates have been working to mitigate the effects of urban space in favour of better thermal comfort, higher energy efficiency and less impact on the population's health. These work objectives are:

- Analyse what is already known about climatic factors and what is not yet known;
- Critically explore urban climate factors through specialists (from the private sector, academics, and the public sector), and discover which factors are believed to be the main ones.
- Critically Evaluate the effectiveness of these options through existing simulations of London's microclimate on mitigating these factors.
- Propose ways in which such knowledge could be embedded in the governance structures of cities.

For this purpose, a mixed methodology will be used, with a literary and documentary review to verify what we already know about urban factors and how they present themselves in the urban regulation of some cities.

2. Background

2.1 Urban climate factors

2.1.1 Heat: Episodes of extreme Heat in cities have frequently been increasing, ate the same time there is evidence demonstrating the existence of a human thermal limit, so copping with these issues comes to be extremely important. Besides, more areas with more significant population agglomeration are also those with higher temperatures and are generally located in urban city centres, which are the most affected areas by UHI (Tomlinson et al. 2011). The damage to human health linked to extreme warming varies from cramps to exhaustion and can even reach heat strokes (Ng et al. 2016).

2.1.2 Wind: Ventilation, air movement, perhaps one of the main factors for human thermal comfort in urban centres, it is present in cities all the time, every day regardless of the season and is directly affected by the urban shape, buildings, blocks, streets and trees (Hebbert and Jankovic 2013). In cities, many factors act to alter their natural movements. Some urban forms can help improve the quality of ventilation in urban centres; one of them is the creation of permeability at the pedestrian level facilitates wind flow. It improves air circulation, in addition to removing pollutants and heat generated at the ground level (Ng 2009).

2.1.3 Precipitation: One of the natural factors influenced by the urban space is precipitation; this is because the construction of cities is based on the modification of the natural area by new surfaces, which often consist of concrete and asphalt, materials with higher thermal inertia that stores a significant amount of heat. Besides, the urban atmosphere is more polluted than its surroundings. Many studies show an increase in precipitation in urban areas, mainly due to three factors: urban heat island, surface roughness, and higher aerosol concentration (Han et al. 2014).

2.1.4 Humidity: Another critical factor in understanding the urban climate is the relative humidity of the air (RH) since the differences in the surface between the urban-rural areas and the vegetation cover in both are very distinct, and this difference causes disturbances in the latent heat fluxes, and so in the temperature of the cities (Zhang and Wu 2018; Hu et al. 2014). The influence of high RH directly interferes in the formation of clouds, fog and smog, reducing the sensitivity and increasing the concentration of aerosol (Zhang and Wu 2018). Also, high RH values can exacerbate heat stress waves (Hu et al. 2014). It is possible to analyze the impact of HR on human health, considering the combination of grand RH with high temperatures increases heat stress (linked to cardiovascular diseases), besides, the RH concentration directly influences the concentration of bacteria, fungi and viruses and it can increase or decrease the speed of spread of diseases. (Zhang and Wu 2018)

2.2 Sources for Urban Climate Abnormalities

2.1.5 Urban form: According to Jabareen (2006), urban form is a composition of elements that are replicated within the city land use, such as streets, blocks and transportation systems. Using a quote by Kevin Lynch (1981) "the spatial pattern of large, inert and permanent physical objects in a city", these patterns occur through agglomerations of elements that are repeated in an unlimited way. Dense cities with little vegetation are considered the heat stress most uncomfortable (Martilli 2014). However, urban forms are nothing more than the result of the planning policies of each region of the city. The urban climate is the result of the set of individual decisions of each building (Futcher et al. 2017). So choices that drive families to regions further away from their jobs and policies that do not induce mixed-used businesses to end up increasing the spread of the city, and end up promoting an increase in GHG emissions, even though there are isolated policies for increasing energy efficiency for isolate buildings, in the end, it is a question of the scale of political intervention (Chakraborty and Allred 2015).

2.1.5 Lack of green infrastructure: The use of these structures in the urban space brings several advantages, among them an improvement in air quality and reduction of air temperature by up to 4.1°C (green roof in mesoscale).However, many of these green structures can have a more significant impact when in quantity, but it is difficult to find spaces for these in the densest areas of the cities - which end up being the areas that need it most, so the singles trees, trees present in the flowerbeds green roofs and vegetated yards are of paramount importance (Saaroni et al. 2018). The trees on the sidewalk are enough to reduce radiant heat load, and heat stress, trees with a higher leaf area index (LAI) can reflect shortwaves and even provide a more shaded area (Kong et al. 2017) in addition to the leaves' transpiration.

2.1.6 Materials: About thermal balance of cities, the materiality of the buildings plays a fundamental role, since they absorb solar and infrared radiation and dissipate part of it in the atmosphere, increasing the air temperature, so it is necessary to study how we can mitigate this impact through the election of the most appropriate materials. Those with the highest reflective potential and infrared emittance are the so-called 'cool materials', as they increase urban albedo and contribute to the mitigation of the heat island phenomenon. Also, the use of cool materials increases the energy efficiency of buildings by reducing the demand for cooling systems and improving the quality of the urban microclimate (Santamouris et al. 2011).

2.1.7 Anthropogenic Heat: Although the contribution of anthropogenic activity to an increase in atmospheric temperature is considered a small fraction within the global scale, this factor influences much in the temperature of urban centres, contributing directly to phenomena such as urban heat island (Smith et al. 2009). Anthropogenic heat is a compound of emissions of fuels, electricity (industries, homes, etc.) and through the heating and cooling of buildings, with these components, it is possible to state that urban expansion has a direct impact on the discharge of anthropogenic Heat (Zhang et al. 2012).

2.1.8 Pollution: The climate crisis, among other things, directly and indirectly, influences the formation of air pollution (Patella et al. 2018), studies show that pollution has Nano and Micro-sized toxins, of which the micro-particles are the most dangerous since it has the potential to penetrate cell membranes and accumulate in the human body (Veremchuk et al. 2016).

2.1.9 Governance: Studies related to urban governance have a fundamental role in the analysis of the urban microclimate, because the urban form partly defines urban morphology, the metabolism of energy exchanges and even the biochemistry of cities, and this has a direct influence on the policies that define them. The need to study more profoundly is due to the importance that many of its indirect consequences have for the urban microclimate (Bai et al. 2010). Today many of the policies are limited to the envelope of each building, and the political issues that have urban climate are limited to lighting and winds, being those that exist today very generic and not taking into account that when contained in the urban fabric they will interact as a whole. Also, there are still no policies that establish the right to natural resources of cities (Futcher et al. 2017).

3. Method

To achieve the objectives of the thesis, the methodology used in this work is mixed, starting by collecting focus group data, analyzing them through literature review and finally a questionnaire with experts in urban climate governance.

In January 2017, an event was promoted by the Adaptation and Resilience in the Context of Change network (ARCC staffed and managed by UKCIP, and hosted by the Environmental Change Institute, University of Oxford), where researchers in the area of climate change and its impact on urban areas, presented their research to a group of practitioners, academics and public sector employees. In total, 78 participants were gathered on one day of the meeting to deliberate about urban climate subject. The presentations were on the following topics: urban climate, urban microclimate, energy management, facility management, health and wellbeing and urban greening.

After each presentation, participants were asked to answer a questionnaire where the studies were evaluated, and ideas were collected for each of the questions related to the subject. The questionnaires have public access through the website at the event[2]. The answers to the questionnaires were transferred to an excel spreadsheet where only the answers corresponding to the following topics were filtered: urban climate, urban microclimate and urban greening. So it was divided into three worksheets that corresponded to the answers to the question "which option does your Idea apply to?": What we already know, what we need to know and how to tackle. From this division, the responses were evaluated and divided into subcategories: thermal effects, knowledge bridge, urban form, governance, transport, green infrastructure, costumers behaviour, social gap, healthy and modelling. So results were obtained through these categories.

After categorizing the reported factors, a literature review of the climatic factors that influence the urban space and which urban factors influence the climate began. In this phase, academic search tools provided by Glasgow Caledonian University were used with the following keywords: 'urban heat', 'urban wind', 'urban precipitation', 'urban humidity', 'urban form', 'green infrastructure', 'building materials', 'anthropogenic heat', 'urban air pollution', 'thermal comfort', 'energy use'. Besides, information was sought on 'urban climate policies', 'environment governance' and on cities that have public climate policies. The researched material was published between the years 2006 - 2019. The study has limitations due to a large number of papers available on Environmental Governance. However, the review focused more specifically on issues raised by experts at the 2017 meeting.

Next a questionnaire was formulated in which some of the specialists of the 2017 meeting were invited to participate. The questionnaire took place online with objective questions using the Google Forms platform from 8 to 15 July. The questionnaire obtained a total of 14 respondents with representatives from the public, private and academia sectors. There are limitations concerning the number of respondents. However, it is a very restricted audience

[2] https://www.arcc-network.org.uk/people-making-changes/urban-micro-climate/

since one of the prerequisites to participate was that they: worked in London, worked on the topic of climate urbanism and understood urban legislation. Despite the limited number of participants, it was possible to reach conclusive results.

4. Results

4.1 ARCC Meeting: Focus Group

The event that took place on the 6th of January featured different presentations content from 6 topics: urban climates, energy management, urban microclimate, facilities management, health and wellbeing and greening cities (Adaptation and Resilience in the Context of Change network 2017). After the presentations, the participants were invited to debate and answer a questionnaire. In the questionnaire, the respondent should mark which topic (urban climate, energy management, urban microclimate, facility management, health & wellbeing and greening cities) their contribution would consist. Then If that fit in 'something already known', 'something we do not know yet' or 'how can we resolve the issue'. Also, it was possible to indicate which sector would be responsible for the suggestion and whether it was a solution or a challenge. In the right corner of the questionnaire, the respondent should describe his suggestion. In other to obtain data from this research, a spreadsheet was created with the contents belonging to the following topics: urban climate, urban microclimate and greening cities. From then on, the subsequent investigation was carried out, among the suggestions brought by the experts, which were the most cited factors when it comes to "what we already know but are not using it", “what we need to know” and “what can be done to tackle” (Figure 1).

4.2 Questionnaire

There were a total of 14 experts that have identified themselves from the following areas: academia (3), private sector (3), public sector (4), private sector + academic sector (2) and private sector + public sector + academic sector (2). The questionnaire was conducted using the Google Forms platform between July 8 and 17, 2020.

Question number one (Q1) asked the respondent to rank between 1 (most important) and 5 (least important) the climatic factors that they believe are the most significant influence in London microclimate (Figure 2). The options consisted were: 'green spaces', 'the heat generated from building and cars', 'urban morphology', 'urban density' and 'materials'.

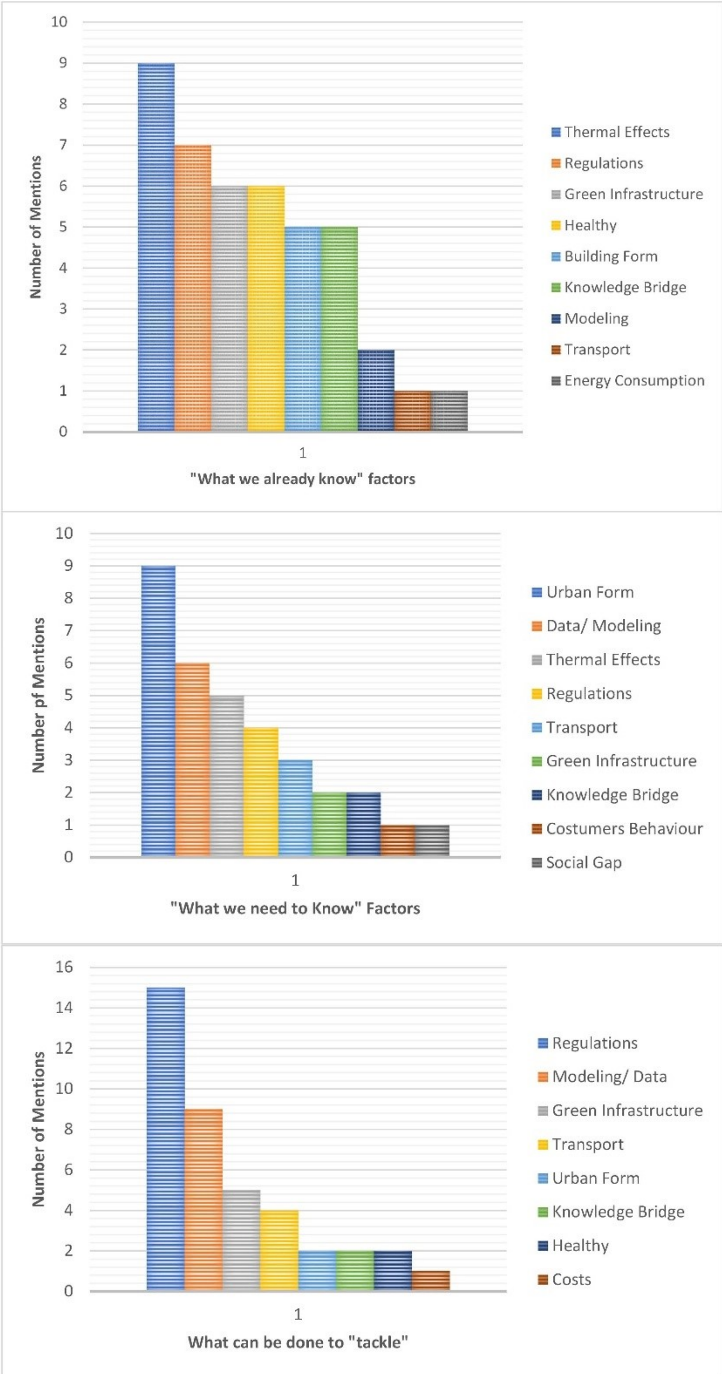

Figure 1: Graph with mentions for the question "what we already know but are not using it" | "what we need to know" | "how are we going to tackle or taking it forward" (Presser 2020)

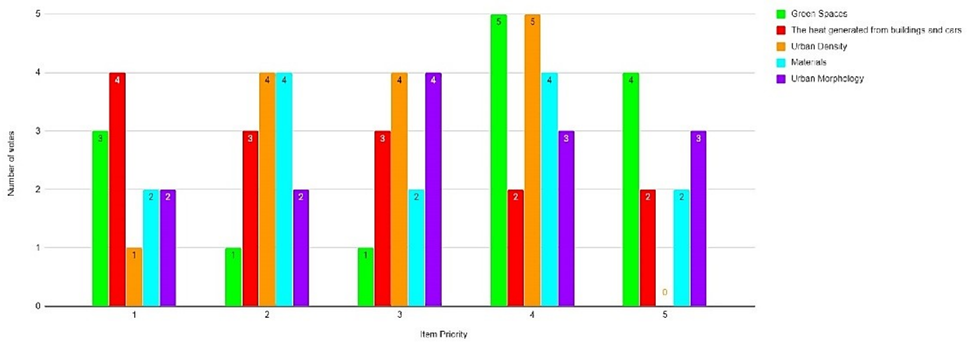

Figure 2: Chart Q1, Number of votes x Item Priority (Presser 2020)

Question 2 (Q2) (Figure 3) shows options for the overheating issue in London and the respondent should point out whether they agree with the strategy on a scale ranging from 'strongly agree' to 'strongly disagree', the option 'do not know' was also inserted if the respondent was not familiar with the strategy.

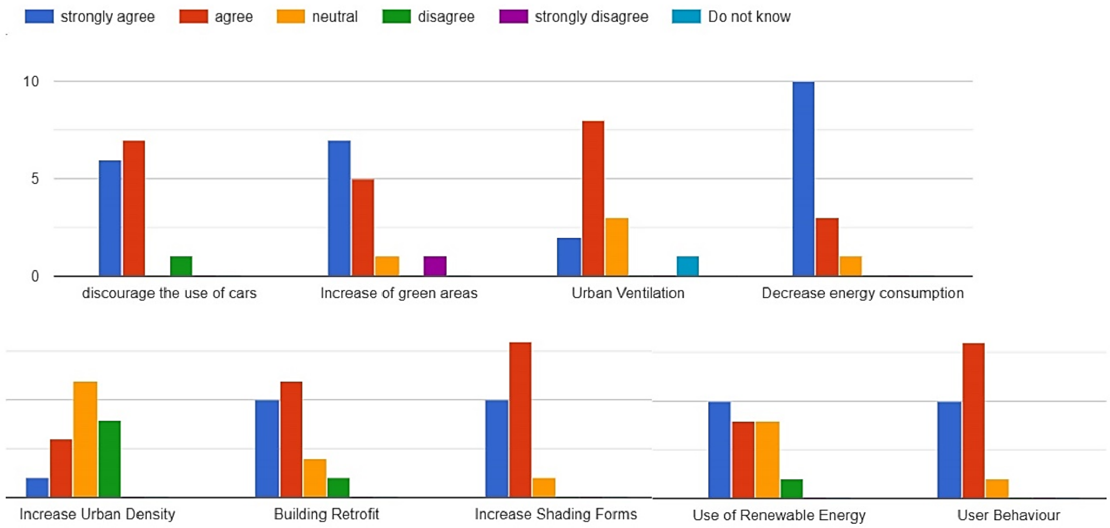

Figure 3: Answers obtained in Question number 2 (Presser 2020)

In question 3 (Q3), the following sentence "The urban heat island effect helps London to save in energy consumption in heating" was presented and respondents should choose whether the answer was true or false. The sentence is correct; however, only 35.7% of respondents opted for this option, corresponding to 5/14 of the respondents.

Question 4 (Q4) (Figure 4) is about the microclimate governance in London, in which statements were made and respondents should agree or disagree on a scale between 'strongly agree' and 'strongly disagree', as well as Q2 with the 'do not know' option in case the responder was not familiarised with the regulation.

Finally, question number 5 (Q5) presents the option of possible barriers that might interfere with the improvement in London's microclimate policies. As in Q1, the respondent must list the alternatives on a scale of importance (1 most important and 7 least important). When we analyze the responses by sector, we will see that the motive that least matter is a consensus 'impossibility caused by Londons heritage sites', as the primary motive the three sectors agree with 'lack of tax incentives', however, the public and academia sectors 'private also point for 'private sectors lobby'.

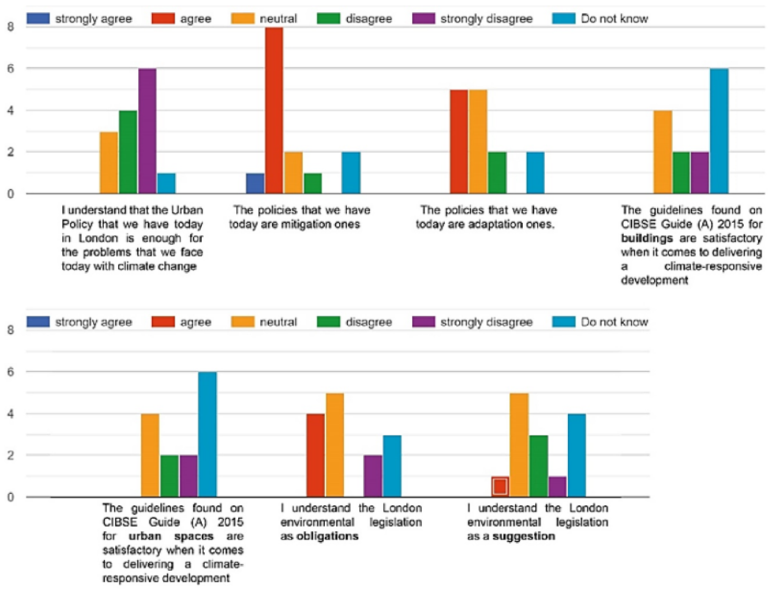

Figure 4: Answers obtained in Question number 4 (Presser 2020)

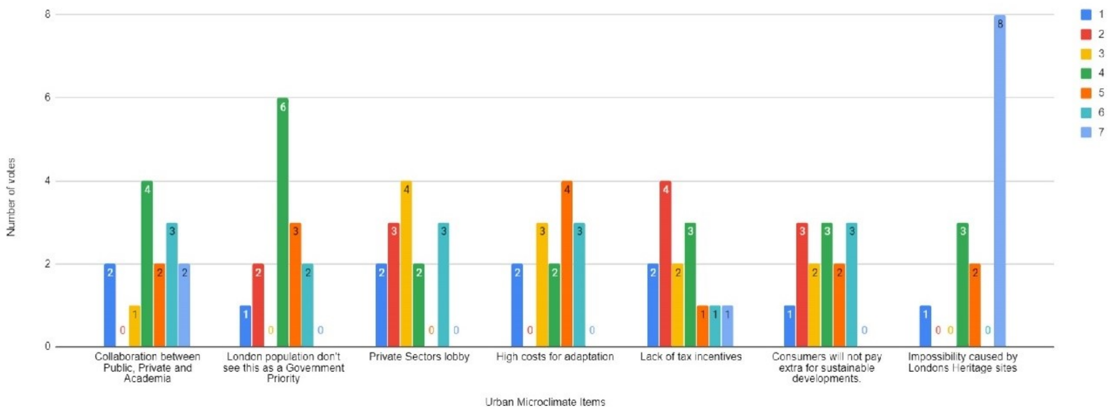

Figure 5: Chart Q5, Number of votes x Urban Microclimate Items (Presser 2020)

5. Implications and Conclusions

Analyzing the results obtained in the questionnaire conducted in July 2020, it is possible to make some interpretations. According to with the experts, the factors that have the most impact on London microclimate are 'heat generated from cars and buildings', followed by 'materials', factors that have proven relevance concerning urban temperature. The issue of materiality is linked to radiation and heat emission, so it is indeed paramount for the urban microclimate. Anthropogenic heat (that consists of the heat generated by cars and consumption of buildings) as shown above, has a direct impact on the UHI effect with a 1 to 3C increase. However, energy consumption is linked to urban density, being higher in the densest areas of the city. Nevertheless, it is possible to state that denser cities reduce the need for commuting by cars, so there would be a reduction in the emission of gases from cars. These facts show that the issues related to anthropogenic heat are complex and must be analyzed along with other factors.

Also, in Q2 was stated that the best way to deal with overheating in London is by reducing energy consumption, as previously seen approximately half of the effects of UHI are caused by energy consumption (Hebbert and Jankovic 2013). Moreover, coherently, the suggestion that received the most focused responses to 'neutral' and 'disagree' was 'Increase of Urban Density, which is directly related to the increase in energy consumption. The reduction of energy consumption is undoubtedly a factor that needs to be reduced. However, to achieve this adequately in cities, it is necessary to think not only about consumption separately, but in conjunction with other aspects that influence its uses - mainly regarding heating and cooling.

In Q5, the experts were asked about the main barriers to the implementation of urban environmental policies. Among the options presented, specialists point out among the options which they believed to be the main reason down to the last. Despite the varied responses, it is possible to notice some bias, for example, the option 'Private Sectors lobby' had most of its answers (9) among the top 3 positions. However, when we analyze the questionnaire by sector, we will see that it was the academia and the public sector that most pointed to this problem. For the private sector, the main barrier was 'lack of tax incentives'. Here it is possible to observe a dispute of interests, within the different points of view and needs of each sector.

From the results obtained in the questionnaire carried out in 2020 and the 2017 meeting with 65 experts in the area of architecture and urbanism in London, together with a literature and documentary review, it was possible to reach some conclusions. The first of them concerns the matter raised by the questionnaire on what the public sector + academia and the private sector see it as the main barrier to the implementation of more effective climate policies in London. While academia and the public sector see the private sector Lobby as the main barrier, it sees the lack of tax incentives as problematic. This shows that it is necessary to deepen the investigation around a regulatory strategy as close as possible to a 'win-win' situation. This can be done through dialogue between the parties where each one analyzes how much they can give in without harming themselves financially. Solutions will not arrive quickly, but somewhat flexible and adjusted as the demands are changing.

The main factor contributing to London's urban overheating according to the results of the 2020 questionnaire, which goes according to the review of the simulations in London, is anthropogenic heat (heat generated from buildings + cars + human heat). As we saw in the simulations, the energy expenditure of buildings is directly related to urban density. However, this same density is the one that allows less mobility for individual vehicles, thus contributing to the reduction of the heat generated from cars. Density issues are linked to the use of heating by residential buildings and air conditioning for office buildings. These issues can be reduced through the use of more suitable materials, better distribution of green infrastructure, ventilation, shading and other factors linked to urban form. Therefore, density should not be seen as the problem, mainly because the opposite would be a greater spread of the city, increasing the displacement by cars, increasing the number of roads and reducing natural cover.

The various factors that affect the anthropogenic heat issue show us how the topics related to the urban microclimate cannot be treated in isolation. There is a codependency between the factors and their intensity. Green spaces affect the urban shape, shading, air humidity, as well as the urban shape influencing ventilation, shading and so on. For this reason, the urban factors present in the regulations cannot be thought of in isolation. These factors must be worked together to improve their efficiency; and when necessary reducing their effects in favour of improving the city's microclimate for both users and energy expenditure. This aggregation of factors can be better evaluated through simulation tools, such as Outdoors Thermal Confort (OTC). This is one of the main questions raised during the ARCC meeting about the subjects "need to know" and "how to tackle". Today, however, alternatives exist that are either very limited or difficult to access for most practitioners. Therefore, the development of easy-to-access simulation tools that integrate the available data, which are specific to each region of the city, are fundamental for the qualification of both the design of projects and evaluation by the public sector.

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URBAN GREENING

Developing protocol on Jakarta green area target setting for urban overheating mitigation

Hanna Meiria Naomi Stepani

Abstract

Climate change contributes to heat stress in cities. Massive transitions from natural habitat to the built environment triggers urban heat island effects. In the context of urban climate adaptation, green open spaces have been recognized as a mitigation strategy. To enforce the application of green infrastructure and following the Central Government Regulation, Jakarta Government has created a target of 30%, supported by the Green Space Masterplan that indicates the development of Green Space Weighting Factor. This study aims to develop a systematic framework on target setting for the green areas of Jakarta for urban overheating mitigation through microclimate simulation (ENVI-met) on targeted local climate zone areas, with green infrastructure quantified by the newly-developed weighting factor. The results of the study show that in order to mitigate UHI and address climate change, urban design policy should not rely entirely on green infrastructure, and only a comprehensive, site-specific spatial and functional analyses can bring targeted green infrastructure that really improve thermal conditions.

1. Introduction

Climate change creates heat stress in cities. Elevated temperature and heatwave events in urban areas create a severe public health concern. As the biggest metropolitan areas in South East Asia, Jakarta, with its massive infrastructure developments and urbanization, experiences changes in the environment which threaten its resilience on climate change. The economic growth of 5.06% that is higher than 2.97% national economic growth (Bank Indonesia 2020) makes Jakarta the highest contributor of the national economy, as well as the most top accelerator in national infrastructure development. The development tendency to fulfil activity functions created a massive transition of the natural habitat to the built environment that trigged Urban Heat Island (UHI) effects.

Green Infrastructure (GI) has been proposed as one possible intervention that may help mitigate the UHI effect that creates an impact on human health and comfort. Trees and other types of vegetation can reduce surface temperatures and also tend to maintain a daytime canopy temperature close to that of the surrounding air temperature via evaporative cooling related to site-specific influences (Adams and Smith 2014).

To enforce the application of GI, the Jakarta Government created a target of 30% of the total area need to be green, following the national law and central government. Due to the necessary land capacity to accommodate urbanization and economic activity, less than ⅓ of this target has been achieved in 20 years. This shows that a legitimate number of green open space calculation should be considered for Jakarta city, compared to other cities in Indonesia. To accomplish the implementation of the target set by the national government, Jakarta developed a Green Space Masterplan that indicates the development of a GI quantification factor. This factor serves as a standard to calculate the achievement of the green area target and mainstreams green infrastructure development. In order to gain hard evidence as a rational basis for the GI target on supporting urban heat island mitigations, a protocol on how to develop a target and to evaluate whether or not the current policy on target set green area of 30% is an effective contribution to the strategy of tackling urban overheating.

2. Background

2.1. Climate Change and Urban Green Infrastructure

The UHI effect is caused by specific changes in urban environments which gave rise to a separate warming mechanism (Stone et al. 2014., WHO 2016, US EPA 2014): the loss of natural vegetation to urban construction, the introduction of non-vegetative surface materials that are more efficient at absorbing and storing thermal energy than natural land covers, high-density urban morphology that traps solar radiation, and emissions of waste heat from buildings and vehicles. UHI's elevated temperature have a significant impact on the community environment and the quality of life in multiple ways: 1) Compromised Human Health and Comfort, 2) Elevated Emissions of Air Pollutants and Greenhouse Gases, 3) Increased Energy Consumption, and 4) Impaired Water Quality (US EPA 2014).

The UHI mitigation strategies can be grouped into three major themes: 1) Increase vegetation cover, 2) Increase thermal reflectivity (albedo) of urban surfaces, particularly roofs, and 3) Manipulate urban geometry (Emmanuel 2005). Increasing the vegetation cover by urban greening efforts has been proposed as one possible intervention that may mitigate the human health consequences of these changes (Bowler 2010). Green infrastructure can reduce the impact of pollutants from the air, carbon sequestration, contribute to rainwater infiltration and flooding risk control, provide shade, cool the air through tree transpiration, and reduce energy consumption in summer and the urban island heath effect. (Basnou 2015., Markevych et al. 2017) provides a framework in which the many potential pathways link greenspace to health benefits in three domains that emphasise three general functions of greenspace: reducing harm (air pollution, heat, and noise), restoring capacities and building capacities. Trees and other vegetation can reduce surface temperatures and also tend to maintain a daytime canopy temperature close to that of the surrounding air temperature via evaporative cooling related site-specific influences (Adams and Smith 2014).

Nazarian et al. (2019) stated that thermal comfort is considered as a top priority with a direct impact on productivity and cognitive performance, well being and health of urban dwellers, and to achieve a climate-responsive urban design, comprehensive, accurate, and easily comprehensible evaluations of outdoor thermal comfort are needed. Nazarian proposed outdoor thermal comfort autonomy, metrics that quantify outdoor space performance with regards to thermal comfort and heat stress. Potchter et al. (2018) carried out several investigations of 165 human thermal indices. Based on the study, the most used indices for outdoor thermal perception studies are PET, PMV, UTCI, SET, and WGBT.

2.2. Previous Approach in Green Infrastructure Quantification

The warming climate increases temperatures in urban areas that already experience the heat island effect. A cooling strategy to reduce the impact of urban overheating will help communities to adapt to climate change impact as well as lower greenhouse gas emissions that cause climate change (US EPA 2014). Urban morphology plays a substantial role in determining microclimates. According to Wong et al. (2011) besides Green Plot Ratio (GnPR), Sky View Factor (SVF), surrounding building density, the wall surface area, pavement area, and albedo, there are three major urban elements which influence local-scale urban temperature: buildings, greenery and pavement. Wong conducted 32 case studies with different urban morphologies with varying density, height, and greenery density to see the degree of impact on altering microclimates. The highest degree of altering temperature impact (can be up to 0.9-1.2 oC) are shown to be influenced by variables such as GnPR, height and density. GnPR has the highest impact due to the shading effect of trees.

Several cities have green calculation tools as a metric on greenery value on development sites. There are different names for green infrastructure quantification tools. Most cities named it

Green Area Factor (GAF) or Green factor. The GAF is a planning instrument developed by cities to achieve an environmental agenda of human and nature reconnection, energy consumption reduction, flood control and the restoration of the full hydrological cycle, preservation and enhancement of wildlife habitats, improvement of urban aesthetics and build a new green identity in a thermally comfortable urban environment (A Vartholomaios et al. 2013). The GAF is composed of three adaptable, interconnected components: a set of ratings, a set of targets, and a final ratio determined for each parcel (Keeley 2011). GAF comparison of eight cities in this study presented in Table 1.

2.3. Local Context – Jakarta and Climate Change

The impact of urbanization in Jakarta and land development induces the changing ecosystem in the environment. According to the Jakarta Disaster Management Department, flooding is one of the significant issues with an increasing intensity. In 2007, flooding was labelled as a national disaster with the total loss of 5 trillion rupiahs. Due to Jakarta topographic position with 40% of the land's elevation under the sea level, Jakarta is also the downstream area of 16 substantial rivers (202km).

One of Jakarta's recent major issues is air pollution that bustled the media during the long dry season at the end of 2019. Landrigan et al. (2018) stated that pollution is the most significant environmental cause of diseases and premature death in the world. Diseases caused by pollution were responsible for an estimated 9 million premature deaths in 2015—16% of all deaths worldwide— three times more deaths than from AIDS, tuberculosis, and malaria combined and 15 times more than from all wars and other forms of violence. This mortality is caused by exposure to small particulate matter of 2.5 microns or less in diameter (PM2.5), which cause cardiovascular and respiratory disease, and cancers (WHO 2016). The WHO (2016) specified air quality guidelines (AQGs) with the base target level of PM2.5 for short-term (24-hour-average) of are25 µg/m3, and long-term (annual average) exposure of 10 µg/m3. Jakarta's annual average exposure of PM2.5 in 2018 is 45 µg/m that puts Jakarta as one of the highest average annual levels of PM2.5 in South East Asia. Pollution threatens health and destroys ecosystems, this linked to global climate change. (Landrigan et al. 2018). Kusuma et al. (2019), found PM2.5 pollution in DKI Jakarta was strongly influenced by humidity, NDVI, temperature and residential areas, whereas pollution, is positively correlated with residential areas and temperatures, and adversely related with NDVI and humidity.

Green infrastructures are considered to mitigate the environmental issues. Under Indonesian Law No. 26/2007, the proportion of ideal green area in big cities like Jakarta is 30% of the total city area, with 20% public green areas and 10% for the private sector. Minister of Home Affairs Regulation No. 1/2007 concerning the Arrangement of Green Open Spaces in Urban Areas classified the functions of green area as a buffer for urban conservation areas, pollution control and environmental damage, biodiversity protection, water system control, and as urban aesthetics. The aim of providing green open spaces in Jakarta is to maintain the harmony and balance of urban ecosystems, both natural and human-made environments.

Jakarta Government, in Provincial Spatial Plan 2030, further arranged the utilization of green open space to consider the distinctive character of Jakarta as delta city, Jakarta carrying capacity of natural resources, and environmental sustainability. The target number remains 30% of total Jakarta area with 20% plotted as public green space and 10% as private. Based on Ministry of Public Works Green City Roadmap 2015, the total area of Jakarta Green space recently was 9.97% out of 20%, and the total Green area that still needs to be met is 6,520 ha. One of the strategies to improve Jakarta's green open space, according to Jakarta Spatial Plan 2030, is to increase the quantity and quality of green open space distribution throughout the city's districts and to maintain the availability of green open space, one of which is the implementation of the Green Area Factor particularly for buildings and vertical greenery.

3. Method

Green infrastructure is expected to reduce the exposure to heat in urban areas. While climate change is projected to increase the frequency and intensity of extreme climate conditions, temperature is the most significant atmospheric parameter to explore the impact of urban heat islands. A combination of the new developed green space quantification factor with WUDAPT Local Climate Zone map for Jakarta has been used to simulate the occurrence of temperature reduction by applying a green elements scenario. The simulation is performed for different LCZ which correspondent with the majority of land use in the Jakarta metropolitan area. The impact of Green infrastructure implementations area is examined for two different scenarios, base case and best case. The base scenario describes the actual condition of land, while the best scenario represents a condition where a maximum of green intervention has been implemented.

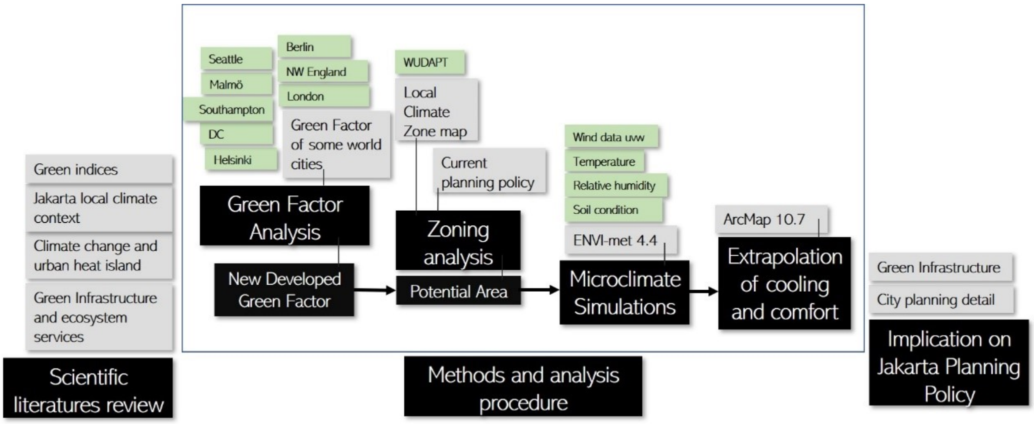


Figure 1. Methodological framework for analysis procedure (Stepani 2020)

4. Results

4.1. Development of New Green Space Weighting Factor

Fifteen general categories were selected to structure the unify value of each landscape element with the consideration of equivalent elements calculation applied in every city. To reach an equal interval of indices, the apportion scale was set to 0 - 1, this applied to Helsinki's indices that originally accounted for 0-3.5 and the consideration on Malmö's original indices, that is rated from 0-20. The 15 elements with the average measurement of the equal elements factor were categorized and apportioned to accommodate as many possibilities as possible for further modelling of green infrastructure development, looking into the difficulties of possibly applying green infrastructure in the Jakarta Metropolitan area.

Table 1. Developed value for new green space weighting factor (Stepani 2020)

	Landscape Elements	Berlin	Helsinki	NW England	Malmo	Southampton	London	Seattle	DC	Developed Value for New Green Space Weighting Factor
1	**Sealed areas**, (non-permeable surfacings without plant growth, including buildings without greenroof)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
2	**Partially sealed areas** (semi permeable surfacing)	0.30	0.29	0.30	0.30	0.40		0.20	0.40	**0.31**
3	**Semi-enclosed areas** (permeable surfacing)	0.50	0.40	-	-	0.20	-	0.50	0.50	**0.42**
4	Vegetation surface not connected to surrounding soil with depth <70 cm	0.50	-	0.40	0.70	0.60	0.60	-	0.30	**0.52**
5	Vegetation surface not connected to surrounding soil with depth >70 cm	0.70	-	0.60	0.90	1.00	0.80	0.60	0.60	**0.74**
6	Vegetation surfaces connected to surrounding soil	1.00	-	1.00	1.00	-	1.00	-	-	**1.00**
7	**Lawn, grass, other groundcover** (plants less than 2 feet tall)	-	0.31			0.45	0.45	0.10	0.25	**0.31**
8	**Shrubs**	-	0.49			0.60	0.65	0.30	0.30	**0.47**
9	**Tree - small**	-	0.66		10.00			0.30	0.50	**2.86**
10	**Tree - medium**	-	0.00		15.00			0.60	0.60	**4.05**
11	**Tree - large**	-	0.80		20.00			0.90	0.70	**5.60**
12	**Large tree - preserved**	-	0.85		20.00			1.00	0.70	**5.64**
13	**Façade vegetation** (Green vertical areas on windowless external walls and walls)	0.50	0.26		0.70		0.60	0.40	0.80	**0.54**
14	**Roof greening**	0.70	0.47		0.60	0.65	0.60	0.60	0.70	**0.62**
15	**Rainwater infiltration and stormwater features**	0.20	0.47		0.20		0.20	0.20	0.20	**0.25**
16	**Bonuses Elements**	No	Yes	No	No	No	No	Yes	Yes	**No**

Table 1 describes that the main weighting factors are mostly defined by cities' preferences. The highlight shows average of the elements. Some cities have several classes for particular landscape elements that are considered as one value for this development purpose. No bonus elements are considered based on major cities' preferences on bonuses application. There are two major factors that differentiate the calculation:

- connection to surrounding soil as the highest value without counting in the factor of vegetation, and the depth of soil structure rather than the vegetation factor
- Inclusive calculation of tree existence and other vegetation covers on top of the soil structure

Berlin and NW England are within the first category, followed by Southampton and London with the inclusion of ground cover vegetation such as grass and shrubs in their calculation. Helsinki, Seattle, DC and Malmö add the value of ground cover, shrubs, and trees in the calculation. Considering the objectives of each city and the similarity of values, the average number of 8 cities' green factors are taken as a model base weighting factor for this study that will be applied in the representative sampling area for further microclimate simulation.

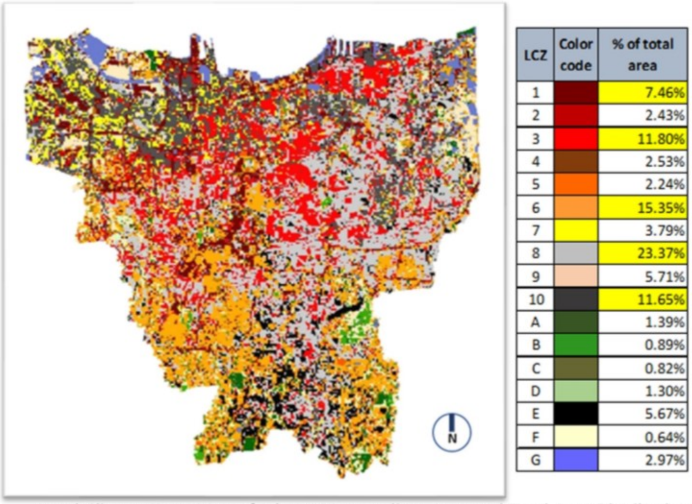
4.2. Zoning Analysis

The Jakarta Local Climate Zone map was developed following the World Urban Database and Access Portal Tools (WUDAPT) protocols on 17 LCZ class using 145 samplings of training areas distributed in the whole Jakarta metropolitan area.

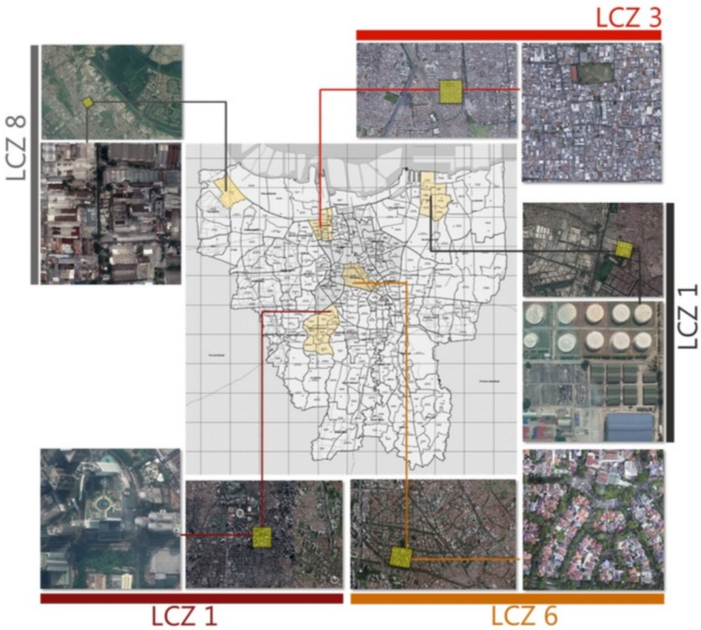
Following the result map and area calculation of WUDAPT LCZ analysis of Jakarta, five LCZ classes representing the majority area of Jakarta that cover almost 70% of the majority climatic area of Jakarta were selected. There are four basic approaches currently being adopted in selecting the representative sample of model areas based on their LCZ classification:

- An area of 400 meters X 400 meters, for ENVI-met simulation optimization
- The sampling located in the same class of LCZ
- Considering development plan, urban design guidelines, conservation area, and some conflict occurs in the area due to the land use and land cover planning. Another consideration to select the areas are ownership, demography context and other supporting regulations
- The possibility of green infrastructure application

Five locations are chosen to be representative of LCZ sampling to perform microclimate simulations. These locations are presented in Figure 2 and Table 2 to Table 6.



Local Climate Zone Map of Jakarta Metropolitan Area and Total Area Distribution



Representative sampling area

Figure 2. Jakarta Local Climate Zone and Representative Sampling Area (Stepani 2020)

Table 2. LCZ 8, Prepedan Industrial Area (Stepani 2020)

Location	**Tegal Alur sub district, Kalideres, West of Jakarta**
Sub district Area	4.97 km^2 (16.44% of total district area) based on Governor Decree of DKI Jakarta Number 171 in 2007.
Population	101.137; Population density: 20.36 people/km^2 (BPS, 2019)
Area highlight	taken as an example of the expansion of industrial zone to tenement housing to support industry workers. The growth of residential areas then also followed by the newly grow home-industry, which made this area considered unorganized and some zoning problem according to Jakarta Territorial Regulation on City Planning Detail
General Build Form	The build form of this area consist of 1-2 stories tall industrial building which extend outward and not upward, variant construction materials, few trees, mostly paved or hard-packed. Moderate cooling demand and moderate traffic flow.

Table 3. LCZ 6, Menteng Residential Area (Stepani 2020)

Location	Menteng District, Centre of Jakarta
Sub district Area	2.44 km² (37.37% of total district area) based on Governor Decree of DKI Jakarta Number 171 in 2007.
Population	29,347; Population density: 12.03 people/km² (BPS, 2019)
Area highlight	Based on Jakarta Territorial Regulation No. 9 of 1999 about Restoration of the environment and cultural heritage buildings in Jakarta Province, this area is considered as one out of three Conservation Areas in Jakarta (Governor Decree of DKI Jakarta Number D.IV6098/d/33/I975).
General Build Form	Residential area. Constructed of 1-2 stories tall detached residential building, variant construction materials, dense trees and abundant plant cover, low space cooling demand, low traffic flow.

Table 4. LCZ 3, Kalianyar Residential Area (Stepani 2020)

Location	Tambora District, West of Jakarta
Sub district Area	0.32 km² (5.9% of total district area)
Population	29.728 people/km²; Population density 92.9 people/km² (BPS, 2019)
Area highlight	Its densely populated area makes this subdistrict one of the most populated subdistricts in South East Asia.
General Build Form	Residential area. Attached or closely spaced 2-3 storey tall residential buildings, narrow streets, heavy construction material, mostly paved or hard-packed which occupy more than 70% building surface factor and less than 30% pervious surface fraction, few trees, moderate cooling demand, and moderate traffic flow

Table 5. LCZ 10, Pertamina Depot Plumpang (Stepani 2020)

Location	Rawabadak Selatan Sub District, Koja District, North of Jakarta
Sub district Area	1.0162 km² (7.70% of total district area)
Population	49.817; population density of 49.022 people/km² (BPS, 2019).
Area highlight	part of state-owned oil and natural gas mining company based in Jakarta
General Build Form	construct of mid-rise industrial structure, openly spaced on hard-packed surface, with construction material dominated by steel, concrete and metal, few trees and low traffic flow

Table 6. LCZ 1, Sudirman Central Business District (Stepani 2020)

Location	Senayan Sub District, Kebayoran Baru District, South of Jakarta
Sub district Area	1.53 km² (11.84% of total district area)
Population	5969; population density: 12.03 people/km² (BPS, 2019).
Area highlight	One of the major Central Business Districts in Jakarta
General Build Form	Dense mix of tall buildings with more than ten storeys. Building free-standing, closely spaced. Significantly reduced sky view from street level. Material of the building is dominated by steel, concrete and glass surface construction. Mostly paved, few trees, high cooling demand and heavy traffic flow.

4.3. ENVI-met Simulations

The ENVI-met simulation will be performed in five representative area by comparing two scenarios, the base case scenario and the best greening scenario. The base scenario simulation will be performed in the existing condition of the site, while the best scenario intends to put a maximum greenery on top of the base case scenario, without paying attention on practicality of the landscape elements' implementations. Table 7 indicates the ENVI-met simulation parameter input for all models in both scenarios. Both scenarios will be quantified using the new developed green space weighting factor (Table 1). Table 8 shows the comparison of green infrastructure score of both scenarios, with the base case as the existing condition of green space, and the best case as the additional green that was added to the base case layer. The models are developed using ENVI-met 'Space' using the default material and modified in AutoCAD for graphic enhancement and area calculation. The result of the simulation will be classified in MRT, PMV and PPD to see the variable distribution of cooling and comfort in the model area (Figure 3).

Table 7. ENVI-met simulation input parameters (Stepani 2020)

	Domain size	400m x 400m
Main parameter	Grid size	dx = 5; dy= 5; dz=3; (for LCZ 1, dx=5; dy=5; dz=15)
	Start date	15/06/2020
	Start time	18:00
	Total simulation time	30 hours
	simple/full forcing	simple forcing
	Nesting grid	no nesting grid for LCZ 8, LCZ 6 and LCZ 3; (8 for LCZ 10 and 1)
Wind uvw	Wind speed measured in 10 m height (m/s)	6
	Wind direction (degree)	230
	Roughness length at measurement site	0.01
Temperature T (ºC) and humidity q (%)	T min	26
	T max	32
	q min	71
	q max	93
Soil data	Initial Temperature upper layer (0-20 cm) (oC)	29
	Initial Temperature middle layer (20-50 cm) (oC)	28
	Initial Temperature deep layer (50-200 cm) (oC)	27
	Initial Temperature bedrock layer (below 200 cm) (oC)	26
	Soil humidity upper layer (0-20 cm) (%)	86
	Soil humidity middle layer (20-50 cm) (%)	78
	Soil humidity deep layer (50-200 cm) (%)	70
	Soil humidity bedrock layer (below 200 cm) (%)	65

Table 8. Comparison of green infrastructure score (baseline and additional) best scenario (Stepani 2020)

Landscape Elements	Factor	LCZ 8				LCZ 6				LCZ 3				LCZ 10				LCZ 1			
		Base case		Best Scenario		Base Case		Best Scenario		Base Case		Best Scenario		Base Case		Best Scenario		Base Case		Best Scenario	
Sealed areas, (non-permeable surfacings without plant growth, including buildings without greenroof)	**0.00**		0.00				0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
Road	**0.00**	7362.30	0.00	7362.30	0.00	22367.83	0.00	22367.83	0.00	8348.10	0.00	8348.10	0.00	55458.08	0.00	55458.08	0.00	68693.72	0.00	68693.72	0.00
Buildings	**0.00**	105876.57	0.00	105876.57	0.00	103146.16	0.00	103146.16	0.00	145852.07	0.00	145852.07	0.00	44077.61	0.00	44077.61	0.00	52175.02	0.00	52175.02	0.00
Partially sealed areas (semi permeable surfacing)	**0.31**	23380.56	7300.46	23380.56	7300.46		0.00		0.00		0.00	8348.10	2606.65	60464.31	18879.67	60464.31	18879.67		0.00		0.00
Semi-enclosed areas (permeable surfacing)	**0.42**	23380.56	9819.84	23380.56	9819.84	0.00	0.00		0.00		0.00		0.00		0.00	29356.60	12329.77		0.00		0.00
Vegetation surface not connected to surrounding soil with depth <70 cm	**0.52**		0.00				0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
Vegetation surface not connected to surrounding soil with depth >70 cm	**0.74**		0.00				0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
Vegetation surfaces connected to surrounding soil	**1.00**		0.00			34486.01	34486.01	34486.01	34486.01	5799.83	5799.83	5799.83	5799.83		0.00		0.00	39131.26	39131.26	39131.26	39131.26
Lawn, grass, other groundcover (plants less than 2 feet tall)	**0.31**		0.00				0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
Shrubs	**0.47**		0.00				0.00	4757.61	2222.48	740.00	345.69	740.00	345.69	984.70	459.99	984.70	459.99		0.00		0.00
Tree - small	**2.86**	16.00	45.83	116.00	332.26	123.00	352.31	123.00	352.31	31.00	88.79	31.00	88.79	18.00	51.56	81.00	232.01	34.00	97.39	77.00	220.55
Tree - medium	**4.05**	9.00	36.45	29.00	117.45	92.00	372.60	107.00	433.35		0.00	83.00	336.15	4.00	16.20	58.00	234.90	13.00	52.65	62.00	251.10
Tree - large	**5.60**		0.00	3.00	16.80		0.00		0.00		0.00	13.00	72.80		0.00	23.00	128.80		0.00	24.00	134.40
Large tree - preserved	**5.64**		0.00			10.00	56.37	10.00	56.37		0.00		0.00		0.00		0.00				0.00
Façade vegetation (Green vertical areas on windowless external walls and walls)	**0.54**		0.00			0.00	0.00	8276.45	4492.93		0.00		0.00		0.00		0.00			280227.49	152123.49
Roof greening	**0.62**		0.00	105876.57	65276.15	0.00	0.00	9678.73	5967.23		0.00	116681.65	71937.81		0.00	25388.28	15652.65			56366.00	34751.36
Rainwater infiltration and stormwater features	**0.25**		0.00				0.00		0.00		0.00		0.00		0.00		0.00				0.00
TOTAL AREA 160000			**17202.58 10.75%**		**82862.95 51.79%**		**35267.29 22.04%**		**48010.69 30.01%**		**6234.31 3.90%**		**81187.72 50.74%**		**19407.42 12.13%**		**47917.80 29.95%**		**39281.30 24.55%**		**226612.17 141.63%**

Table 9 shows the summary of best scenario application. And Figure 4 shows the 24-hour plot of MRT difference in every LCZ and PPD plot of all LCZ base case and best greening scenario. The values are obtained by calculating the MRT on best scenario minus MRT of the base case. Negative means decreased value on MRT/PMV, and positive value means the increase MRT.

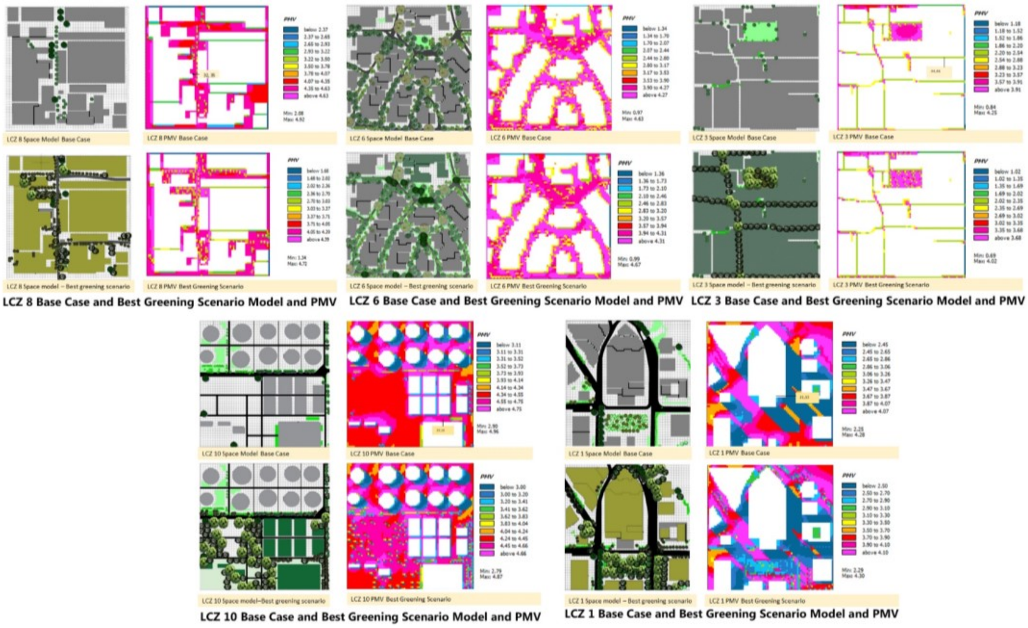


Figure 3. ENVI-met Simulation model and PMV for Baseline and Best Greening Scenario (Stepani 2020)

Table 9. Summary of best greening scenario impact on MRT and PMV (Stepani 2020)

LCZ8					
Parameter		**Base case**	**Best scenario**	**Change**	**Average**
Green Space Ratio		10.75%	51.84%	41.09%	
MRT	min	43.95	41.1	-2.85	
	max	71.5	68.8	-2.7	-2.775
PMV	min	2.08	1.34	-0.74	
	max	4.92	4.72	-0.2	-0.47
LCZ 6					
Parameter		**Base case**	**Best scenario**	**Change**	**Average**
Green Space Ratio		22.04%	30.00%	7.96%	
MRT	min	40.32	40.75	0.43	
	max	68.7	69.1	0.4	0.415
PMV	min	0.97	0.99	0.02	
	max	4.63	4.67	0.04	0.03
LCZ 3					
Parameter		**Base case**	**Best scenario**	**Change**	**Average**
Green Space Ratio		3.90%	49.12%	45.22%	
MRT	min	35.72	32.86	-2.86	
	max	64.19	61.86	-2.33	-2.595
PMV	min	0.84	1.34	0.5	
	max	4.25	4.72	0.47	0.485
LCZ 10					
Parameter		**Base case**	**Best scenario**	**Change**	**Average**
Green Space Ratio		12.13%	31.12%	18.99%	
MRT	min	46.87	45.18	-1.69	
	max	75.16	73.86	-1.3	-1.495
PMV	min	2.9	2.79	-0.11	
	max	4.96	4.87	-0.09	-0.1
LCZ 1					
Parameter		**Base case**	**Best scenario**	**Change**	**Average**
Green Space Ratio		24.55%	141.63%	117.08%	
MRT	min	36.81	36.65	-0.16	
	max	65.35	66.64	1.29	0.565
PMV	min	2.25	2.29	0.04	
	max	4.28	4.3	0.02	0.03

Table 9 also shows that in LCZ 8 and LCZ 3, the additional >40% green cause a reduction of >2.5ºC MRT. In LCZ 10, the additional 19.99% green lowers MRT up to 1.5ºC. However, in LCZ 6, which only has less than 8% of green, MRT level is increased, also for LCZ 1 by an additional a very high greenery factor by (117%) MRT is increased. The PMV level increases or increases on PMV in conjunction with MRT level in all models. There is positive effects on green infrastructure in LCZ 8, LCZ 3, and LCZ 10. Based on these three models, the higher index of green infrastructure shows a higher reduction of MRT. This finding supports the previous study on reducing temperature by an increase of green percentage that has been discussed earlier. On contrary, LCZ 1, the heavily built up area, shows an increase of temperature even with extreme greening percentage. Shadows from high rise building also create wide cooling pockets, however the impact of heavily built area in outdoor thermal comfort can be seen in the simulation result. The contrast also shown in LCZ 6, that the low implementation of greenery index also shows increased on MRT.

Figure 3 indicates the correlation of the greening impact in every LCZ. It shows that the highest decrease of MRT in most LCZ happened at 16:00, with LCZ 8 have the highest value (over 10 °C).

The ENVI-met simulations shows the uneven distribution of minimum and interval MRT in different local climate zone area. The percentage of additional greenery also depends on the availability of the area. The absolute maximum green scenario effect at 2.00 PM in each location is shown in Table 10. The extrapolation of the result in entire area of Jakarta is shown in Figure 5.

Table 10. MRT range on simulation models base and best case (Stepani 2020)

	LCZ 8		LCZ 6		LCZ 3		LCZ 10		LCZ 1	
	BASE	BEST	BASE	BEST	BASE	BEST	BASE	BEST	BASE	BEST
MRT min	43.95	41.1	40.32	40.75	35.72	32.86	46.87	45.18	36.81	36.65
MRT max	71.5	68.8	68.7	69.1	64.19	61.86	75.16	73.86	65.35	66.64

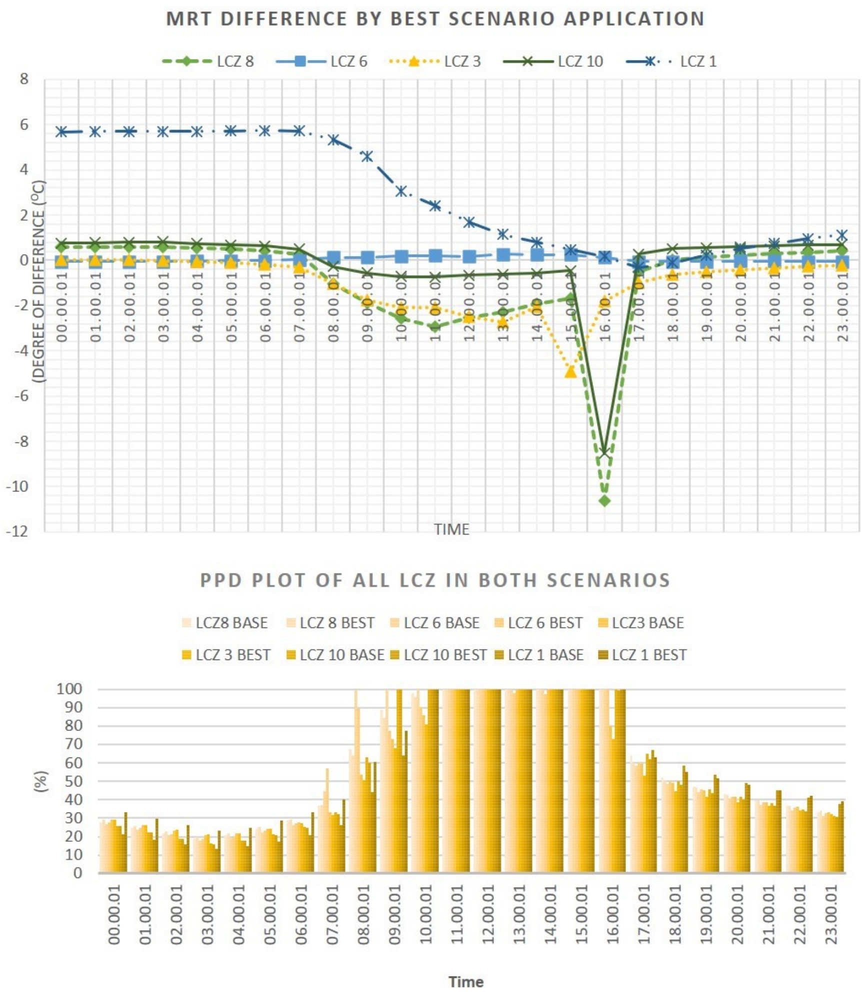


Figure 4. 24 hours plot of MRT difference by best scenario application and PPD plot of all LCZ base case and best greening scenario (Stepani 2020)

5. Implications and conclusions

Jakarta has reached a certain point of land cover change and development trigged by increased population that need an immediate mitigation strategy of UHI. The green area target set is one of the methods. This study found that for the development of the Jakarta metropolitan area, three points should be considered regarding target setting of Green Area in the whole region of Jakarta:

- Targets should be relevant to the local and existing conditions of the city. The implementation of the general target set will not bring the same climatic value in different zoning. There is no such a uniform way on target set that will increase the comfort. Green infrastructure makes difference in different areas. In some areas, greening for cooling doesn't work, or even could worsen the thermal sensation. However, even in the area where greenery increase the MRT, there are pocket areas that could benefit people by cooling. Some other areas show that building alone can create the decrease the temperature.
- The whole area of Jakarta needs diverse cooling strategies to reach a lower percentage of discomfort during the day that cannot entirely be created by green infrastructure alone. In order to achieve a substantial cooling effect by green infrastructure, a different development model should be considered. The greening approach should focus on areas with high impact in UHI mitigation function, and area that still have a significant greening potential in the areas with less significant effects of greenery, a different mitigation approach can be considered.
- Current urban development will need urgent climate-sensitive urban planning to mitigate overheating that is already happening in the entire area of Jakarta. Related to green area target, the urban planning consideration can set target in the area with high possibility of temperature and comfort improvement by green infrastructure. Another way of planning consideration is the changing of land use, to have a better chance in green infrastructure improvement.

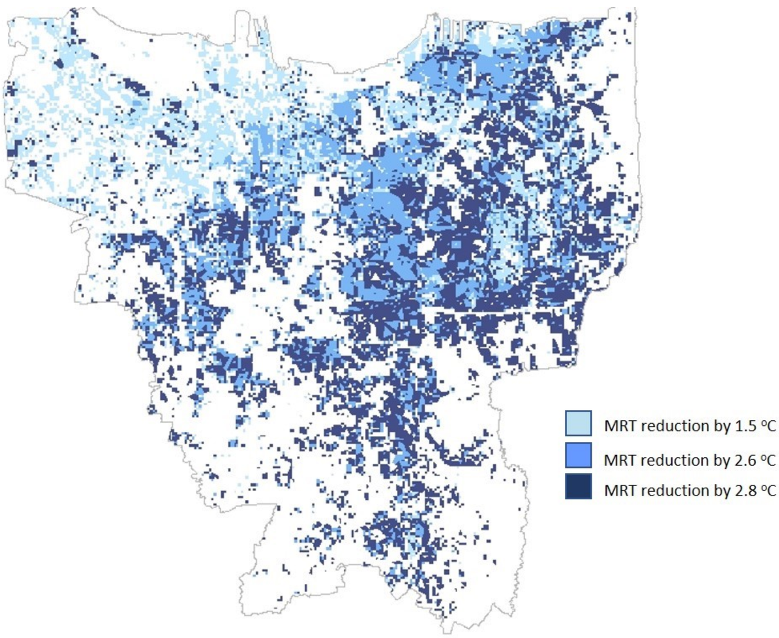


Figure 5. Extrapolation of Cooling and Comfort in Jakarta Metropolitan Area (Stepani 2020)

One of the more significant findings to emerge from this study is that maximum green intervention approach could reach the green area target with optimum MRT reduction. However, this approach might not be practical in certain areas. And by reaching the maximum target, the maximum MRT reduction that can be obtained is below 3 degrees.

The following conclusions can be drawn from the present study:

- Only comprehensive, site-specific spatial and functional analyses can bring targeted green infrastructure index solutions with optimal shape, structure, and distribution that improve thermal conditions. This effect could contribute to other urban green infrastructure benefits, such as urban aesthetics, flooding and pollution control or air purification, enhancing biodiversity, etc. in urban areas.
- Although there is just slight difference in temperature reduction, there are some areas that is comfortable due to the adding of trees. For a climate sensitive planning, there is a need to consider a landscape design that is located where people are doing the activities. This effort is to enhance quality of pocket area that contributes to cooling and benefits for the people.
- Jakarta is located in a tropical climate where diurnal cooling is necessary to reduce the level of discomfort in the outdoor environment. The study shows that in terms of PPD, maximum greening does not support an increase of the thermal comfort level.
- Other cooling options should be taken into account to reduce temperature and improve thermal comfort. In order to mitigate UHI and address climate change, we cannot rely entirely on greenery. Green infrastructure has many values that support the environment, biodiversity, aesthetic, psychology, health and many other aspects, but for climate control, the role of urban planning in a climate-sensitive design should be considered.

The purpose of this study is to demonstrate on how to build the protocol on green infrastructure target setting and how it works. There are some limitations on the process. The stages developed in this study are a concept to build a way of greening target calculation in a simplified model, not by the real existing urban and architectural condition. To overcome these limitations, some stages have been done. The limitation on the process and following steps needs to be done before this study could be used as a new index and quantification of the effects on greenery in Jakarta.

There is a need to develop a further study of Climate-sensitive urban design with climatic simulation in Jakarta, especially the major land use such as low residential and industrial areas, where urban elements and buildings geometry play an important role along with green infrastructure. This study shows some areas where building and tree interaction contributes benefit in reducing temperature. A further study on this will develop the design possibility on enhancing thermal comfort in built up urban area.

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The Green Area Ratio as a planning tool for sustainable green infrastructure in densely built arid environments

A case study of Lima, Peru

Carol Torres Limache

Abstract

Green infrastructure (GI) can be multifunctional as it delivers a range of ecosystem services (ESs) that are highly beneficial for cities. However, in densely built arid environments, implementing GI can worsen water scarcity, limiting its use and effectiveness as a climate change mitigation measure against urban heat islands (UHIs). The Green Area Ratio (GAR) could therefore be helpful to calculate the quantity of functional GI, useful and sensitive to these concerns. However, it has been not fully explored in arid contexts. Therefore, this thesis establishes a GAR suitable for such environments, using Lima, Peru as a study case. It analyses the suitability of greenery and high-albedo practices as UHIs mitigation measures with ENVI-met, under the lens of local water-sensitive approaches. The results show existing GARs can be helpful in their original contexts if their limitations are acknowledged but may not be fully suitable for an arid context. Therefore, a tailored GAR-model is necessary. Although its creation may demand thorough testing to warrant a balance between water conservation and thermal regulation, it represents a preliminary framework for better understanding of how to maximise the benefits provided by GI in densely built urban areas and is basis for potential implementation in arid environments.

1. Introduction

GI can be considered 'ecologically functional'. It delivers a wide range of ESs such as thermal regulation and water conservation which benefit habitats, life quality and resilience (Pauleit et al. 2017). Its implementation within the built environment has become a key principle of sustainable urban development (MVCS 2017).

However, within densely built arid environments, GI's implementation is challenging. Dense configurations lead to areas with few vegetated surfaces that can barely counteract the threat of increasing hard surfaces that lead to UHIs. While increasing GI is widely suggested, its widespread use in arid environments can exacerbate water stress, paradoxically increasing vulnerability to droughts (Doherty 2017). High irrigation costs may encourage its overprotection, thereby restricting its accessibility and subsequent delivery of ESs. Therefore, a functional, water-sensitive and climate-responsive approach towards implementation of GI is key within these environments (Eisenberg et al. 2014; Erell et al. 2011). However, there is still little guidance in this regard (Ivanir et al. 2015).

The GAR could be a helpful tool to guide the implementation of ecologically functional GI, sensitive to water saving and thermal regulation, within highly densified, arid, urban developments. It is an internationally recognised planning tool that has helped cities implement GI with high awareness about its benefits. The tool calculates the ratio of areas that are ecologically functional and deliver key ESs within open spaces of private developments. Thus, it measures the contribution of different infrastructure types (from green to grey infrastructure) towards the mitigation of a city's environmental challenges. However, it has not been fully explored in arid environments.

Hence, this thesis proposes the establishment of a GAR model for densely built arid urban environments, that guides the implementation of GI that is highly sensitive to water saving and thermal regulation, using the city of Lima, Peru, as study case. Lima is the capital of the world's third most vulnerable country to climate change (MINAM 2020), facing severe water stress and temperature rise, where mitigation measures are mainly based in greywater treatment and increasing vegetation.

2. Background

Lima has extremely low average rainfall (Figure 1). This is expected to decline further due to climate change (SENAMHI 2009). Despite being in the tropics, Lima has mild temperatures with cloudy days and high relative humidity. However, it experiences extreme dangerous ultraviolet radiation values (up to 13) (Ccora 2015) and UHIs due to the high quantity of asphalt surfaces and scarce vegetation (Teruya Revilla 2016). These conditions make Lima highly vulnerable to droughts and heat waves, which are major concerns in most districts of Lima (PROACC 2018).

About 10 million inhabitants (3,329 inhabitants/km2 (LCV 2015) live in scarcely vegetated areas distributed unevenly across the city. Affluent districts have approximately 40 times more green area per person compared to others (MINAGRI and ANA 2018). The high costs of irrigation based on potable water lead many neighbourhoods to fence GI, limiting its access and depriving others from ESs, such as shade and outdoor leisure.

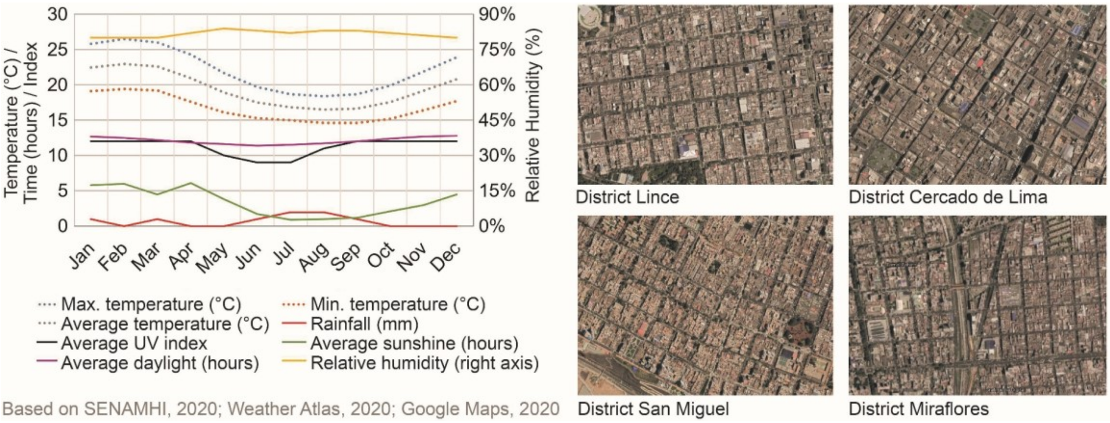


Figure 1: Climatic profile and urban fabric of Lima (Torres Limache 2020)

Despite these challenges, local guidelines (Table 1) allow additional density in return for the implementation of 'sustainable measures' that support increasing GI. These include high-albedo roofs, xeriscaped green roofs (extensive and intensive) and green walls, donation of private area to public space, irrigation using privately treated domestic greywater, and achievement of sustainable building certifications. While globally such practices represent potential solutions (Speak et al. 2013; Chow and Brazel 2012; Pradhan et al. 2019) some limitations exist. Xeriscaping, for instance, can come at the expense of an increase of temperature (Chow and Brazel 2012). The widespread use of white coatings and high-albedo roofs can result in glare (Akbari et al. 2012). Optimal performance of green roofs is dependent on a range of parameters, including local climate and irrigation (Van der Meulen 2019). However, irrigation is morally questionable for some authors (Doherty 2017), even if the water used is recycled (Shaka 2015), while for others if it supports vegetation´s cooling effect (evapotranspiration) is then desirable, provided that it does not compete with other essential demands (Werthmann 2008).

Table 1: Examples of local guidelines (Torres Limache 2020)

Document Name	***Origin***	***Source***
Ordinance N° 510-MM-2020. Ordinance amending Ordinance No. 510 / MM, that establishes, regulates and promotes conditions for sustainable buildings in the Miraflores district	Peru (Miraflores)	N° 539/MM
Ordinance N° 474-MSI-2019. Integrated Regulations and Norms for the district of San Isidro	Peru (San Isidro)	N° 474/MSI

Note: The full list of local guidelines revised can be found in the original document of this thesis

Many cities have used GAR tools to efficiently implement such systems within built environments. Nine well documented cases were identified (Table 2). In addition to advantages such as its flexibility and practicality (Keeley 2011), limitations have been indicated, including the lack of transparency on how practice weightings are established, how they contribute to benefitting from ESs (Barton 2016; Keeley 2011) and the limited accounting of certain positive GI attributes found in the original model (Biotope Area Factor – BAF). However, the literature notes that some cities have been overcome some of these, for instance by introducing the 'layering' system (Kruuse 2011).

Table 2: Cities with GAR tools and density statistics (Torres Limache 2020)

Name	***Origin***	***Density (*) (people/km2)***	***GAR information source***
Biotope Area Factor	Berlin, Germany	4,114	Landschaft Planen und Bauen and Becker Gieseke Mohren Richard, 1990
Green Space Factor	Malmö, Sweden	2,198	Malmö stad, 2020
Green Space Factor	Stockholm, Sweden	3,749	Stockholms stad, 2015
Green Space Factor	Southampton, UK	5,067	Southampton City Council, 2015
Urban Greening Factor	London, UK	6,945	Greater London Authority, 2017
Green Factor Tool	Helsinki, Finland	1,883	City of Helsinki Environment Centre, 2016
Green Infrastructure Score	North West England, United Kingdom	5,661(**)	Community Forest Northwest, 2010
Green Area Ratio	Washington DC, USA	4,457	Department of Energy and Environment, 2017
Seattle Green Factor	Seattle, USA	1,169	City of Seattle, 2020

(*) City Population, 2020 | (**) Based on information provided for Manchester, UK

Vartholomaios et al. (2013) and Miranda et al., (2015) indicated if the GAR is applied outside its original context, the tool should be adapted. Vartholomaios et al. (2013) indicated priorities differed among cities, hence, they compared the GARs of 6 cities to create and apply a GAR in Greece. However, the authors do not provide details about how these practices contributed to the achievement of local necessary ESs, nor how their weightings are established. Miranda et al. (2015), on the other hand, highlighted the benefits of the BAF to increasing GI in Peru. While they suggested its adaptation to suit the Lima context, they did not indicate how, and nevertheless applied it to a local project ('Palas' - Figure 2).

3. Method

3.1 Suitability of previous models in Lima

Lima´s climate statistics and guidelines (building regulations and sustainable incentive mechanisms), as well as documentation related to the identified nine GARs (calculators, handbooks, reference documents, scientific publications, city statistics) were revised to establish similarities in the level of aridity, achievement of ESs (objectives) and mitigation practices. Information included in the practices part of the calculators and Lima´s local guidelines were classified based on types of practices, relevance (weightings) and other attributes. The decision on whether to adopt an existing model or create a new model for Lima was taken based on similarities in these aspects.

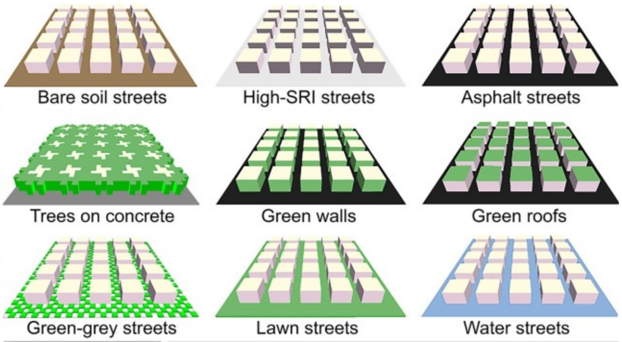
3.2 Construction of a GAR-Lima

The ESs and the practices (to achieve them) to be included in the new GAR were extracted principally from local guidelines. However, the ESs and practices included in previous GARs were also used to enrich the scope of the new model. In all cases, each was included based on local priorities. These ESs and practices were taken to an environmental performance assessment (EPA) matrix, developed by Keeley (2011), to establish their weightings. The EPA scored each practice based on its contribution to achieve each ES on a scale of 0 (no contribution) to 3 (high contribution). Each ES was assigned a prioritisation factor (1 if less relevant or 3 relevant for Lima) to ensure practices mitigating key environmental challenges achieved higher weightings. The scores were multiplied by the prioritisation factors, then summed to give each practice a final weighting, then adjusted to fit within a '0.00 to 1.00' weighting scale. Given the scope of this study, scoring for each ES was based on scientific literature collected from scientific platforms, with special consideration to local studies or with similar concerns, and complemented by a microclimate analysis with ENVI-met 4.4.5 due to the relevance of UHI.

3.3 Microclimate analysis

A uniform urban fabric was the base to simulate different scenarios under consistent local climatic conditions (Table 3). Scenarios were run for each practice applied as street surfaces. The effects of including green walls, trees and shrubs, changing soil depth, increasing surface reflectivity and applying practices to roofs (e.g. green roofs) were also simulated. Material attributes (including thermal properties, albedo) were maintained as suggested by the software database in all cases, except where required they were customized and complemented standard ones.

Table 3: Input parameters and urban fabric with example scenarios for ENVI-met (Torres Limache 2020)

Model location	Campo de Marte, Jesús María, Lima Lat -12.07° Long -77.04°		
Model time	Total run time: 30h Start 18:00 22/12/2019		
Simulation settings	Simple forcing; advanced simulation		
Wind at 10m	5m/s, 225° from north		
Atmosphere temperature	Min.17°C Max. 24°C (Eisenberg et al., 2014)		
Relative humidity 2m	Min. 79% Max. 88% (Eisenberg et al., 2014)	**Model Arrangement**	Blocks 20m x 20m, H=15m; street W=10m
Measurement location	Coordinate: 14,14	**Model Size**	170m x 170m x 40m

The average impact in air temperature (AT) across 24 hours at pedestrian level produced by the implementation of practices (as surfaces, e.g. vegetated covers or concrete pavers) was used as an indicator to determine their level of impact. Additionally, the impact of roofs surface was measured above roofs and pedestrian level. To score practices, the surfaces' impacts were ranked from lowest to highest and then grouped in four groups according to the proximity of their values.

3.4 Sensitivity of the GAR-Lima

A GAR-Score was calculated for three typical local projects (Figure 2) in highly dense urban districts. Additionally, hypothetical 'retrofitting' scenarios (e.g. addition of water-sensitive practices, xeriscape, neglected gardens and alternative surfaces such as high-albedo surfaces) were tested in 'Olavide' to observe their impact on the GAR-Score. While the number of projects was limited, and no GAR-Target was proposed, this was sufficient to observe the level of 'sensitivity' to Lima's concerns, achieved by traditional and 'sustainable measures'.

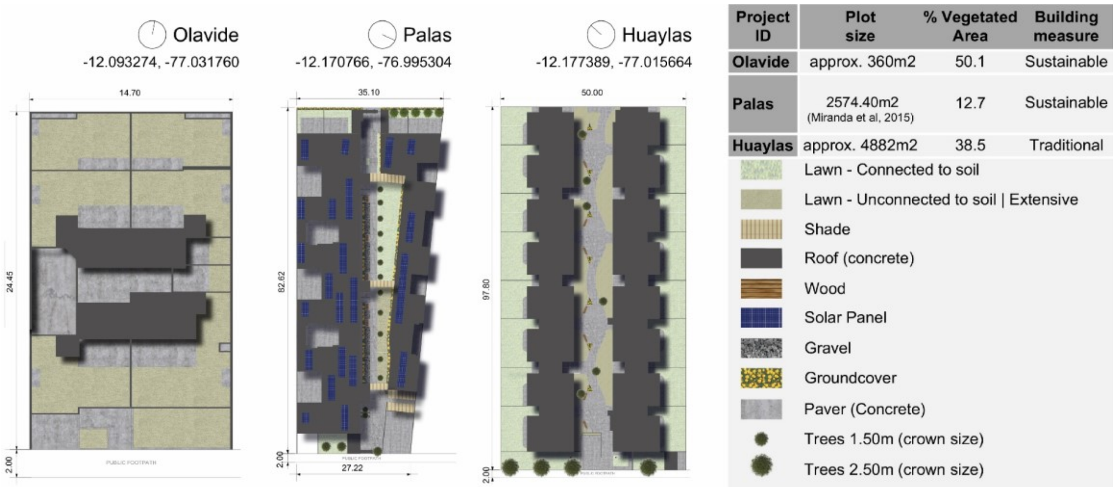


Figure 2: Case study projects (Torres Limache 2020)

4. Results

4.1 The GAR in arid cities

Lima is considerably drier than the cities examined where GARs have been applied and is the only city categorised as arid (Figure 3). The ESs indicated as objectives by each city differed across their documentation and information about how the practices contribute to their achievement was limited. However, 12 different ESs were identified, including 'Water saving' (WS) in irrigation and 'Thermal regulation' (TR).

Notwithstanding, not all these ESs were pursued by each city. Only 3 included practices specifically targeted to shading and cooling, being the latter based on stormwater. WS was linked to using stormwater. Therefore, it was concluded that none of the nine GARs would adequately address the ESs of most importance (WS and TR) for Lima. Therefore, the development of new GAR-model was proposed.

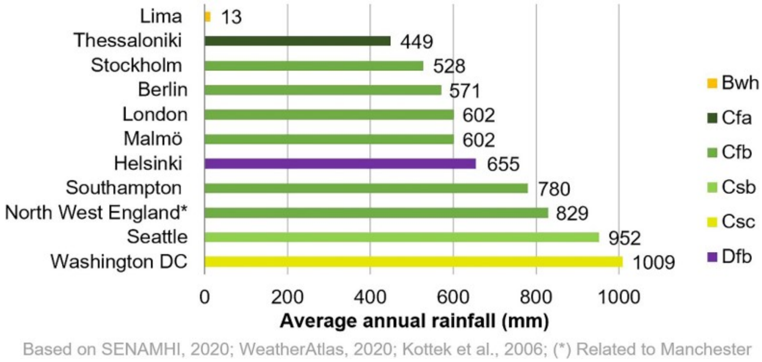


Figure 3: Cities' Köppen-Geiger climate classification and rainfall levels (Torres Limache 2020)

4.2. Environmental Performance Assessment

The practices (Table 5) encompassed systems with diverse attributes and considerations. For instance, some were simple trees and others vegetated structures (e.g. green roofs and vegetated pergolas) with different composition (extensive or intensive) and spatial and functional conditions (at balcony, at roofs, as pavers, for agriculture, etc.). Therefore, a grouping system, generalisation (surfaces: permeable and impermeable, shading units, vegetation units, etc.) and a layering approach were adopted to simplify the EPA while retaining effectivity in the resulting GAR (e.g. scoring vegetated surfaces not only for providing shade but also food at the same time).

While local guidelines indicated Lima pursued 11 of the 12 ESs pursued by the nine GARs, all 12 were taken to the EPA. ESs related to TR and WS were assigned the high prioritisation factor (3). However, 'Social cohesion and recreation' was also highly relevant because most local guidelines demanded the 'de-privatisation' of green areas and the reduction of related social conflicts (fencing). Hence, this ES was also assigned the factor 3. However, only 9 ESs could be scored under the EPA (Table 5), regardless of their relevance: 'Reduced air pollution', 'Biodiversity' and 'Noise reduction'. This was due to limited information, lack of clarity on the definition of the goal (e.g. scale of impact, particle type, etc.) and/or potential detrimental outcomes in certain circumstances (e.g. dependent on spatial arrangement and wind direction). For practicalities, some practices were not scored against specific ESs, mainly due to the lack of direct impact - e.g. the contribution of solar PV surfaces in 'Urban agriculture/Food Reduction' or the contribution of insect/habitat shelter to 'Water saving'.

4.3 Weightings per ecosystem service

Scoring results are shown in Table 5. The full scoring criteria can be found in the original thesis document but summaries for the ESs 'Water saving' and 'Thermal regulation' are presented below.

*4.3.1 Water saving***:** Scoring was based on the capacity of a practice to minimise potable water use. Therefore, all practices, vegetated and non-vegetated, were assessed. Practices without vegetation and not requiring irrigation (e.g. asphalt) scored 3 points. 'Wetland' scored 3 points as it facilitates water storage and treatment. Fountain' scored 0 points, as did 'Lawn' since they are typically water intensive and may require replenishment due to evaporation. Other practices based on vegetation (including mixed green-grey) scored 1 point. Under 'Functional surfaces', drought tolerant vegetation practices scored 3 points, while vegetation irrigated using treated water scored either 2 points (high efficiency irrigation) or 1 point (standard irrigation). Any irrigation method using potable water scored zero points.

4.3.2 Thermal regulation:

Surface systems

Practices could be grouped into four categories (Figure 4 – Surface System scenarios) based on the average impact on AT across the day. In ENVI-met, 'Fountain' and 'Wetland' had the highest average cooling effect (3 points) at pedestrian level, followed by 'Lawn' and 'Groundcover' (2 points), then mixed 'green-grey' systems and permeable surfaces (1 point) (e.g. 'Grid-grass' and 'Sand'). The warmest effect was produced by hard surfaces (e.g. 'Concrete', 'Asphalt' and 'Red terracotta tile') and 'Green walls' (zero points).

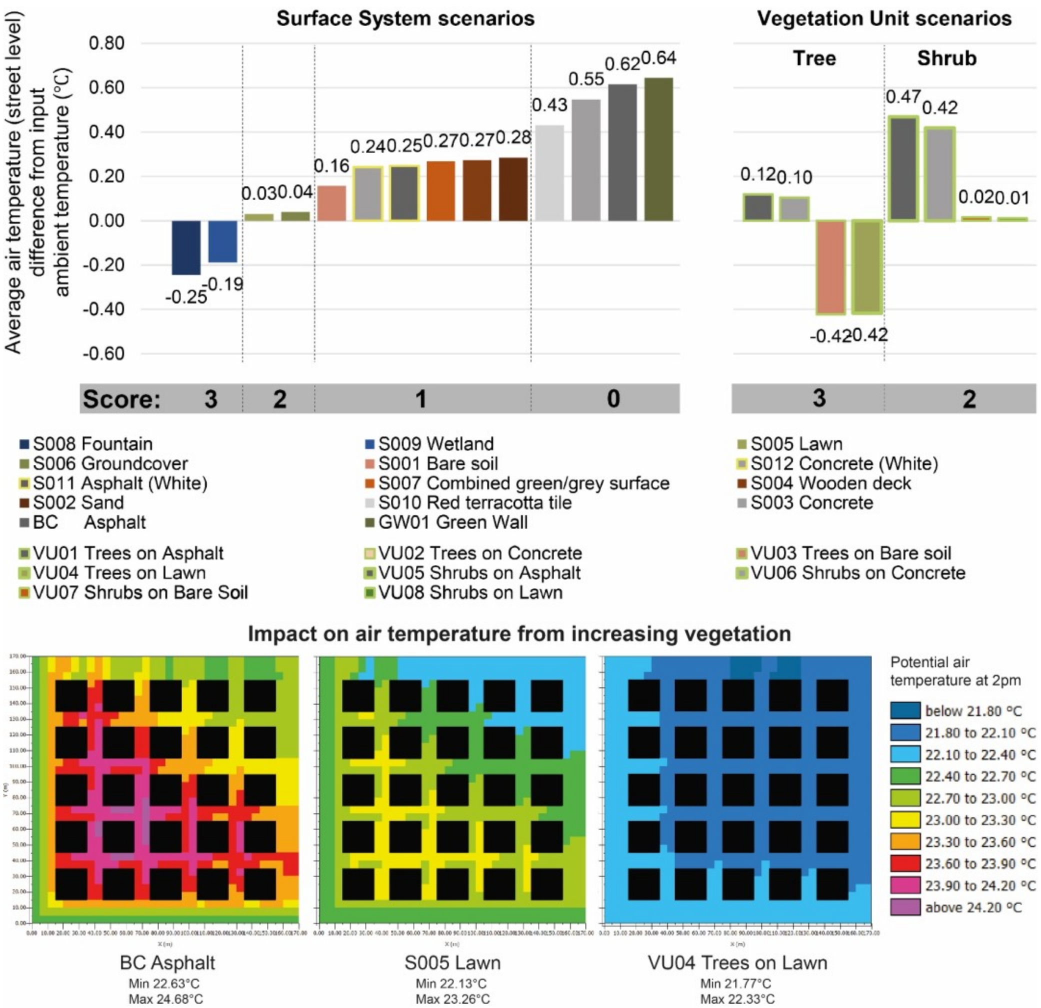


Figure 4: Microclimate analysis results for selected 'Surface system' and 'Vegetation unit' scenarios (Torres Limache 2020)

The impact on AT of ‘Artificial turf’, ‘Gravel’, ‘Mulch’ and ‘Solar PV’ in streets was established only through literature. Despite ‘Artificial turf’ having the same albedo as ‘Lawn’ it cannot produce evapotranspiration, therefore scored zero. The other three contributed similarly to mixed ‘green-grey’ and permeable surfaces so scored 1 point. The impact of changing the roof surface material had almost zero impact on AT when measured at street level. When measured above roof level (17.5m above ground), green roofs resulted in a decrease in AT, albeit small - e.g. from ‘Concrete’ roof to an extensive green roof such as ‘Lawn’ on ‘Unconnected shallow soil’ (20cm soil depth) resulted in a 0.11°C reduction, being this the highest impact.

Vegetates units

‘Trees’ and ‘Shrubs’ were added to scenarios composed by streets of ‘Asphalt’, ‘Concrete’, ‘Lawn’ and ‘Bare soil’. In all cases there was a significant cooling effect (Figure 4 – Vegetation Unit scenarios). The coolest scenarios were ‘Trees’ on ‘Bare soil’ (VU03) and ‘Trees’ on ‘Lawn’ (VU04), while the greatest cooling effect (0.58°C) was observed for ‘Tree’ on ‘Bare soil’ (VU03 compared to S001). ‘Shrub’ did not produce the same magnitude of cooling effect as ‘Tree’. ‘Tree’ therefore scored 3 points and ‘Shrub’ 2 points. Additionally, the ‘Functional surface’ ‘Vegetation-Trees-Preserved’ scored 1 point to account for the immediate benefit provided by existing trees.

Shading units

These practices could not be modelled with ENVI-met. The scoring rationale is shown below.

Table 4: Thermal regulation scores for Shading units (Torres Limache 2020)

Score	Practice	Rationale
2	‘Shading structures with vegetation'	Performance similar to a ‘tree’ due to shading and foliage (evapotranspiration) but the latter is likely to be limited. Additional materials with different emissivities or heat capacities may influence its cooling effect.
1	'Shading structures without vegetation'	Lack of the additional cooling potential of vegetation (evapotranspiration) and the presence of additional materials (as above).
2	‘Shading structures with solar PV’	Local guidelines suggested the use of ‘solar PV’ as shading devices, therefore 2 points were given: 1 point due to PV’s ability to absorb and convert solar radiation to electricity and another point due to shading.

Soil connection

‘Lawn’ above subterranean structures (e.g. green roofs: extensive 20cm and intensive 1m depth, on basement carparks) was compared to ‘Lawn’ with ‘Connected soil’ applied in streets. Across 24 hours, the average AT difference for both extensive and intensive cases was negligible. The AT above the extensive green roof was slightly warmer, but only by a maximum of 0.074°C (2pm). Due to the small differences all ‘Soil connection’ practices scored zero.

Surface reflectivity

High-albedo (white-painted) versions of ‘asphalt’ and ‘concrete’ resulted in AT reductions compared to their original versions (Figure 4 – Surface System scenarios) - e.g. ‘S012 Concrete (White)’ was 0.31°C cooler than ‘S003 Concrete’. For both ‘Asphalt’ and ‘Concrete’, the high-albedo versions resulted in similar temperatures as those ‘Surface Systems’ which scored 1 point. Therefore, ‘Surface reflectivity’ also scored 1 point.

4.4 Final weightings of the GAR-Lima

'Wetland' (as water treatment plant – Table 5) had the highest weighting, due to it receiving maximum scores for multiple ESs. The next highest were 'Bare soil', 'Mulch' and 'Sand' followed by 'Groundcovers'. 'Trees' and 'Shrubs' also received high weightings. However, not all vegetated practices received high weightings. 'Lawn' received a relatively low weighting, while 'Green wall' received the lowest weighting alongside common local hard surfaces, e.g. 'Asphalt', 'Concrete' and 'Red terracotta tile'.

4.5. Application

The 'traditional' project resulted in a slightly higher GAR-Score (0.51) than the two 'sustainable' projects (both scoring 0.47) (Figure 2). In the retrofit scenarios (Figure 5) developed for 'Olavide', all 'water sensitive' (recycled water and xeriscape) scenarios obtained a higher GAR-Score than the original case. All the 'non-water sensitive' scenarios (irrigation with potable water) also scored higher. The two 'neglected' cases also received slightly higher GAR-Scores. The three 'alternative surfaces' (high-albedo and artificial turf) resulted in a lower GAR-Score in comparison to the original case.

Table 5: Environmental Performance Assessment (Torres Limache 2020)

PRACTICE GROUP	PRACTICE TYPE	PRACTICE	FINAL WEIGHTING	COMBINED WEIGHTING	Aesthe-tics / Visual Interest	Social cohesion and recreat-ion	Clean energy	Urban agricul-ture / Food provision	Water saving	Flood risk reduct-ion	Reduced air pollution	Noise reduct-ion	Thermal regulat-ion	Bio-diversity	Insect / Animal habitat	Un-disturbed nature
					CULTURAL	CULTURAL	PROVISIONING	PROVISIONING	PROVISIONING	REGULATING	REGULATING	REGULATING	REGULATING	SUPPORTING	SUPPORTING	SUPPORTING
				ECOSYSTEM SERVICE PRIORITISATION FACTORS	1	3	1	1	3	1	1	1	3	1	1	1
Surface System	Permeable	Bare soil	0.70	19	2		0		3	3			1		2	
		Gravel	0.63	17	2		0		3	3			1		0	
		Green wall	0.33	9	3		0		1	0			0		3	
		Groundcovers	0.67	18	3		0		1	3			2		3	
		Lawn	0.56	15	3		0		0	3			2		3	
		Mulch	0.70	19	2		0		3	3			1		2	
		Sand	0.70	19	2		0		3	3			1		2	
	Semipermeable	Combined green/grey surface (e.g. block grass, grass grid)	0.41	11	2		0		1	2			1		1	
		Permeable paver (preferably unbound)	0.52	14	0		0		3	2			1		0	
	Impermeable	Artificial turf	0.41	11	2		0		3	0			0		0	
		Asphalt	0.33	9	0		0		3	0			0		0	
		Concrete	0.33	9	0		0		3	0			0		0	
		Impermeable paver (bound)	0.33	9	0		0		3	0			0		0	
		Red terracotta tile	0.33	9	0		0		3	0			0		0	
		Solar PV	0.56	15	0		3		3	0			1		0	
		Wooden deck	0.52	14	2		0		3	0			1		0	
	Water bodies	Water features (incl. fountains, water mirrors, ponds etc)	0.52	14	3		0		0	0			3		2	
		Wetland (as water treatment plant)	1.00	27	3		0		3	3			3		3	
Vegetation Unit		Tree	0.78	21	3		0		1	3			3		3	
		Shrub	0.67	18	3		0		1	3			2		3	
Shading Unit	Shading measure / structure	Shading structure	0.48	13	1		0		3	0			1		0	
		Shading structure with vegetation	0.48	13	3		0		1	0			2		1	
		Shading structure with solar PV	0.70	19	1		3		3	0			2		0	
Functional Surface	Intended use	Area intended for recreation in donated public/semi-private spaces (e.g. playground, sports areas within donated public spaces or multifamilar shared spaces, etc.)	0.33	9		3		0							0	
		Area intended for social interaction in donated public/semi-private spaces (e.g. social areas with furniture within multifamiliar development, social shared spaces within the same development, etc.)	0.33	9		3		0							0	
		Area intended for food production (e.g. communal garden)	0.44	12		3		3							0	
		Non-accessible vegetated area, visible from public pedestrian area (not intended for activity) (e.g. ornamental garden)	0.11	3		1		0							0	
		Area intended to exclusively provide insect / animal shelter	0.11	3		0		0							3	
	Public access / use	Donation of private area or shade for public use (donated surface area + tree canopy area in public space)	0.33	9		3										
	Soil connection	Connected soil	0.22	6						3			0		3	
		Unconnected - Deep soil (incl. Intensive green roof)	0.07	2						0			0		2	
		Unconnected - Shallow soil (incl. Extensive green roof)	0.04	1						0			0		1	
	Vegetation water demand	Vegetation - drought tolerant species (e.g. xerophytes, etc.) - minimal irrigation	0.33	9					3							
		Vegetation - high efficiency irrigation with recycled/treated water	0.22	6					2							
		Vegetation - standard irrigation with recycled water	0.11	3					1							
		Vegetation - high efficiency irrigation with potable water	0.00	0					0							
		Vegetation - standard irrigation with potable water	0.00	0					0							
	Preserved trees	Vegetation - Trees - Preserved	0.22	6									1			3
	Reflective surface	Surface with high SRI (e.g. white roof)	0.11	3									1			

Not scored | Resulting score

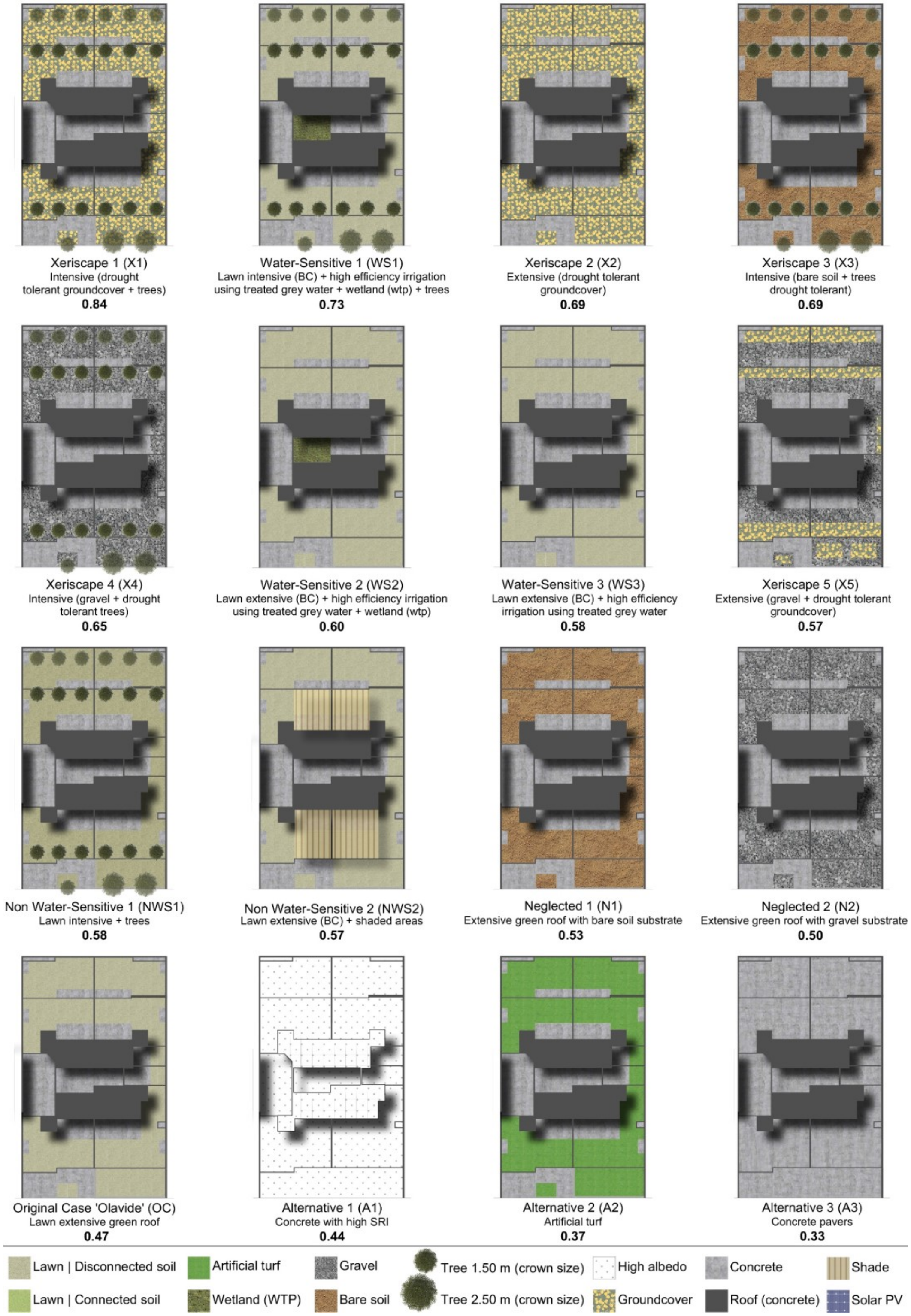


Figure 5: GAR-Scores of retrofitted scenarios (Torres Limache 2020)

5. Implications and conclusions

Consistent with Varthomalois et al. (2013), priorities differed across cities. Nevertheless, similarities in the interests in ESs and practices were found, suggesting urban solutions could be generalized and the GAR could support different contexts after some adaptation. However, for Lima, significant adaptation is required. The risk of disservices is high due to the significant difference in the rainfall levels and social synergies around GI (fencing). Therefore, the direct application of any of the nine GARs in Lima is not suitable and the BAF-Score calculated by Miranda et al. (2015) may not fully reflect the actual GI's local functionality of 'Palas', as neither TR nor WS were considered by the BAF.

The need for rapid decision-making and ensuring the sustainability of actions within the built environment means the GAR-mechanism is based on generalizations and omits certain design parameters, putting its transparency and effectiveness at risk if it is not used with sufficient understanding of GI's performance and the tool itself. For example, while cities indicated that 'Reduced air pollution' could be achieved through GI, GLA (2019) indicated that certain tree-canopy spatial arrangements could trap rather than dissipate pollution. However, the GAR cannot take wind direction into account, nor can it guide in such wind-tree-shape considerations without losing practicality. This, in addition to limited public information on how practices achieve ESs, aligns with the appreciation of Keeley (2011) and Barton (2016), but mainly, indicates the tool has limitations and requires expertise in the field to predict potential disservices.

Unlike other cities, GI implemented under mistaken approaches may be more detrimental in arid environments. Besides intensified water-stress, arbitrary GI implementation may also bring additional disservices (e.g. poor air quality in this case). While this can be overcome through proper scientific research, it mainly suggests that increasing GI quantity in densely built arid environments does not come necessary aligned with better urban quality. This is illustrated in Figure 2, where the 'traditional' project had a higher GAR-Lima-Score than the two 'sustainable' projects, despite one 'sustainable' having a much higher proportion of vegetated area. esides questioning the contribution of local 'sustainable measures' to increasing collective benefits in terms of WS and TR, this suggests GI should not be considered the main resource to mitigate and offset the harmful impacts resulting from some urban activities (e.g. densification, transport, etc.). In addition to more comprehensive guidance on the application of greenery on buildings, emphasis in the exploration of alternative practices should be given (e.g. collective cooling/shade islands, better ventilated building arrangements, low-carbon mobility, bigger open space-to-plot ratio, etc.).

GAR-Lima addresses some of the aforementioned limitations to an extent, by considering local parameters and scientifically justifying their inclusion. Their impact is finally reflected by each final weighting. The highest values (mostly vegetated practices) suggest the presence of GI in Lima is important despite aridity. However, further medium-high values indicate other surface types and considerations (e.g. Functional surfaces) must be present to ensure GI's sustainability and contribution, and to make its presence beneficial within arid environments. This partially aligns to the green-desert tension moderated by the 'spectrum of desertness' of Ivanir et al. (2015), and xeriscape principles, where the logic behind vegetation's ratio is mainly intended to facilitate and favour urban human-activity – an approach that should be considered, for instance for shading in public areas.

However, GAR-Lima is not without limitations. Despite the relevance of some ESs (e.g. 'Reduced air pollution'), the GAR-Lima does not pursue them. This is because to perform as desired, GI must follow some parameters which cannot easily be reflected in the GAR model. Further, while the high GAR-Scores of xeriscape with vast foliage (X1, WS1 and X2) and low

GAR-Scores of hard surfaces (A1 to A3) demonstrate the tool's sensitivity to WS and TR (Figure 5), intermediate GAR-Scores suggest certain acceptance of some unfavourable scenarios. High GAR-Scores for X3 and X4 suggest it may be sufficient to have limited vegetation foliage (low cooling effect) with vast exposed soil and gravel (high warming effect), or to have trees in intensive private green roofs (no public benefit). Moreover, WS2 and WS3 suggest that vast private lawns could result more 'acceptable' than shaded ones (NWS1) and that the vast use ' are soil' (N1) weighs the detrimental effects of irrigation with potable water (as in OC). Ultimately, acceptability will be determined by comparison to a GAR-Target.

This means some disservices in certain ESs could be masked due to good practices' performance in others - in this case resulting detrimentally for TR. This may be the result of trying to broaden the tool's scope to 9 ESs. While this promotes broader sustainability (for instance by prioritising also social aspects), the quantity of ESs included may have limited the influence of the prioritisation factor, resulting in a loss of focus on the most important ESs. This could be improved by increasing the prioritisation factors or alternatively, by separately calculating the contribution of practices solely to TR and WS and setting individual targets for these ESs, as part of implementation. Notwithstanding, achieving balance between all ESs is challenging and requires foreseeing potential negative interactions over time, which also demands regular monitoring. Given that it is a method based on 'averages', relying solely on GAR-Scores is risky, especially without expertise and critical analysis.

The scores established only for TR, however, provide a better understanding of the impact of GI and alternative surfaces in AT at pedestrian level. They revealed the importance of vegetation and shade as cooling elements in combination with other surfaces. However, there is room for further improvement. The negligible impact in the AT above roofs due to roof material change may be a consequence of the model simplicity (buildings with the same height), which facilitated wind flow above roofs and the subsequent dissipation of heat. Moreover, each practice´s performance is subject to the material properties established by ENVI-met, which in some cases could not be modelled (e.g. solar PV). Therefore, the scoring scale contains values determined under different lenses: literature or simulation. The input climatic conditions for the latter did not consider typical cloudiness or air pollution - factors greatly influencing AT. It is, therefore, necessary to validate such scenarios with in-situ measurements in different days or include a more complex spatial model.

The GAR as a planning tool can contribute to achieve ESs provided its limitations within the context of application are acknowledged. However, existing models may not be effective outside their original contexts, particularly in arid environments. The resulting GAR-Lima is more suitable and sensitive to WS and TR, but its application should be subjected to further testing, as its sensitivity to both ESs is not necessarily always achieved. Given that the original tool mechanism was not conceived for arid contexts, and no previous application in densely built arid urban contexts was found, the GAR-Lima represents a very novel approach, that needs further research to conclude if it is effective. However, its composition provides a sense of the collective benefits obtained from GI, contributing to a better understanding of the performance of practices and synergies associated to WS and TR and other ESs. Its application could help compare the benefits obtained by local 'sustainable' guidelines over 'traditional' ones. This can be a basis for potential implementation.

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Vulnerability and Glasgow Greendex: A framework to optimise the impact of Green Infrastructure in improving socio-environmental vulnerability

Megi Zala

Abstract

The aim of this dissertation is to investigate the socio environmental vulnerability blended with the potential of GI in Glasgow to demonstrate how two different aspects such as social and environmental that often are treated separately in relation to green infrastructure can be combined to archive a better comprehensive approach for the planning sector. Using the case study of Greater Glasgow, a development of a Greendex planning tool is proposed to investigate through simulation software to what extend it can be beneficial for the city. The results demonstrate that GI depending on the urban structure has the potential to provide Glasgow with the various socio environmental benefits and ecosystem services essential in combatting climate change and archive climate justice while preserving biodiversity. Nevertheless, the study has effectively communicated the potential and objectives where further research can be conducted. This approach can be beneficial to prioritise decision making by giving power to decisions based on evidence, with the focus where vulnerability and potentials are high. Given the versatile nature of this methodology, it can be replicated and adapted further for other case studies.

1. Introduction

Today 60% of the European population lives in cities. Urban growth and the increasing density in urban structures are putting green infrastructure under pressure by bringing to a reduction in the amount of vegetation and sometimes their loss, by causing extreme weather event (European Commission 2015). Cities are taking important initiatives to mitigate and adapt to climate change, including the improvement and addition of green infrastructure. However, this being considered a relatively new concept for the planning sector have demonstrated uncertainties in the application that can lead to inequalities.

Using the case study of Greater Glasgow, this dissertation investigates the exposure, sensitivity and adaptivity to climate change in relation to GI and explore how a GI tool can be beneficial for city planners and its inhabitants.
With a working experience as a city planner, and being able to realise everyday's challenges in decision making, this research has particular importance to help city planners and as variables for future research. This research aims to facilitate decision making by identifying at datazone level the potential and vulnerability of implementing GI and further, to regulate and quantify the benefits with the use of a Greendex for Glasgow.

It has six main objectives, as follow:

- To explore the importance and benefits of Green Infrastructures application of similar GI index through literature review.
- To understand the spatial distribution of the Environmental and Social Vulnerability pattern for Grater Glasgow at datazone level.
- To map the potential of Green Infrastructure by taking in consideration three indicators: land availability, cooling and flood mitigation potential within Greater Glasgow limits.

- To integrate the potential of GI and socio environmental vulnerability in creating a hotspot map that can help in decision making.
- Establishing a classification of green infrastructure and developing a scoring system part of the new Glasgow Greendex tool.
- Evaluate the Greendex through microclimate program simulations (ENVI met and ArcGIS) for two different scenarios: (a) Compact mid rise; (b), Open low rise area by taking in consideration the influence of vegetation.

2. Background

<u>2.1 Green Infrastructure Index as a planning tool</u>

Green Infrastructure Index is seen to be an important indicator in the planning process that serves as a guide to balance the ratio between the built and non-built environment. Depending on city's regulation and priorities, the GI Index can have a different focus in emphasising specific ecosystem services as a parameter for urban qualities. This tool gives a weighted scoring system to green features according to their ecological value, and it is mostly used for new developments.

The concept of this strategic planning tool originates in Berlin and later on, has been adapted and applied in different cities such as Malmo, Seattle, Stockholm, Helsinki, Southampton, London, etc. These case studies reflect how the scoring system and their policies have involved throughout the years, proving that the initial implementation was not entirely successful. Further, Kabisch & Haase (2014) highlights that inequality can occur from a distributive and accessibility perspective, and it is important to consider the most vulnerable during the planning process. Nevertheless, it is important to acknowledge the positive impact on the development of green spaces and the solutions on the way that the natural environments of cities provide against climate change induced heat stress (Kabisch, 2015).

A summerise of this concept based on different literature is presented and summarised in the form of a SWOT analysis by identifying the strength, weaknesses, opportunities and threats of a Green Infrastructure Index tool.

Table 1. SWOT analysis of a Green Infrastructure Index (Zala 2020)

S Strengths	W Weakness	O Opportunities	T Threats
• It is a flexible tool that sets a minimum target and gives freedom to developers in decision making, landscape design and achievement. • Practical tool to accustomed. • Transferrable method.	• The concept of GI Index has remains more or less the same since the first application in Berlin. • Lack of policy action based on scientific findings. • Mostly applicable in new development. • Lack of dissemination.	• A relatively new concept in Planning. • Can set up a new societal "business model" for developers to see business values and facilitate its integration. • Improves liveability and resiliency. • Equal opportunity to green spaces.	• Lack of integrating the evaluation performance of the new GI. • Can lead to inequality and gentrification.

2.2 Glasgow Study Area Profile

2.2.1 Urban Heat Island: While a warmer climate for Glasgow can be considered as beneficial for the lifestyle and consequently more outdoor activities, the current housing infrastructure is not prepared to perform efficiently under heat stress. In Glasgow, it has been observed an increase of temperature by 1°C between 1961 and 2004 and a higher rise it is expected by 2050 (Adaptation Scotland 2017).

The intensity of UHI in Glasgow can reach up to 4°C under certain atmospheric conditions, but yet there are uncertainties on determining the factors for explaining the local UHI (Krüger et al 2018). A study of the cooling effects of GI conducted by Emmanuel and Loconsole has identified that a third to a half of the expected extra UHI effect in Glasgow can be eliminated by increasing the green cover of the city by approximately 20% over the present level by 2050 and can reduce the surface temperature by up to 2°C (Emmanuel & Loconsole 2015). Moreover, studies highlight that interventions are important in key areas where they can have the greatest equitable impact, areas that can be able to mitigate climate risks (Emmanuel et al. 2014).

2.2.2 Flooding: In the last decade, severe weather events are becoming more frequent. A total number of 161 weather events were reported in Glasgow between 1991 and 2009 (Glasgow and Clyde Valley Strategic Development Planning Authority 2010).

The city is considered to have the highest number of zones classified as having above average social vulnerability to flooding and one of the highest percentages of residential properties in local authorities exposed to surface water flooding (Kazmierczak et al. 2015). Further, Glasgow has a total number of 191 zones classified as extremely high or acute vulnerability to flooding, which demonstrates one third of the total zones in Scotland and presents the highest concentration of surface water flood disadvantage (SEPA 2015).

2.2.3 Inequality distribution, accessibility and standard of green spaces: The city of Glasgow has a significant inequality mostly associated with economic decline, high vulnerability to flooding and lately climate change as a higher risk on increasing further this inequality. The negative impacts of climate change are likely to be felt by the most already vulnerable groups (Glasgow City Council 2020). Therefore, studies pointed out that this should bring new mechanisms and tools in order to reduce vulnerability in a more effective way (SNIFFER 2017).

The city demonstrates an inequality distribution of green spaces where only 1% of green spaces is located in city centre area, 17% in Inner Urban Area and 82% in the Outer Urban Area (OSS 2020). Further, proximity to green spaces has been considered as a determining factor in its use and with the increase in the elderly population will become a stronger indicator of use (De Oliveira & Mell 2019). Further reports highlight that only 10% of Glasgow is classified as Public Park or Garden, and 30% is considered Private Garden (Greenspace Scotland 2018).

Glasgow being a postindustrial city still faces consequences such as having the largest area of the city authorities of a derelict and vacant land consistently for the past years (2012 to 2018). Reports confirm that Glasgow has 9% of the Scotland total derelict land of 1,005 hectares and the most urban vacant land in Scotland with 425 hectares, 35.6% of the total in Scotland. In Glasgow, it is estimated that 60.1% of the population live within 500 meters of a derelict site (Greenspace Scotland 2018).

To conclude, Glasgow presents complex socio environmental conditions, where it is demonstrated a lack of public green spaces, high availability of vacant land, high vulnerability to flooding and risk of heat stress. Intensive progress is made from local and central authorities to address these problems at the policy level. However, there are still gaps that require more attention, such as supplementary tools and guidance that support the actual policies on GI and can help in decision making.

3. Method

For this research, a case study method was conducted in the specific context of Greater Glasgow. It is characterised by a qualitative and quantitative approach in which was essential to analyse existing urban policies implementations of GI Index and to quantify the complexity of socio environmental vulnerability, microclimate analysis and GI Index. Figure 1 presents a summarise of the three research stages of this dissertation.

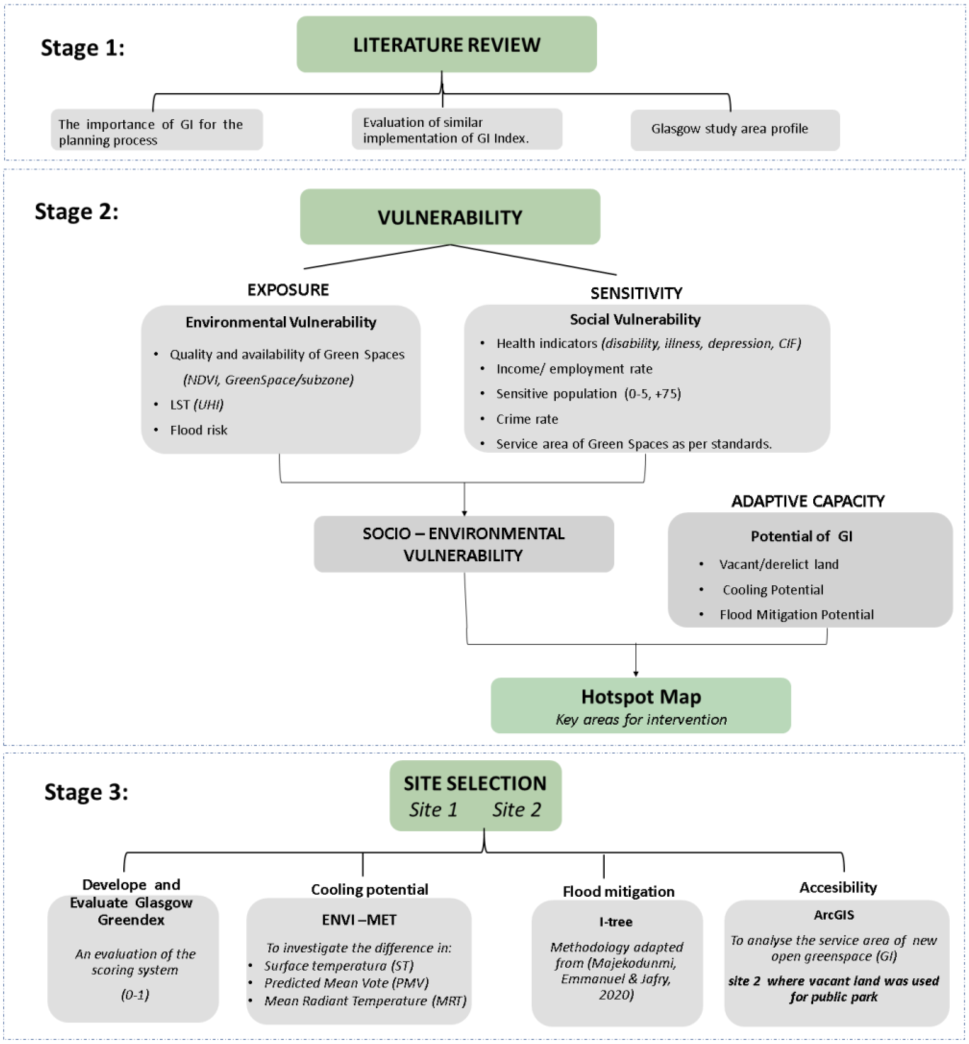


Figure 1: Diagram of the research stages (Zala 2020)

3.1 Data collection and analysis

The data collection process aimed to gather all the data required to create the key indicators for the vulnerability assessment and Glasgow Greendex. For the purpose of the research, sets of secondary data were collected from different sources in the form of publications, books, imagery, geospatial data and Census data summarised in **¡Error! No se encuentra el origen de la referencia.**. Secondary data was decided to suit best to the research, taking in consideration the scope and giving the greater volume that can be analysed.

The data were analysed by using different software. The vulnerability assessment was built by using the geographic information system (ArcGIS ver.10.6) in order to quantify and qualify each indicator at the data zone level. This technique was seen to suit best given the ability of this software to integrate and display information based on its location and giving a visualisation of the data analysed in the desirable scale (data zone).
Further, after identifying the potentials zones within medium to high socio environmental vulnerable areas, a selection process of two sites was conducted to create a hypothetical proposal and test to what extend the GI Index can be beneficial in the contextual cases.

Table 2. Indicators, data collection and sources (Zala 2020)

	Indicator description	Format data	Source and provider	Date	Indicator processing details
Social Vulnerability	Disability / people in ill- health (% people whose day- to-day activities are limited)	Excel (xls)	Census, ONS	2011	Census table KS301. The number of people whose day to day activities are limited a lot + number of people whose day to day activities limited a little, divided by the total population and multiplied by 100. Converted in normalised data (0-1)
	Depresion (% of population who are depressed)	Excel (xls)	SIMD2020	2017	The proportion of population being prescribed drugs for anxiety, depression or psychosis. Converted in normalised data (0-1)
	Comparative Illness Factor: standardised ratio	Excel (xls)	SIMD2020	2017	The CIF is a combined count of the total number of people receiving one or more of Disabled Living Allowance (DLA), Attendance Allowance, Incapacity Benefit (not receiving DLA), Employment Support Allowance and Severe Disablement Allowance. Converted in normalised data (0-1)
	Number of population	Excel (xls)	NRS	2017	NRS 2017 small area population estimates
	Sensitive population % (young children under 5 years elder people over 75 years)	Excel (xls)	Census, ONS	2011	Census table 102. The number of people divided by the population and multiplied by 100. Converted in normalised data (0-1)
	Income deprived rate %	Excel (xls)	SIMD2020	2020	Percentage of people who are income deprived. Converted in normalised data (0-1)
	Employment deprived rate %	Excel (xls)	SIMD2020	2020	Percentage of people who are employment deprived. Converted in normalised data (0-1)
	Crime rate %	Excel (xls)	SIMD 2020	2020	Recorded crimes of violence, sexual offences, domestic housebreaking, vandalism, drugs offences, and common assault per 10,000 people. Converted in normalised data (0-1)
	Servise area of green spaces / datazone	Vector	Generated from a combination of indicators		PAN65 refers to 'open space' as any greenspace consisting of any vegetated land or structure, water, path or geological feature within settlements, civic space, market, paved or hard landscaped areas with a civic function
	-Green Open Spaces	Vector	PAN65 Data	20017	
	- Road map and access point (entrance)	Vector	Digimap, Ordnance Survey	2019	Total service area under each datazone was obtained using the criteria of greenspaces >0.3 ha and 400m walking distance from access points obtained from Ordinance
Environmental Vulnerability	Normalised difference vegetation index (NDVI)	Raster	Sentinel-2 satellite image. Spatial resolution of 10m	June 2019	The NDVI map was generated from Image analysis process in ArcGIS. NDVI is used to analyse the state of vegetation (quality) and as a proxy indicator for Biodiversity (Bawa et al.,2002).
	Availability of Green Space/ subzone	Vector	PAN65 Data	2008	PAN65 - open space with the criteria of >0.3 ha
		Vector	Digimap, Ordnance Survey	2020	Subzone shapefile obtained from Ordnance Survey
	Land surface temperature (LST)	Raster	LANDSAT 8 - spatial resolution of 30 meters	28-06-2019 11:15	LST is the radiative skin temperature of the land derived from solar radiation (Copernicus,2018). The satellite images processed in ArcGIS for the LST map has a cloud cover lower than 20% and with a high estimation solar radiance.
	Flood risk map	JPG	SEPA	2020	The data were created as a raster file refereeing to the interactive Map generated from SEPA official website http://map.sepa.org.uk/floodmap/map.html
Potential	Floor mitigation potential	Vector	(Majekodunmi, Emmanuel & Jafry, 2020)	2020	The map obtained by adapting a method from the TR55 model of the i-Tree tool. Soild cover data and the extent of grass cover (PAN65) classification were used to assign a weighted to the flood prevention capability. The result obtained estimates the flood mitigation in 3 categories (low-medium-high)
	Cooling potential	Vector	(Majekodunmi, Emmanuel & Jafry, 2020)	2020	The study adopts a methodology established by Zardo et al., (2017), together with the methodology used by Keeley (2011) in which the cooling provided depends from the type of GI and the extend of GI. A weighted score of GI was then merged to produce a cooling potential map.
	Vacant land	Vector	Digimap, Ordnance Survey	2019	The Scottish Vacant and Derelict Land Survey is a national data collection undertaken to establish the extent and state of vacant and derelict land in Scotland. For the purpose of the study, the distribution of vacant/derelict land was reclassified by ownership by prioritising only the ones under public the ownership of Public Authorities.

3.2 Vulnerability assessment

The methodology followed to scope the Vulnerability Assessment was adapted from the Conceptual Framework of Vulnerability (AR4) IPCC 2007 by taking into consideration the context specific of Greater Glasgow, choosing the set of indicators carefully. It includes three dimensions: exposure, sensitivity, and adaptive capacity. This concept is well known in literature and has been adapted in a large number of research papers (McCarthy et al. 2001; Turner et al. 2003; Polsky et al 2007; IPCC 2007).

Exposure reflects " the nature and degree to which a system is exposed to significant climatic variations" (IPCC 2001). For this assessment, the exposure analysed for the Environmental vulnerability includes four indicators: Quality and availability of Green Spaces (NDVI, GreenSpace/subzone), LST (UHI) and flood risk.

The dimension of sensitivity was adapted to observe and map the most vulnerable part of society that has the less adaptive capacity to climate changes. Eight indicators were considered for this process: Health indicators (disability, illness, depression, CIF), Income/ employment rate, sensitive population (age 0 to 5, +75), Crime rate and service area of Green Spaces as per Accessibility Standards.

Thus, it was important to identify adaptive capacity, taking in consideration that Glasgow is a city with the largest area of vacant/derelict land in Scotland. Therefore, three indicators were taken into consideration: vacant/derelict land under the Public ownership of the Local Authority, Housing Association and Urban Regeneration Company, Cooling Potential and Flood Mitigation Potential.

The analysis was built combining ArcGIS following the Multicriteria Decision Analysis (MCDA) model. This method serves in transforming and combining geographic data and preferences (value judgments) to obtain information for decision making (Malczewski & Rinner 2015). Malczewski & Rinner (2015) highlight that three main concepts are involved in tackling spatial multi criteria problems: value scaling, criterion weighting, and combination.

3.3 Green infrastructure index for Glasgow

The methodology applied in other UK cities (London, Southampton) and Berlin helped in developing the indicators and scoring factors for Glasgow considering to have a similar ecological aim, similar scope on specific ecosystem service such as the run off infiltration, cooling potential, and improve health and wellbeing. Emphasis is given to elements that provided the specific ecosystem service to regulate the urban microclimate and with a high capacity of absorbing such as trees in natural soil, vegetation on deep soil, rain gardens, intensive green roofs and green pavers. Less scoring it is assigned to vegetation in shallow soil, extensive green roofs and green walls, giving the context specific climate. Different from green roofs, a lower score was given to the green facade, based on different critical studies that highlight the uncertainties of the performance of green/living walls, long term / high cost maintenance and the irrigation required that can directly affect the life and quality of performance (Riley 2017).

3.4 Hotspot analysis and site selection

Based on the evaluation of the vulnerability assessment and the potential areas of intervention, the hotspot map of interventions generated can help in decision making and fulfils two criteria: to fall under high to medium vulnerability and at the same time have a high to medium mitigation potential.

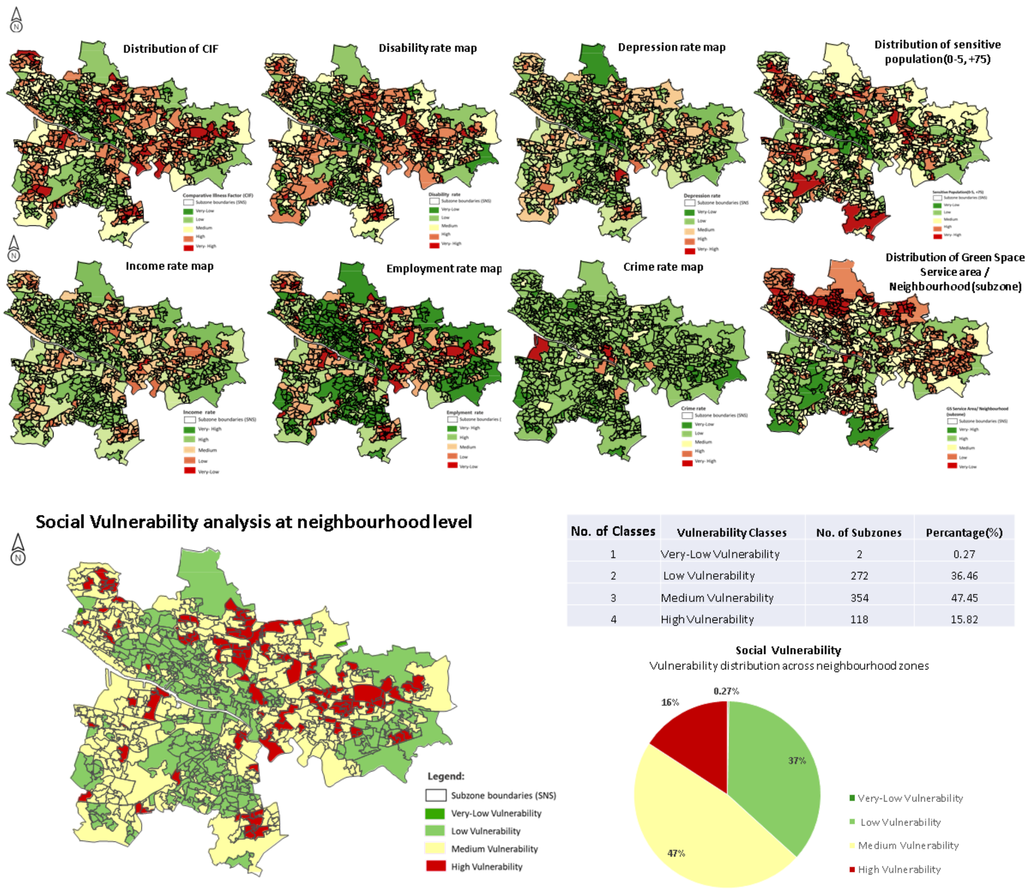
The hypothetical scenario was created, taking in consideration the maximum addition of GI elements for each specific site. The cooling potential has been analysed with the help of simulations in ENVI Met (4.4.5). The program helped in comparing Near Surface Temperature (NST), Potential Air Temperature (PAT) and Mean Radiant Temperature (MRT) between the current scenario and the hypothetical scenario proposed. NST and PAT served to identify the

presence of the UHI effect and its potential mitigation. MRT was used as a proxy indicator to analyse human thermal comfort.
To conclude, giving the scope of the GI Index, an evaluation of the scoring system was needed to understand the potential for each site and create space for discussion on its application.

4. Results

4.1 Social vulnerability

Was conducted to analyse the most sensitive population with less adapted capacity. Overall, the MCDA conducted in ArcGIS for the social vulnerability took into consideration the eight indicators analysed previously, and a vulnerability map was produced (Figure 2). The classification is illustrated with a colour scale from green to red (very low to very high) according to the vulnerability influence. The results indicate that 16% of Greater Glasgow has a high social vulnerability, and 47% has a medium vulnerability. From the total number of 756 datazones, 118 fall under high vulnerability and 354 datazones under medium vulnerability. The resulting Map indicates that communities with the highest vulnerability are mainly located in the North and East of the study area, zones that are well recognised as fragile since the post industrial period. These subzones are the most exposed to social vulnerability and therefore are the ones that have the least adaptive capacity in adapting to climate change.



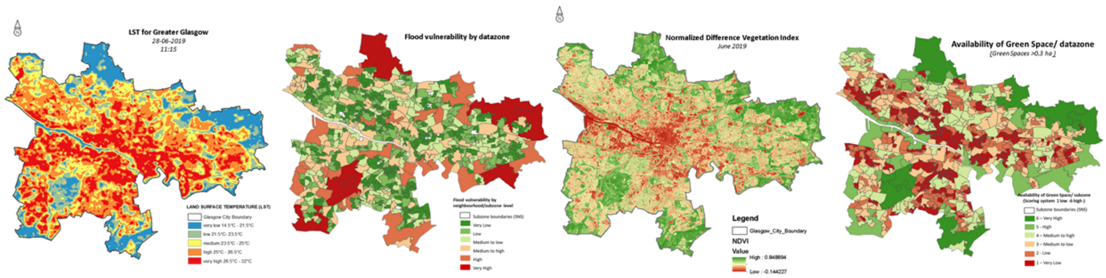
No. of Classes	Vulnerability Classes	No. of Subzones	Percantage(%)
1	Very-Low Vulnerability	2	0.27
2	Low Vulnerability	272	36.46
3	Medium Vulnerability	354	47.45
4	High Vulnerability	118	15.82

Figure 2: Social Vulnerability Map, indicators and analysis results (Zala 2020)

4.2 Environmental vulnerability

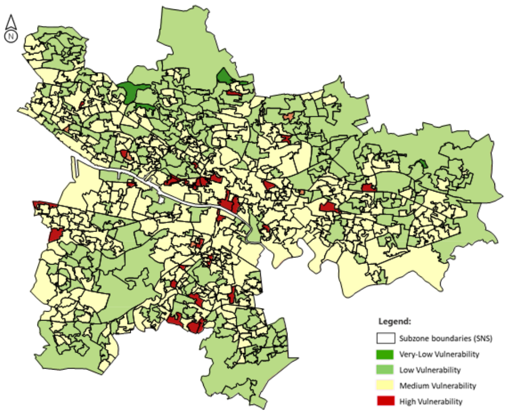
This was conducted analysing four indicators: NDVI, LST, flood risk and distribution of GS/ datazone. For each indicator, a map is presented as an output of several analysis in ArcGIS to identify the spatial dynamic.

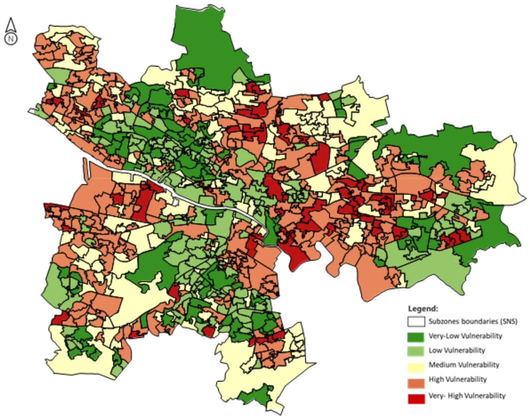
The Map for Environmental Vulnerability was produced through overlay analysis and categorised into four classes (Figure 3). The result indicates that 3.62% of Greater Glasgow has a high environmental vulnerability and 60% has a medium vulnerability. From the total number of 756 datazones, 27 fall under high vulnerability and 452 datazones under medium vulnerability. The resulting Map indicates that the highest vulnerability is mainly presented in the inner city, including city Centre, Glasgow East and Central South, zones that are well recognised as urban areas with lack of GI. Further, 34% of Greater Glasgow is classified as low environment vulnerable that correspond in a total number of 252 datazones.



Environmental Vulnerability analysis at datazone level

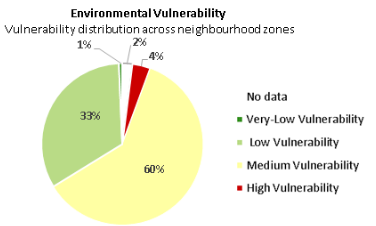
Socio-environmental Vulnerability analysis at datazone level





No. of Classes	Vulnerability Classes	No. of Subzones	Percantage(%)
1	No data	15	2.01
2	Very-Low Vulnerability	5	0.67
3	Low Vulnerability	247	33.11
4	Medium Vulnerability	452	60.59
5	High Vulnerability	27	3.62

No. of Classes	Vulnerability Classes	No. of Subzones	Percantage(%)
1	Very-Low Vulnerability	83	11.13
2	Low Vulnerability	176	23.59
3	Medium Vulnerability	140	18.77
4	High Vulnerability	278	37.27
5	Very-High Vulnerability	69	9.25



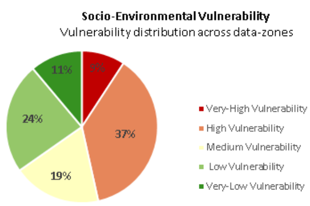


Figure 3: Environmental Vulnerability Map (indicators), and SE vulnerability analysis (Zala 2020)

The final output of Socio Environmental Vulnerability illustrates the degree of vulnerability for each subzone. It is produced as a combination of all the indicators (raster calculator + zonal statistics), and it presents a non-homogenous vulnerability. The resulting Map highlights a higher vulnerability in the North and East part of the study area. The results indicate that 9% of Greater Glasgow is classified as very high vulnerable, and 37% has a high vulnerable. From the total number of 756 datazones, 69 falls under very high vulnerability and 278 datazones under high vulnerability. Further, a medium vulnerability is presented in 140 subzones that correspond to 23.6% of the study area.

4..3 Hotspot Analysis of prior interventions

In order to prioritise decision making, a combination of previous output was required to generate a hotspot map. The Hotspot map that identifies the most vulnerable datazone combined with the potential of GI integration. The Map offers the major areas that need an immediate intervention of the application and improvement of GI (Figure 4). Overall, Glasgow presents an equal distribution of the adaptive capacity.

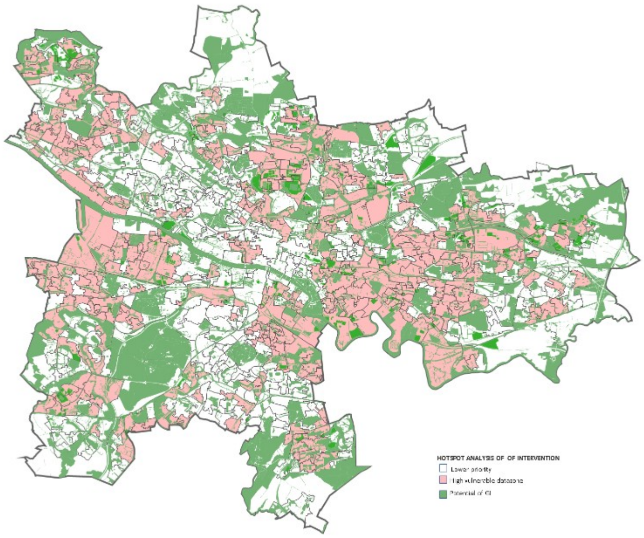


Figure 4: Hotspot analysis Map for prior interventions (Zala 2020)

4.4 Results from ENVImet simulations

The simulation scenarios were evaluated only for summer in order to estimate the model performance at its day time peak, and it is considered the most widely evaluated model on ENVImet for microclimate with the accuracy in the results (Stok et al. 2018). The two parameters MRT and PAT were calculated in ENVImet at the pedestrian level to investigate the outdoor thermal comfort. Results show that for both MRT and PAT, the spatial average values are reduced (Figure 5).

Site 1 presents a complex geometry with a low intervention potential of integrating new GI elements due to a dense urban form. The results offer an average reduction of MRT of 2.32°C and an average for PAT of 0.35°C. The highest temperature reduction is present where the highest volume of GI is proposed. The dense urban structure demonstrates that in combination with addition GI can reduce the PAT mostly in street canyons. In the case of MRT, the decrease in temperature does not present a significant relation to the urban structure. We can conclude that it is present in street canyons and open spaces but not in all the cases.

Site 2 presents a simple geometry compared to the first site, and it shows a better distribution of the temperature difference throughout the site. Given the opportunity to have within the site an existing vacant land under the administration of GCC, it gives the potential for creating a new park in the site with dense trees. Further, two additional investigations were conducted the influence of green roofs with the help on ENVImet (Leonardo) by analysing MRT and PAT (h=7.5m for Site 1 and h=10m for Site 2). For both sites, the reduction of MRT is almost insignificant compared to the PAT that gives a higher impact on the difference in temperature after 13:00.

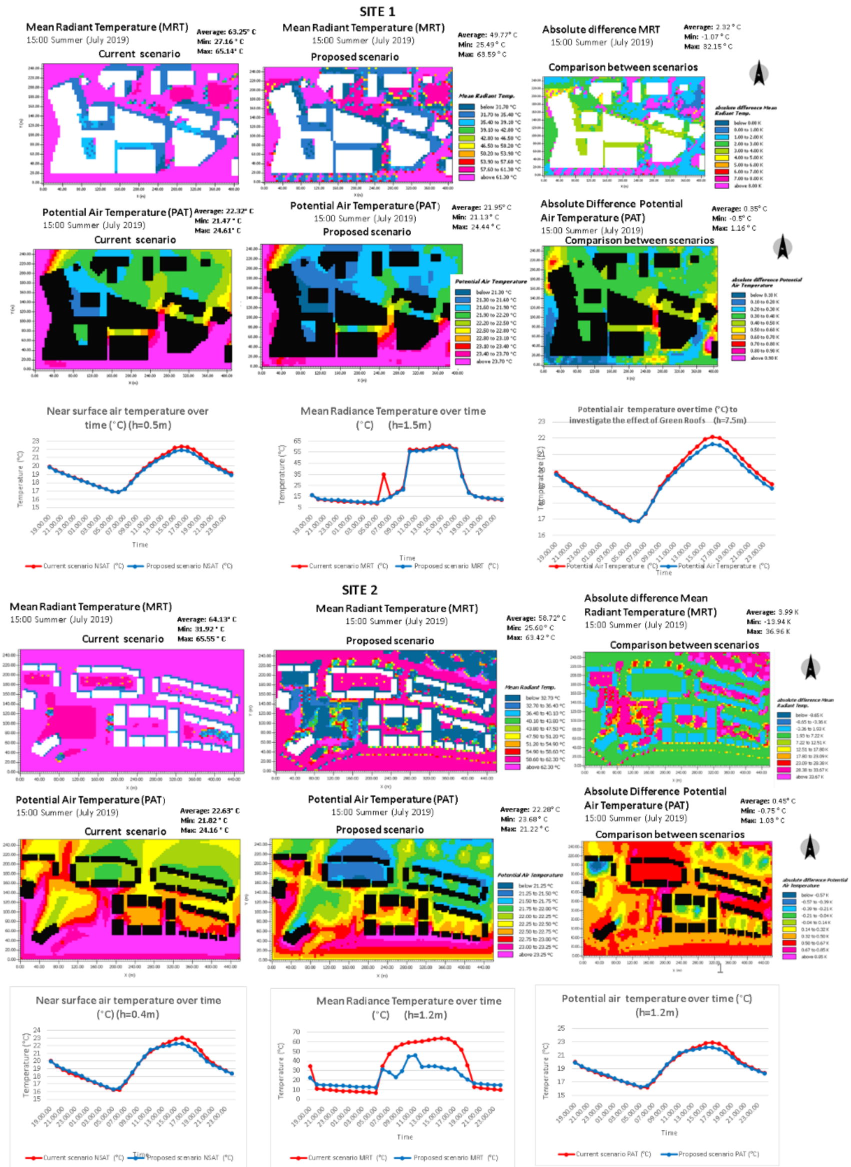


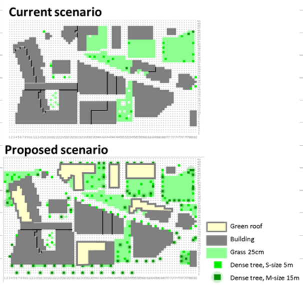
Figure 5: Microclimate output analysis of the two sites (MRT, PAT) (Zala 2020)

4.4 Preliminary analysis of the Glasgow Greendex

Site 1 under the subzone "City centre East 04" presents a compact mid rise urban structure and a low intervention potential for GI, commonly found close to the city Centre, where interventions are very limited. The site includes several new developments characterised by flat roofs such as City of Glasgow College, Strathclyde University, Student Roost St.Mungo's accommodation and Townhead Village Hall Community Centre that give the potential of integrating new extensive green roofs. The calculation of the Greendex for the current scenario results in a low Greendex score of 0.09.

Although the site does not offer a high possibility to integrate GI, the proposal scenario has tried to improve the existing GI whenever possible by adding more trees, new rain gardens, green roofs and therefore reaching a score of 0.25.

Table 3. The Greendex Scoring analysis for Site 1 (Zala 2020)



Site ilustration	No.	Surface cover type	Factor	Existing (m²)	New (m²)
	1	Semi natural vegetation / wetland / water surface	1		
	2	Large trees in natural soil (per m2 of canopy cover)	1	75	850
	3	Medium-small trees in natural soil (per m2 of canopy cover)	0.8	85	450
	5	Vegetation on deep soil	0.6	1500	2700
	6	Vegetation on shallow soil	0.4	6700	9700
	7	Rain Garden / vegetation	0.7		1000
	8	Intensive green roof (vegetation over structure) min depth 150mm	0.6		
	9	Extensive green roof (vegetation over structure) 60-150mm	0.3		8800
	10	Green walls / vertical vegetation	0.3		
	11	Green pavers	0.4		
	12	Permeable paving	0.2		
	13	Concreate/ asphalt / impermeable materials	0		
		TOTAL AREA = 95000 m²		**0.09**	**0.25**

Site 2 under the subzone "Milton East 03 and 04" presents a simple urban form of 1 to 4 stories buildings classified as open low rise, commonly found outside inner Glasgow. Most of the buildings were built with the scheme in the early 1950' excluding a new development block of 2 to 3 stories located at the centre of the site. The buildings are characterised by a shared backyard. The site includes an existing vacant land under the administration of GCC that has a high potential to be converted into a dense park. The calculation of the Greendex for the current scenario results in a score of 0.22. The new proposal offers the application of extensive green roofs for all the buildings, referring to similar successful regeneration projects in Buccleuch Street, funded by GCC and Scottish Government. Further, an improvement of existing GI is proposed by adding supplementary trees and rain gardens with an improvement score of 0.53.

Table 4. The Greendex Scoring analysis for Site 2 (Zala 2020)

Site ilustration	No.	Surface cover type	Factor	Existing (m²)	Proposed (m²)
	1	Semi natural vegetation / wetland / water surface	1		
	2	Large trees in natural soil (per m2 of canopy cover)	1	175	12000
	3	Medium-small trees in natural soil (per m2 of canopy cover)	0.8	64	152
	5	Vegetation on deep soil	0.6	21000	25000
	6	Vegetation on shallow soil	0.4	1000	2000
	7	Rain Garden / vegetation	0.7		250
	8	Intensive green roof (vegetation over structure) min depth 150mm	0.6		
	9	Extensive green roof (vegetation over structure) 60-150mm	0.3		14737
	10	Green walls / vertical vegetation	0.3		
	11	Green pavers	0.4		
	12	Permeable paving	0.2		
	13	Concreate/ asphalt / impermeable materials	0		
		TOTAL AREA = 102000 m²		**0.22**	**0.53**

To summarise, the preliminary analysis presents a better understanding of the capacity of each site to integrate GI by quantifying and comparing the scenarios. Limitations can be observed in both sites, taking in consideration that the sites present an existing urban structure. For both the sites, the analysis was conducted to evaluate an approximate maximum potential of GI. However, site one had a lower capacity compared to site two.

4.5 Research findings

The framework vulnerability analysis and evaluation of the Greendex require the formulation of a methodological framework based on literature. Based on these analyses, the following findings are presented:

- Datazones with high income/employment rate have overall demonstrated to have a good indicator of health.
- City centre presents the lowest distribution rate of the sensitive population (0 to 5, +75).
- The maps generated identify clusters that present a relation between the sensitive population and availability of Green spaces. These can bring to the assumption that there is a lack of GI present for one of the most vulnerable groups and might require more attention to further analysis.
- The distribution and accessibility of green spaces demonstrates a lack of public green spaces and the high proportion of private green spaces.
- Overall, Glasgow demonstrates to have an equal statistic distribution of socio environmental vulnerability, in which 63% of the study area is classified as high to medium vulnerable for social conditions and, 64.21% for the environmental conditions. However, the environmental vulnerability demonstrates to have a significant impact for 60% of the city under medium vulnerability, compared to 47% for social vulnerability.
- The comparison of LST map with the NDVI demonstrates clearly the relation between the two indicators and confirms the presence of the UHI effect in the study area. Thus, in align with the results of LCZ that reflects the highest urban sensitivity in the dense urban area where there is a lack of green spaces.
- Relatively High potential of improving and implemented GI is observed for the most vulnerable areas, giving the potential for intervention in future.
- By increasing the vegetation cover in urban areas can lead to a significant reduction of MRT but less significant reduction of PAT. However, these demonstrate to successfully improve human thermal comfort in both scenarios.
- The analysis of site number two presents a great example of how the GI Index can be implemented in producing good results. Further, it reflects how vacant/derelict land can be converted in a dense urban park, that has a significant impact for the urban microclimate and in the accessibility of GI.

5. Implications and Conclusions

Green Infrastructure Index is a concept that still reflects uncertainties in implementation and due to missing knowledge or lack of scientific findings (Wilkinson et al. 2013). Learning from previous case studies, this research brings a holistic and comprehensive approach for Glasgow by considering the combination of Socio Environmental indicators that can help in the implementation of the Index by emphasising where inequalities and potentials are present and prioritise decisions.

This study has demonstrated how two different aspects such as social and environmental aspects that often are treated separately in relation to green infrastructure can be combined and integrated into the city planning strategies towards a common goal of sustainability and resilience. For instance, this study showed that many datazones could have a good indicator of GI per capita, but service areas can be limited due to accessibility or ownership.

As a support of the new urban agenda and SDGs, this approach incentives to be an addition to the climate change measures and strategies of Glasgow City Council and moreover counteract social inequities in support of sustainable cities and communities with inclusive and accessible green spaces for the most vulnerable. To follow up with evidence based approach, better measurements are vital for the planning process, as this tool demonstrates. However, limitations are present for implementing GI in dense urban areas that are mostly characterised by low availability of GI such as presented in the case of the selected site in "City centre East 04". Nevertheless, GI reflects to has the potential to provide Glasgow with the various socio environmental benefits and ecosystem services essential in combatting climate change and archive climate justice while preserving biodiversity. The vulnerability framework analysis conducted for Greater Glasgow blended with the potential of GI implementation can archive a better comprehensive approach for the planning sector by helping prioritise decision making where vulnerability and potential are high. The study has effectively communicated where further research can be conducted as follow:

- The adapted vulnerability framework can be developed further from GCC by adding other indicators that due to data limitation were not considered for this study. For instance, this research used NDVI as a proxy indicator of biodiversity due to limited data available. Hence, this indicator can be added to the framework by analysing to what degree biodiversity is exposed to climate change.

- LCZ maps can be used on other studies as a proxy indicator to determine the ecosystem services available in local areas (e.g. some of the more open LCZ classes could be said to have higher cooling/flood mitigation potential). Following this, City Planners can carry out LCZ mapping as a shortcut to determining local environmental attributes.

- Supplementary guidance for the Greendex score should be considered further, giving a specific score to different series of trees according to their ecosystem services provisions and prioritising native species.

- Increasing awareness on the multidimension benefits of GI is essential for encouraging citizen to get involved in the process, especially on existing developments and in context of Glasgow where 30% of green spaces is classified as private garden.

- The NDVI analysis, LST and ENVImet simulations were conducted only for the month of July. The analysis can be extended further by considering the winter season and quantify the annual benefits of GI.

- This dissertation looks at the linkage between socio environmental vulnerability and potential of GI and does not incorporate the economic benefits of GI. This can be a new potential study to quantify the economic benefits of GI for Glasgow with the help of software such as I-Tree.

- Addition analysis can be performed for any pilot project to recalculate the environmental vulnerability of the new proposal and creating new indicators such as the Vulnerability Reduction Potential (VRP).

- The versatile nature of this methodology can be replicated and adapted for other case studies given the proper datasets. Nevertheless, we need to acknowledge that we cannot solve every socio environmental problem for the city by including the Greendex concept at the policy level. But giving its multi dimension benefits and the metric ability can serve as an addition to the climate change measures and strategies, giving more power to decisions based on evidence.

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CIRCULAR SYSTEMS

Developing a conceptual framework for a Bio-based Circular Economy

Approach to waste management in Bahar Colony, Lahore, Pakistan

Samira Nazir

Abstract

The traditional approach to economic growth based on "take, make, use, and dispose" concept is not sustainable and is affecting the environment and human health. This has promoted many countries to find a sustainable way of waste management and the most recent identified solution is "Circular Economy (CE)". This study aims to develop the Conceptual Framework (CF) based on CE for biowaste management of Bahar Colony Lahore, Pakistan. It includes literature on Finland's BIOREGIO project as an example. The methodology adopted to collect the data includes field surveys and interviews of residents, Private Waste Collector (PWC), and Lahore Waste Management Company (LWMC) officials. Both qualitative and quantitative data were gathered to critically analyse the baseline situation and waste management issues from generation till disposal. The results revealed that besides the availability of sanitary landfill waste is illegally dumped at open spaces. There is no formal segregation and recycling system. The higher rate of organic waste production depicted CE potential which was assessed through SWOT analysis based on which CF was developed. The study concluded CE a feasible solution for sustainable biowaste management. However, the framework benefits can only be achieved once the existing gaps will be resolved through the adoption of measures suggested in the paper.

1. Introduction

There are different types of waste such as municipal (household, commercial, and demolition), hazardous (industrial), biomedical, electronic, and radioactive (Solarimpulse Foundation n.d.). This study focused on Municipal Solid Waste (MSW). In MSW, the amount of biodegradable waste is normally 1/3 of the total waste (Halkos & Petrou 2016). The global production of MSW is approximately 1.3 billion tonnes/ year which is expected to increase to approximately 2.2 billion tonnes/ year. Accordingly, the waste generation rate in the next fifteen years will increase from 1.2 kg to 1.42 kg/ person/ day (Iqbal 2019). Waste is a problem in many developing countries including Pakistan where waste segregation is not much practiced and, in most cases waste is illegally disposed in open spaces and drains. Additionally, for many developed countries, Pakistan has become the favourite destination for waste disposal which is severely affecting the health condition of the public. It is estimated that approximately 5 million annual deaths in Pakistan are due to waste-related diseases (Ilyas 2018).

For the last 70 years, Pakistan had no scientific landfill but recently in 2016 "Lakhodair Sanitary landfill" has been constructed in Lahore. Beforse the construction of this landfill, waste of the city was disposed at three open dumping sites; i) Mehmood Booti, ii) Saggian, and iii) Baggrian. According to a study conducted in 2010, sixteen points were selected near these dumping sites for groundwater sampling and were found highly contaminated. The pollutant concentration was higher than the recommended upper limits of the Pakistan Standards and Quality Control Authority (2004) (Akhtar & Zhonghua 2014).

The Lakhodair first sanitary landfill has also now turned into a dumping ground (Raza 2019). because the capacity of the sanitary landfill is not enough and the waste is disposed in a traditional manner such as open dumping (Randhawa 2017) which produces an unpleasant odour, acts as a breeding ground for bacteria and viruses, contributes to the spread of dust and filth during the storms, and encourages the entry of illegal scavengers to extract recyclable materials (Akhtar & Zhonghua 2014). The exact proportion of recycling is not known but almost 27% by weight of the total waste is recycled (Azam et al. 2020). The study conducted in 2008 estimated that if recycling is adopted as an industry in Lahore it could generate revenues of Rs. 530 million (US$8.8 million) per year and can save an enormous amount of energy and natural resources (Batoola et al. 2008). Also, the waste at many places is burned which causes the emission of toxic gases such as carbon monoxide, nitrogen oxide, and soot which are sources of air pollution (Khan 2011) and adds to the intensity of smog production especially in winter (The Express Tribune 2018).

This demands the introduction of feasible strategies through CE that could bring positive change in terms of waste management. To analyse CE applicability in Lahore, an area named “ ahar Colony (C)” was selected. The study is designed bearing in mind the fact that Pakistan is an agricultural country where recycling of biowaste combined with the relatively cheap labour could bring positive benefits for the government, locals, and the environment. Finland was taken as an example who is known for bio-based expertise and innovative solutions in the field of CE (Business Finland n.d.).

The study aims to develop a CF based on CE principles that promote sustainable bio-waste management in BC. The objectives attached to the aim were:

- Baseline survey of BC to assess the current waste management practices from generation till disposal with specific reference to MSW.
- Critical analysis of existing issues through interviews of relevant stakeholders including BC residents, informal PWC, and LWMC officials.
- Appraisal of Lahti’s IOREGIO project to identify key areas of good practices.
- Development of CF to address key problem areas of biobased waste management.

2. Background

The current world population is 7.7 billion and is growing at a rate of around 1.05% per year (Worldometer n.d.). To meet the needs of this population the existing trend of production activities and usage of resources are exploiting the resources at a faster rate than replenishing which is causing resource degradation, climate change, biodiversity loss, environmental pollution, and more waste generation. Globally a lot of research is being conducted in waste management (Halkos & Petrou 2016) and to-date wide range of techniques are available to manage the waste such as landfills, incineration, recycling, composting, and energy recovery (Solarimpulse Foundation n.d.). Some of these techniques convert waste into energy and fuel and hence promote public health, environmental protection, and minimum greenhouse gases (GHGs) emissions (Bogner et al. 2008) and waste production. However, waste is still a widespread problem both for developed and developing countries (Abdel-Shafya & Mansour 2018) because many of these emerging technologies and current practices are linear (Halkos & Petrou 2016) where waste is discarded into the environment based on the concept of “take, make, consume, and dispose” (Drljaca 2015), in developed countries because of the abundance of materials and energy availability (Sariatli 2017) while in developing countries because landfills and open-dumping are considered as the cheapest options for waste disposal (Akhtar & Zhonghua 2014). Uncontrolled landfills are the world’s third-biggest source of methane emissions (Azam, et al. 2020) and contribute to about 5 percent of global GHGs emission (UN environment programme n.d.). Therefore, managing waste is a vital component of sustainability. However, it remains a challenge for many developing countries as it demands 20-50% of municipal budgets (WB 2019). Hence, in Pakistan like many other developing countries, it is the most neglected sector (Syeda et al. 2017) and therefore requires the introduction of technology that is more affordable, effective, and sustainable (Bogner et al. 2008). This idea of sustainable waste management is highly related to the concept of CE

(Halkos & Petrou 2016) because it deals with a closed-loop system that involves an equilibrium between economy and environment to bring social improvements by contributing to more financial benefits (Geissdoerfer et al. 2017).

2.1 Conceptual Understanding of CE

Unlike the traditional linear model (Drljaca 2015) CE emphasises on designing-out of waste and pollution by keeping products in use for longer and facilitate the regeneration of natural systems (Trueman 2019). It takes into consideration a holistic approach from raw materials, design, production, distribution, consumption, collection, and recycling back to the reuse of materials (Halkos & Petrou 2016). Hence, what used to be considered as 'waste' can be turned into a valuable resource (Bourguignon 2016). Thus, it is considered as a viable, sustainable, and unavoidable alternative to manage waste (Sariatli 2017). However, moving towards CE is challenging, as shown in Table 1 (Bourguignon 2016):

Table 1: CE opportunities and challenges (Nazir 2020)

Opportunities	Challenges
• Reduce climate change issues by reusing the resources and better waste management.	• It would involve considerable transition cost and a lack of appropriate finance for market innovations.
• Reduce landscape and habitat disruption which would in turn help to limit biodiversity loss.	• Incentives for producers and recyclers to work together to improve performance within and across specific value chains and markets for secondary raw materials.
• Enhanced security of supply of raw materials.	• It would require technical skills that are currently not present in the workforce.
• It could strengthen growth and create new jobs.	• Systematic shifts in consumer behaviour who have little knowledge about the potential benefits of CE and tend to be reluctant to adopt new business models.
• It triggers a large innovation for material and product redesign for circular use.	• Transition to CE would require action at many levels (for example international, European, national, local, business and individual) and in many policy areas.

2.2 Bio-based Waste Management in Finland through CE

Bio-economy means the reliance of industries on renewable biological resources which not always mean circular. By combing the principles of both bio-economy and CE, a bio-based CE can be achieved (Medkova et al. 2017). Finland aims to become a global pioneer in the field of CE and was the first country who prepared a national road map to CE in 2016 (Sitra n.d.). Lahti a pioneer city in Finland in terms of CE has made huge progress in recycling and material processing innovation (Smart & Clean Lahti n.d.). It aimed to stop the incineration and landfilling by 2050 (Lahti 2017). In 2018, only 3% of MSW was landfilled (Interreg Europe 2020). An example of a bio-based CE can be seen at the Kujala Waste Centre (KWC) under BIOREGIO project (Lahti 2017).

2.2.1 BIOREGIO project

BIOREGIO is a five-year-long Interreg Europe project (Vanhamäki & Manskinen 2017) and includes the collaboration of eight partners from six European regions “Spain, Greece, Slovakia, France, Romania, and Finland”. The project aims to enhance biobased CE through the transfer of expertise, and improvements in regional policy instruments and knowledge regarding biobased CE (BIOREGIO 2020).

KWC is home to LABIO biogas and composting plant (PJH n.d.). The process of biowaste treatment starts with waste sorting at the source (Vanhamäki 2020). The segregated bio-waste is converted into biogas through the process of dry fermentation. This raw biogas is then processed into biogas similar to natural gas in composition and is then directed to the natural gas network to use as a transport fuel (PHJ 2008). The digestate from the fermentation process with other bio-waste is transferred to the composting plant for compost production and is used as a soil-improving agent (PHJ 2018). This process offers an environmentally friendly and odourless production of biogas and compost (Vanhamäki 2020).

2.3 Waste Management in Pakistan

Roughly 20 million tonnes of waste is generated annually in Pakistan with a growth rate of about 2.4 percent (Lew 2020) and most of it belongs to cities (Iqbal 2019). Treatment technologies such as sanitary landfill, composting and incineration are comparatively new (Climate and Clean Air Coalition n.d.) and the existing capacity of municipal institutions is not enough to deal with the current and upcoming waste. Therefore, unfortunately, none of the cities have a proper Solid Waste Management (SWM) system and a big difference can be seen between the amount of waste generated and the amount that reaches the landfill (Pak-EPA n.d.). This poor management of waste is putting the country's fragile eco-system in danger (MoF 2012-13). The underlying causes for the deteriorating conditions are due to the employment of corrupt individuals, obsolete infrastructure, dearth of public awareness (Javaid 2019), lack of reliable data and research, and financial and technical difficulties (Kaynat et al., n.d.). Many existing laws are outdated and inadequate (Nasreen 2012). Moreover, the institutions are primarily led by public sector workers and politicians who are not aware of waste management practices (Lew 2020). Therefore, the big cities including Lahore are confronting severe issues in handling waste (Javaid 2019).

Lahore is the second-largest city of Pakistan with a population of 11 million (Ashraf et al. 2016). SWM has long been a neglected sector by the government (LWMC n.d.), and LWMC the latest entity developed also does not show high performance. Despite working in two shifts the waste collection efficiency is still (Lew 2020) 68% approximately (Masood et al., 2014) and it remains unsuccessful in disposing waste in a scientific manner (Raza 2018).

3. Method

The research approach used to conduct this study is deductive which is theory-testing. The process started with the selection of the case study. Lahore was chosen because it is a pioneer city in Pakistan for the establishment of a separate waste management company and a sanitary landfill. However, keeping in view the time limit, and city size and population the scope was narrowed down to BC which generally represents a similar situation of waste management like in most other areas of Lahore. The case study provided deeper insights into the existing waste management system, issues, and opportunities for CE from generation to disposal. All stakeholders dealing with waste of BC were consulted which includes BC Union Counsellor, BC residents, informal PWC, and LWMC officials (Managers, Supervisor, and Research Associate). This helped in getting more accurate, diverse, and rich data on ground reality. Although the focus of the study was on biowaste but due to lack of waste segregation practices the overall waste was studied.

The research tools used to collect information were field surveys, questionnaires, interviews focus group discussions, and personal observations. Three different sets of questionnaires were prepared for residents, PWC, and LWMC officials. For LWMC, it was further divided for Manager Planning and Manager Operations/ Supervisor. Keeping in view the COVID-19 outbreak convenient-based sampling was chosen and only 10 households were interviewed. The field surveys were carried out from 07 March 2020 to 11 April 2020. During these surveys, the primary data on all the positive and negative aspects were collected which consisted of both quantitative and qualitative information. For data analysis, Microsoft Excel and SWOT analysis were used which helped in understanding the profile and opportunities of CE in the existing system, based on which CF was developed.

4. Results

4.1. Profile of LWMC

The SWM was formalised in 1978, at that time City District Government Lahore was responsible for the collection and disposal of waste. It was realized later that its capacity was not enough to manage the waste and therefore on 19 March 2010, LWMC was established to “improve and modernise the SWM” in the city. LWMC also remained unsuccessful, hence in March 2012, it outsourced and privatised the provision of SWM services to two Turkish companies “Albayrak and OzPak”. Their responsibility includes manual sweeping, mechanical sweeping, mechanical washing, container-based collection, and waste transportation to the disposal site. LWMC supervised and monitored their activities and can impose penalties in case of delays in the timely resolution of complaints because it is answerable to the government for all waste-related issues of the city. It has organised monthly or quarterly training programmes for employees and daily awareness programmes for public which are delivered through print and electronic media. There are 274 Union Councils (UC) in Lahore and LWMC has divided them into two zones for waste management: zone 1 for Albayrak and zone 2 for OzPak. BC falls under zone 2.

4.2. Profile of BC

C is located in “Gulberg Town” which includes eight UCs and C falls in UC 226. C is a residential area that includes churches, schools, small parks, and an open wastewater drain. The area is inhabited by 16,241 persons living in 1320 dwellings. It is comprised of middle class income people and around 80% of them are educated. Detailed information on waste management practices from generation till disposal is as follows.

Waste generation

The total waste generation of Lahore is 5500-6500 tonnes/ day which ranged between 0.55 to 0.65 kg/capita/day. The exact data on the amount and composition of the waste generation of BC was not available with LWMC. However, according to PWC, BC generates around 3-4 tonnes of waste/ day. The residents reported 70-80% of the waste they produced daily is organic. No segregation is practiced, however in some cases, informal segregation is carried out by maids who separate recyclable materials and sold it in the market for cash. Nevertheless, it requires time and different bins thus in most cases it is disposed together in a common bin. The bins are then daily placed at the doorstep for PWC to empty it but this is not the case for everyone. There is a group of people who are directly disposing the waste in empty plots, streets, and wastewater drain to avoid the cost associated with PWC.

Waste collection

Waste in BC is collected by both PWC and OzPak. As OzPak lacks door-to-door waste collection facilities, the predominant system of waste collection from households is through PWC. However, to avail, this facility residents have to pay 200 Pak.Rupees/ month to PWC. The PWC sort wastes at the source and placed it in different bags attached to its vehicle. The vehicle used by PWC is a motor rickshaw having a capacity of 0.2 tonnes/ day. The segregated recyclable material is sold in the market to waste dealers while the leftover organic waste is disposed in LWMC waste containers. There are total 31 containers in UC 226, 10 of which are allocated to BC. The containers are made up of iron and the capacity of each container is 0.225 tonnes. These containers were not provided with any cover and most of them were rusted. The total waste collected by OzPak from UC 226 is almost 35 tonnes/ day, out of which 10-12 tonnes belong to BC. The frequency of waste collection is 2-3 times a day but priority changes to main roads during the rainy season to avoid flooding of roads and containers are left unattended.

Total 33 workers are working in UC 226, out of which 14 are responsible for BC. Their responsibilities include sweeping of streets and removal of waste from containers and unattended waste heaps. The tools used by workers for cleaning includes broom, shovel, and scrapper. The waste from the streets is hauled through hand carts to the containers. The containers are then emptied mechanically into the compactors. There are two compactors deployed for UC 226 each with different capacities: 4-5 tonnes/ day and 8-10 tonnes/ day. Compactors make 2-3 trips/ day to lift the waste. The compactors are unloaded at the Valencia Transfer Station from where the waste of BC is finally transported to the landfill through the trailer. The capacity of the trailer is 35-40 tonnes/ day.

Waste disposal

The waste at landfill comes under the responsibility of LWMC. The "Lakhodair landfill" was operationalised in 2016 to handle the MSW. The vehicles at landfill are first weighed at the weighing bridge and then diverted to the dumping sites for unloading. The total waste ranges between 5500-6500 tonnes/ day, of which around 5000 tonnes is diverted to the controlled dumping site and the remaining 500-1000 tonne to the sanitary landfill site. Almost 65% of the total waste is biodegradable. At both sites, the waste is disposed without any segregation in a controlled way, which means the waste is only compacted and then covered by a layer of soil without any facilities for leachate and gas collection.

The waste segregation at landfill was practiced until 2019 where 800 tonnes of RDF and 500 tonnes of organic waste were transported to the DG cement industry and LWMC composting plant to use as fuel and compost respectively. Due to some political and internal issues, the contract with the DG cement industry had been terminated and the composting plant is not running anymore. Some informal segregation is being carried out by the scavengers and they usually collect 5-6% of the recyclables from the total waste brought to the landfill daily. The lack of waste segregation and gas collection system has caused the fire hazard at landfill many times. Additionally, the average height of waste heaps has reached above then the recommended level of 20 feet. Therefore, LWMC is planning to supply 2000 tonne of waste to China for electricity production. The waste is sometimes alight by the workers as well in winters to keep themselves warm. The overall visualization of waste flow from generation to disposal is presented in Figure 1.

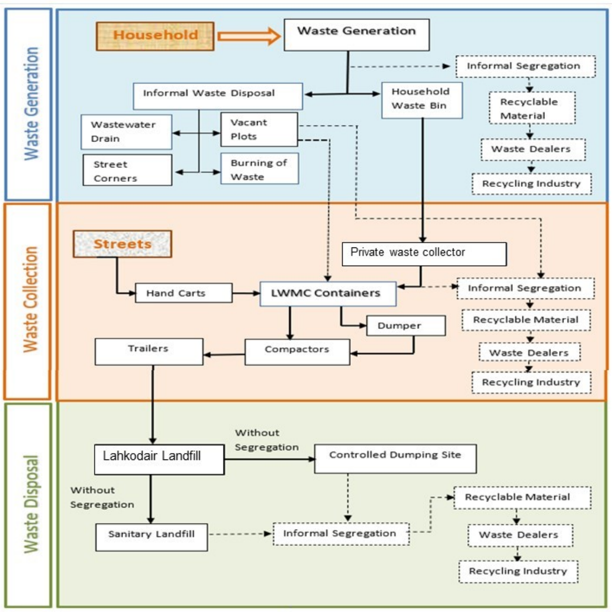

Figure 1: Waste flow diagram of the existing system (Nazir 2020)

4.3. Issues and feedbacks

The data on the current waste management issues gathered from residents, PWC, and LWMC officials is illustrated in Table 2.

Table 2: General feedback on issues (Nazir 2020)

Residents	PWC	LWMC
• Lack of door to door waste collection facilities. • Inappropriate distance, number, height, and capacity of containers. • Containers normally remained overflowed. • During the rain, leachate percolates through the containers due to damages in containers. • Waste heaps and open containers have increased the activities of flies, mosquitoes, stray animals, and scavengers. • No awareness is delivered by LWMC on SWM. • Majority of residents are not aware of the LWMC complaint redressal system. • OzPak sanitary workers are not cooperative and regular in performing their duties. • No involvement of residents in the decision-making process. • No action and penalties against illegal waste disposal. • 80% of respondents showed interest in having proper knowledge of SWM. • 60% were willing to segregate waste at source based on facilities provided to them. • 70% showed interest in using electricity and gas produced from biogas. • 80% were concerned only for air and water pollution, not solid waste pollution.	• No proper place is allocated for waste disposal. • Payment has to be made to waste dealers to dispose waste in empty plots. To avoid cost waste is normally disposed in LWMC containers. • LWMC staff is not cooperative and supportive to use containers for waste disposal. • The disposal of waste in containers normally generates conflict between both of them. Therefore, to avoid conflict waste is normally disposed secretly.	• Lack of cooperation and satisfaction among locals towards the role of LWMC. • Involvement of informal scavengers. • Disposal of waste by PWC in containers that fills it again which if not removed timely Managers can impose penalties on Supervisor. • Involvement of politicians in the decision-making process, not having proper education and awareness on waste management. • Political pressure that does not allow to impose penalties on persons violating the rules. • Waste disposal outside the containers. • Workers' negligence to work in areas under construction activities. • Workers ignore wearing proper Personal protective equipment (PPE) and therefore suffer from respiratory and skin issues. • Lack of proper regulation. • No latest study is conducted on waste characterisation and generation, thus the data of study conducted in 2014 and own observation are being used. • Several studies were conducted to assess the number of recycling units, but they remained unsuccessful because many units are not registered, and some belong to big mafia groups. • Dependency on the government for funds.

4.4. Major gaps

Based on the existing waste flow pattern and issues mentioned above, the major gaps identified in the system contributing to the health and environmental hazards are shown in Figure 2.

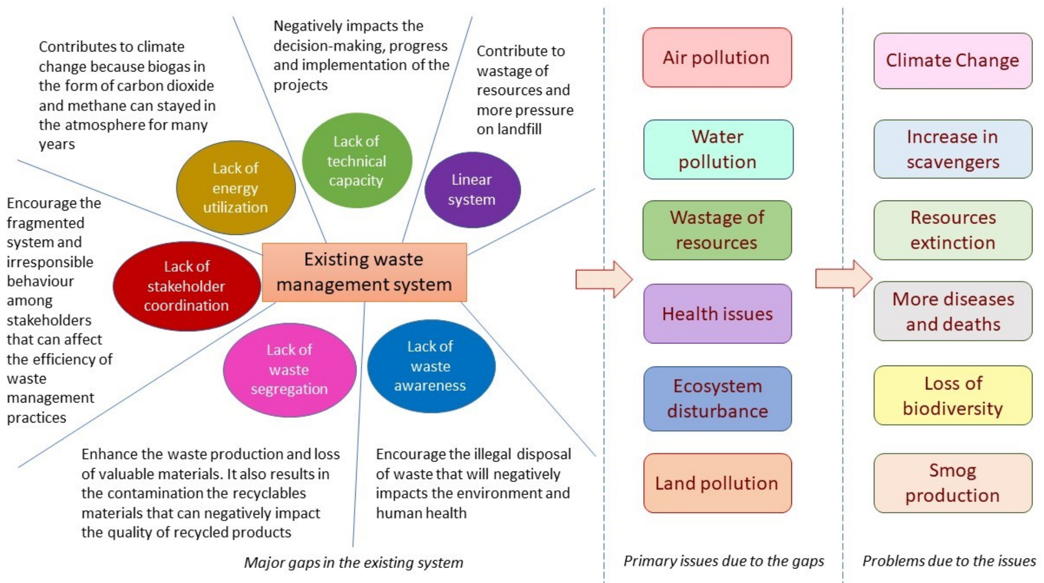

Figure 2: Gaps and associated problems (Nazir 2020)

5.1 SWOT analysis

To avoid the damages occurring due to the current system there is a need to introduce the concept that can contribute to sustainable waste management. The higher rate of organic waste production in the existing system shows CE potential, as depicted in the literature that CE is a relevant principle for biowaste management. Its potential in the existing system was assessed through SWOT analysis which helped to understand the opportunities and factors that can impact CE implementation, as shown in Table 3.

Table 3: SWOT analysis of CE (Nazir 2020)

Strength (S) • Higher percentage of organic waste production in total waste. • Production of methane gas at landfill and willingness of residents to use it as a source of energy and fuel. • Availability of land and labour to operate waste recycling facilities. • Easy transfer of knowledge to educated residents. • Favourable environmental conditions for composting process. • Availability of PWC, waste dealers and informal scavengers who can be used for formal collection and segregation of waste. • Availability of waste recycling industries and LWMC composting plant. • Less environmental impacts of organic compost than synthetic fertilizers. • Willingness of majority of residents for waste segregation. • Access of LWMC to general public through the communication department. • LWMC existing monitoring system for complaints resolution.	**Weakness (W)** • Lack of waste segregation practices which contaminates the overall waste. • Lack of awareness and education of stakeholders on waste management. • No coordination and cooperation of stakeholders. • Absence of proper and relevant laws and regulations. • Lack or research and studies on waste management. • Existing system is linear and fragmented. • Free disposal of waste at any available vacant places, streets and drains. • No penalties on illegal disposal and burning of waste. • Absence of proper infrastructure and network for supply of renewable energy and resources. • Existence of informal units in the system. • No incentives and facilities to promote waste segregation and recycling. • Difficult to change behaviour and habits of some residents. • Lack of database and record keeping.
Opportunity (O) • Waste management is direly needed, and CE can provide cost-effective ways of waste management. • Waste can be used as a fertilizers, fuel and energy production. • LWMC can use technical expertise of Turkey and China for installation of waste treatment and recycling technologies and can produce its own electricity. • Recycling can enhance the revenue generation through more export and less import of products. • Improve the environmental condition and reduce transmission of diseases and health issues. • Reduce the burden on the landfill and accordingly land requirement. • Enhance business and job opportunities in the market. • Reduce wastage of resources. • LWMC can be a pioneer in the country in the field of CE.	**Threats (T)** • CE is a new concept in Pakistan and therefore its acceptability among the stakeholders can be an issue. • Waste management is the most neglected sector in the country. • Availability of government funds to follow and implement CE principle for waste management. • Uncertainties in government decisions and policies. • Rigid attitude of politicians for whom waste is a useless trash. • Corruption and lack of transparency in the system. • Low productivity of organic compost compared to synthetic fertilizers.

5.2 Development of CF

Based on the outcome of the SWOT analysis and example of the BIOREGIO project, the CF based on CE principles was formulated for the existing system, as shown in Figure 3. The process starts with waste sorting at the source in different colour-coded bins which will be collected by the PWC and waste dealers from homes. PWC will collect organic, mixed, and hazardous waste, while the waste dealer will collect the recyclable material. The collected waste from both will be handed over to LWMC, PWC by disposing waste into containers and waste dealer by transporting the waste to the landfill. The waste from containers allocated for different waste types will be collected by different compactors who will unload the waste into trailers for its final transportation to the landfill. The waste at landfill will undergo mechanical sorting to ensure complete segregation of organic, hazardous, RDF, and recyclables fractions. Different waste types will undergo different treatments, for biowaste, it will be diverted to biogas and composting plants where it will be treated to produce biogas and compost respectively. The biogas will be supplied to homes in the form of fuel and electricity, while compost will be used as a soil fertilizer. The landfill in this process is considered as the last option after consideration of all possible measures for material and energy recovery.

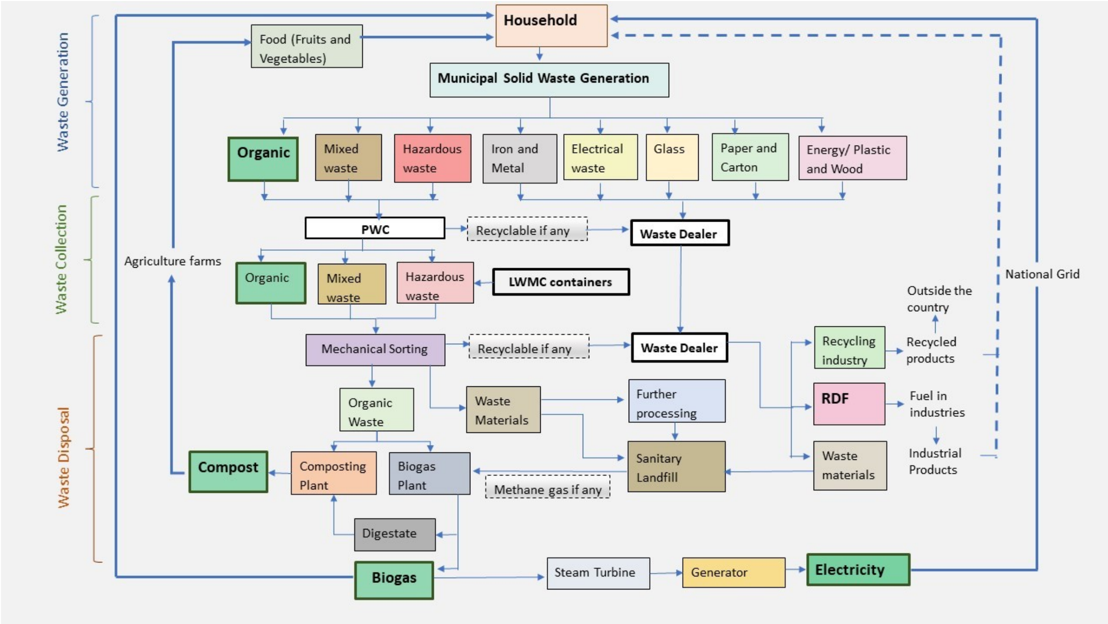

Figure 3: Proposed CF based on CE principles (Nazir 2020)

Apart from managing the waste, the proposed framework will help in meeting the objective of Sustainable Development Goals with several other benefits as illustrated in Figure 4, which show it is environmentally effective, economically affordable, and socially acceptable.

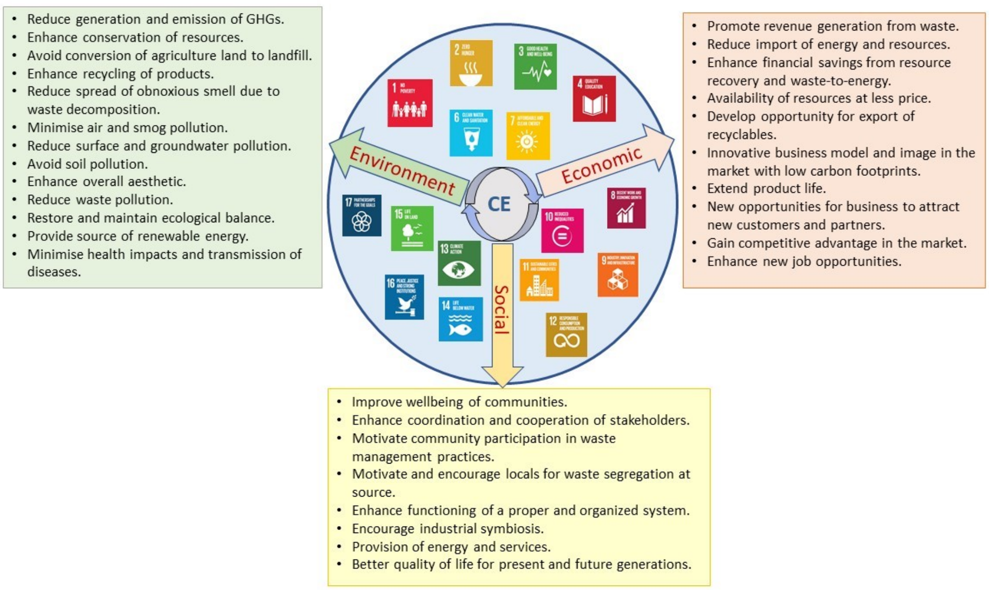

Figure 4: Benefits of proposed CF (Nazir 2020)

5. Implications and Conclusions

The results show besides the continuous efforts of LWMC the SWM is still a problem. Although some improvements have been made in the context of waste collection, but these have not been sufficient to resolve the problem. LWMC current strategy is not effective as it ignores the two important stages such as "waste generation and disposal" without which waste cannot be managed. Waste disposal is considered as a resource-intensive solution, therefore, the cheapest option such as landfill is always preferred by LWMC. The identified gaps further confirm LWMC's inefficiency which is currently being ignored both by the public and the government. The continuation of such practices can cause serious threats to human life and therefore demand the introduction of sustainability in the system. Based on CF that reveals concrete opportunities and benefits of CE in the existing system, the study concluded CE a feasible solution for LWMC to meet the desired objective of sustainable waste management with continuous improvement in its efficiency, as shown in Figure 5.

Figure 5: LWMC efficiency improvement cycle (Nazir 2020)

For the successful implementation of CF and to avail its benefits, it is required to first resolve the existing gaps which otherwise could be barriers and affect the usefulness of CE. The set of recommendations prepared to mitigate the identified gaps is mentioned in Table 4.

Table 4: Stage-wise recommendation for LWMC (Nazir 2020)

Waste Generation	• Enhance the participation of residents in the decision-making process. • Provide incentives and facilities such as different colour-coded bins or bags to encourage waste segregation at the source. • Ensure all residents are familiar with the LWMC complaint redressal system. • Encourage people to use organic waste as compost.
Waste Collection	• Place different containers for different waste types with proper labeling to avoid contamination of waste. • Formalise the involvement of PWC and waste dealers to enhance the waste collection and segregation efficiency. • Ensure the availability of enough workers to clean the area properly and regularly, in the monsoon season as well. • Ensure good conditions, proper size, and enough number of containers keeping in view the amount of waste generation and population density. • Ensure the covering of containers to avoid the direct contact of insects and rain with the waste. • Use of GIS to optimize the position and collection of waste from containers by assigning data to each street and containers.
Waste Disposal	• Encourage mechanical waste sorting and proper classification of waste to enhance waste segregation efficiency. • Discourage the practices of controlled dumping. • Restrict the activities of informal scavengers by making them part of the system. • Proper collection and treatment of leachate. • Ensure regular monitoring of groundwater contamination. • Operationalise the existing LWMC composting plant. • Ban and impose penalties on illegal dumping and burning of waste. • Prohibit the disposal of organic and recyclables in the landfill. • Avoid the emission of landfill gas in the atmosphere by the installation of measures that can promote its collection and efficient utilisation. • Ensure placement of safety signs and boards to avoid any hazards. • Adopt measures to prompt waste-to-energy treatment technologies.
General	• Ensure proper awareness and education of all formal and informal stakeholders through the effective and interactive mode of communication. Ensure all ages of locals are targeted from children to seniors for effective results. • Ensure wearing of proper Personal Protective Equipment by the workers while handling the waste. • Ensure the coordination and cooperation of all stakeholders to enhance waste management efficiency. • Ensure the hiring of relevant and competitive staff to strengthen the technical capacity of the institution. • Formulate and enforce proper laws and regulations on waste segregation, recycling, and management.

The limitations of this study are addressed as implicit recommendations for future research both in terms of theory development and concept validation. First and foremost, this study is limited in scope due to the time limitation and COVID-19 outbreak. Only 10 households were willing for the interview, the larger group of people could provide representative data on waste management issues. Moreover, this study was mainly focused on MSW, future studies on other waste types and areas can provide a holistic view of waste management. The visits to both landfills "Lakhodair and KWC" were cancelled due to COVID-19. In the case of Lakhodair the concerned person was diagnosed with COVID-19 and therefore the relevant information was collected through telephone.

It is the first study conducted on CE in Pakistan, hence more research and studies are needed to further refine and assess the awareness and limitation of CE to promote its practical implementation. The proposed framework model can be replicated for other cities, especially where LWMC's sister companies are working to elaborate its benefits. LWMC is required to conduct annual waste characterisation studies and record-keeping of the data, which will help it in better planning and management of the waste. This study is useful for waste management professionals and researchers to understand how circular models are constructed and will help them in the setting of priorities and formulation of policies.

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Circularity in cities: the socio-spatial dimension of the circular economy as a step towards climate-sensitive urban planning

A case study of Glasgow, United Kingdom

Carlos E. Soto Nieto

Abstract

The contribution of urbanization to resource consumption, environmental degradation and climate change is a reminder of the need of stronger mitigation and adaptation approaches. This has brought a considerable amount of concepts that have emerged under the umbrella of sustainability, resulting in green, smart, resilient, eco-friendly, low-carbon and more recently "Circular" cities. The aim of this research is to contextualise the alignment of the circular economy to socio-spatial issues by leveraging the discussions on the implications of circularity in urban planning and design as a climate-sensitive approach. For that, this dissertation is based on a combination of methods; literature review, interviews and the exploration of Glasgow as a case study amid the "Circular Glasgow" agenda. The spatialisation of variables through GIS techniques is carried and a synthetic view of an urban circularity model is drawn to inform 'where' and 'how' the transition towards a circular city could address aspects such as urban resource management, regeneration, stakeholder's cohesion and wellbeing. This work resulted in the identification of socio-spatial variables/stocks in the city of Glasgow, seen as a multi-variable resource mine with challenges, opportunities and examples not only to pilot but to scale up circular initiatives from the spatial planning perspective. Finally, this thesis contributes to the discussion and invites to further research that should benefit the understanding of both socio-spatial and climate-sensitive aspects associated to the circular economy in cities.

1. Introduction

Climate change has been widely studied, its relationship with cities and the consequences for both natural and urban environments have been the focus of many research lines worldwide. However, the connections between climate change and the consumption patterns for sustaining functionally and physically the current urban settings are not always aligned with the strategies that cities are implementing for becoming environmentally friendlier while tackling social and economic issues. Sometimes it is because of the lack of understanding between the different agendas under the umbrella of sustainability and the frictions between spatial and economic planning.

The Circular Economy concept has gained ground in the last decade, and as many of the concepts adopted in sustainability studies, it has a blended origin in between economics and ecology. Hence, its relevance as an approach to shape the climate-sensitive route of organisations and cities lies in its links with a resource-led system thinking and the ecologic idea of 'feedback' proposed by other concepts related to looping cycles (Geissdoerfer et al. 2017) which suggest a switch to the way resources and material consumption and production are understood as part of a living metabolism rather than a mechanism (Wolman 1965). The CE represents the latest framework adopted by the business sector to achieve a better alignment with a sustainable development, by transitioning from a 'consumption to disposal' linear model to a circular one, reducing and rethinking waste (European Investment Bank 2019). However, as happens with many emerging concepts that sometimes seem to pursue fashionable conceptual ideas that have little success in their actual application (Savini 2019), what circularity means for cities aside the economic, natural resources and waste management perspective is still under exploration (Korhonen et al. 2018a; De Vita et al. 2019;

Paiho et al. 2020). Could it be a framework to improve the way local authorities execute/manage urban assets, projects, services and facilities in cities? If so, how and where this circularity might happen?

Glasgow has recently given some steps towards becoming a circular city, as a case study it has the potential to illustrate the linkages between circularity, spatial planning and engagement as it is a city where urban regeneration has deep roots in its narrative, which some studies have associated to an ongoing dialogue between health issues and urban dereliction (Maantay & Maroko 2015) as well as its local economies (Macdonald et al. 2018).

<u>1.1 Aim and objectives</u>

The aim of this research is to contextualise the alignment of the circular economy to socio-spatial issues relevant to the sustainable planning of cities, taking Glasgow as a case study amid the "Circular Glasgow" agenda, so that the spatialisation of variables can inform where and how the transition towards a circular city could be seen as an opportunity to address some of the key aspects of post-industrial settings: urban resources management, regeneration, stakeholder's cohesion and wellbeing. To achieve this, the following objectives give direction and milestones in two phases; (1) a conceptual understanding and a (2) local case study; the first representing a review of literature and a tailored benchmarking of local policies and plans that is later used to feed an urban circularity model from a local perspective.

Specific objectives for the conceptual understanding

- Review and identify the theoretical framework and knowledge needs to cover the gaps of circularity in terms of its application to the urban scale.
- Synthetise the key elements of a circular city model.

Specific objectives for the case study

- Identify local plans, projects and initiatives framed in the sustainability and climate agenda of Glasgow to connect their relations with circularity.
- Spatialise (when possible) a set of key variables for circularity in Glasgow.
- Explore the strategic potentialities of circularity in Glasgow at the city and neighbourhood level, from an urban planning/design perspective (urban services, facilities, regeneration, participation).

2. Background

<u>2.1 The context</u>
We live in a world increasingly urban; 3 million people are moving to urban areas every week (IOM 2015) and even though cities occupy about 2% of the land area, it is where half of the world population lives. It is well known that cities generate about 85% of global GDP, while consuming 75% of global resources, emitting around the same percentage of global energy-related greenhouse gas emissions (UN 2019). Circa 50% of all waste is generated in cities and this is expected to increase by 70% over the next 30 years (Enel 2019) unless radical reversal actions are put in force.

<u>2.2 Circular Economy and Urban Metabolism</u>
The traditional economy, also referred in academic literature as 'Linear Economy', follows a "Take – Make – waste" flow. This manner of economic development ruled and increased since industrial revolution, but more recent evidences and trends are the baseline for scientific papers on the needed transition into more efficient ways of consumption and production. By definition, the Circular Economy (CE) see stocks and flows of resources and materials through

the lens of a living metabolism (Ellen Macarthur Foundation 2013). Geissdoerfer et al. (2017) points out that contemporary definitions of CE and its practical applications incorporate different features and contributions from a variety of previous concepts and disciplines including and not limited to industrial ecology, regenerative design and cradle to cradle. Moreover, the understanding of urban metabolism (UM) requires to be deepened in how we look at material flows (Bahers et al. 2018) and life cycle approaches (Maranghi et al. 2020; Butt et al. 2020; Petit-Boix et al. 2017) in order to embed this kind of systems--thinking into sustainable ideas of urban environments. An urban metabolism is 'the total sum of the technical and socioeconomic processes that occur in cities, resulting in growth, production of energy, and waste.' (Kennedy et al. 2007, p44, as cited in Prendeville et al. 2018). This means that UM is a descriptive concept, not a prescriptive one as the circular economy or circular metabolism.

Previous research identified gaps when linking social-temporal processes and spatial attributes to comprehend the multi-scaled relationship between buildings forms and energy use, or local food production and waste management and climate comfort to produce a comprehensive ground for the metabolism in cities (Palme & Salvati 2020) also recognising missing links between UM analyses and the execution of real-world design solutions for integrating urban planning and urban ecology (Perrotti 2020). Thus, while the potential of seeing cities through the lens of a circularity to support urban design, planning and policy development is supported in scientific literature, its practical implementation is so far limited to the resource efficiency of economic/business activities (Musango et al. 2017).

Feedbacks between definitions of CE and Sustainability as a paradigm are complex to identify through scientific papers only (Kirchherr et al. 2017, Geissdoerfer et al. 2017, Shemirani & Moztarzadeh 2013), so the contributions of documents and reports from the industry should be also considered, as scientific research moves slower than the practitioner's community (Korhonen et al. 2018a; 2018b). For instance, Williams (2019a) proposes an alternative for understanding circular cities based on the RESOLVE framework by the Ellen Macarthur Foundation, her paper makes a critical appraisal on how the principles of the circular economy need to be adapted if applied to the urban context, beyond the economic settings. In her work, done in the Circular Cities Hub at UCL, she conducted a workshop-based research identifying barriers and challenges for deploying circularity in cities (Williams 2019b).

Other studies offer characterisations of CE for urban areas (Marin & De Meulder 2018) but do not propose a specific visualisation of scales/scopes for a circular city, something that is partially covered by Paiho et al. (2020) when addressing the enablers and scenarios as key aspects of the concept. Similar works build understanding on how the circular economy translates to urban governance and territories by exploring methods (Obersteg et al. 2019: Amenta et al. 2019, Bristow & Mohareb 2019), tools and technologies (Arciniegas et al. 2019) to reinforce the urban application of the CE, but these are still lacking contribution in terms of alignment and readability for urban planners, practitioners and decision-makers.

3. Method

This study follows a cross-sectional and pragmatic approach, presenting both qualitative and quantitative methods that best suit each milestone of the research. The design of the research is comparative-descriptive with an exploratory perspective, since it was based on the review of different sources of information to identify alignments, describe findings and suggest further steps. In order to answer the investigative questions of this work, the methods were grouped in two phases; (1) Understanding and (2) Localising. Each of them with data collection and analysis tools; namely literature review, semi-structured interviews with key stakeholders, content and thematic analysis through diagrams, tables and mapping to visualise and compile findings.

3.1 Phase 1: Understanding urban circularity

This phase is centered on the review and synthesis of theoretical information and professional reports on (A) the theories and concepts in which circular economy is inserted, to later (B) identify key information on the urban implications of circularity to (C) come up with a comprehensive and visual understanding of the circular city model according to the key elements of circularity.

3.2 Phase 2: Localising urban circularity

With an emphasis on the case study, this phase aims to (A) understand the connections and alignment of local initiatives and agendas directly and/or indirectly pursuing sustainable and circular solutions and the views from stakeholders on circular economy in cities for later (B) selecting and interpreting sample data as inputs for the spatialisation of variables to illustrate the potential of urban circularity from a socio-spatial perspective and finally (C) describe examples of certain planning components that function as levers of urban circularity.

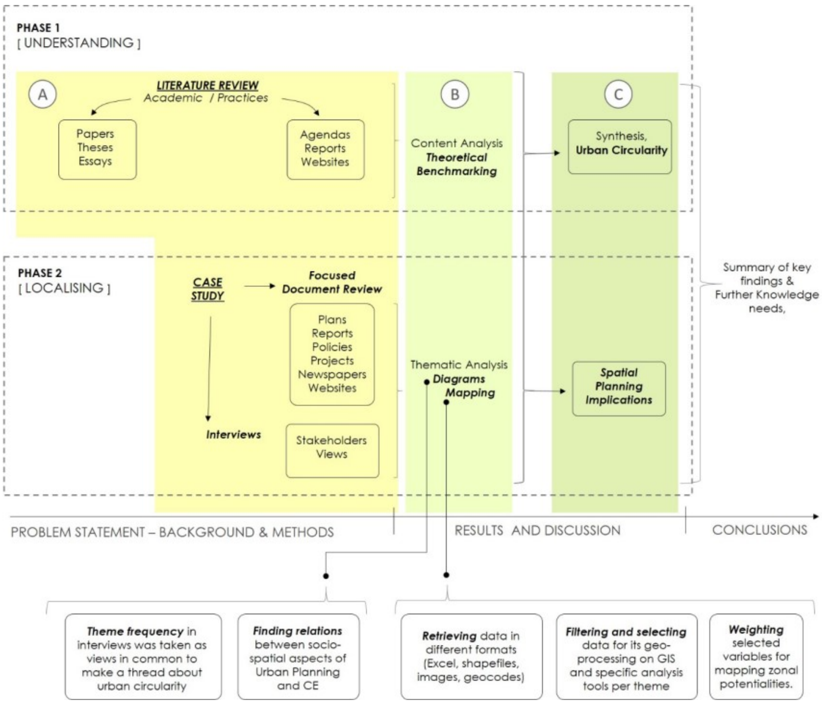


Figure 1: Diagram of the structure of the research (Soto-Nieto 2020)

For the literature review process, the documents were found by carrying an online scanning through academic search engines using sentences combining the three main topics of this dissertation i.e. circular economy, urban planning and climate action. Report and policies for the case study were retrieved from official websites. For the sampling of interviewees, the selection was done according to the knowledge required from the participants, starting with the stakeholders directly involved with the Circular Glasgow agenda and organisations that were connected with the urban practice of Glasgow. Finally, for the mapping, a total of 10 sets of maps were generated according to key urban layers/systems. The data was collected from multiple sources; digital platforms such as EDINA Digimap/Ordnance Survey and Geomni, official reports and planning documents and open sources such as the UBDC (Urban Big Data

Centre) along with the own processing and spatialisation of secondary records and excel spreadsheets. Some maps are descriptive, made by arranging and overlaying thematic data on ArcGIS to draw comparative results, whereas other maps required a more structured analysis to come up with the results (Map Algebra, Intersections, Spatial Joints and a final Weighted Overlay of selected variables). The main streams of data and general processes are shown in the Figure 2.

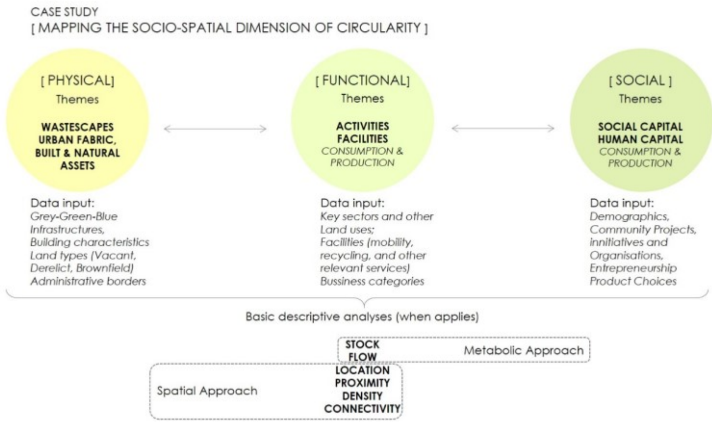


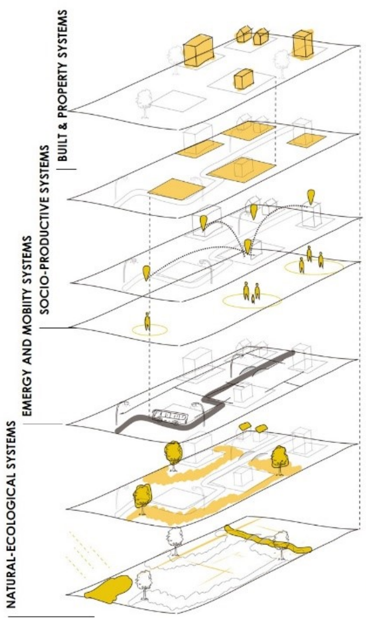
Figure 2: Thematic streams of data (Soto-Nieto 2020)

4. Results

<u>4.1 Schematisation of urban circularity</u>

To visualise urban circularity, it was important to define what resources and systems were relevant to impulse circularity in cities. Thus, as a way of summary of findings from literature and own adaptations, The Table 1 sets a perspective on the approach to 'circular' metabolism taking into account the dynamics that form part of the urban systems.

Table 1: The urban systems through the lens of circularity (Soto-Nieto 2020)



Traditional lens	Circularity lens
Real state market, Land use and value, Development Planning and Management (Building regulations), social and economic offer and demand of urban activities (housing, local economies, facilities...)	Building and their material content (Stock for urban mining), Life cycle of buildings physically and functionally (Flow) flexible design, resource-efficient buildings. Temporary or Long term land use and availability and use (Stock and Flow - SnF)
Actors: Academy, NGOs, Government, Businesses, their interactions/networks and needs, their products and services	Actors: Academy, NGOs, Government, Businesses, circular procurement, consumption and production patterns, localisation.
Citizens: demographics and their needs, community-led projects, social participation, well-being.	Citizens: individual behaviour, household consumption choices, entrepreneurship, community-led circular initiatives, services over goods.
Grey infrastructure: Road Network, Gas and Electricity Pipelines, Transport, Internet and other networks that satisfy social and economic demand of urban activities. Waste management.	Grey infrastructure: Road Network, Gas and Electricity Pipelines (Material content, supply and sources of energy), Transport, Internet and deployment of modes that support symbiosis. Waste looping.
Natural environment normally seen as positive for the well-being and with demands of conservation and sustainable management for ecosystem preservation, nature seen as separate from urban, regulations mostly present in suburban areas or the outskirt of the city (green belts) but rarely or slightly seen as assets that are part of the infrastructure in the inner city	Green infrastructure (SnF): Urban greenery/forestry, timber and food production, NBS for mitigation, carbon sequestration and other ecosystem services, urban biodiversity and means towards bio-regeneration. Blue infrastructure (SnF): Water surfaces, sustainable drainages and other structures for water harvesting and management towards bio-regeneration.

The Ellen MacArthur Foundation (2013, 2017) is one of the principal promoters of the CE in the UK and Europe. However, after reviewing other frameworks and guidelines from selected organisations (public-private); a set of key strategic elements for the transition were identified by frequency, similarity and relevance. The application of these principles in urban areas was screened on the basis of the formulation of actions involving urban components (Table 2). The actions of optimisation, looping and adaptation were identified as pillars of circularity in cities.

Table 2: Circular economy elements and urban planning components (Soto-Nieto 2020)

			P1	P2	P3	P4	P5	P6
CIRCULAR APPROACH	Bioregeneration	Aiming to recover resources to the biosphere, reclaim, retain, restore natural ecosystems, wastewater, energy, carbon and other natural resources through conversion, digestion and treatment, considering cost/benefit accounting.	H	M	H	L	M	L
	Functional Dematerialisation	Enabling collective sharing of info and assets through the use of both physical and digital platforms. Promote direct and indirect dematerialisation of products by focusing on the commercialisation of services over products and turning traditional procedures into paperless, remote-basis, data-led etc. when convenient.	L	M	H	H	M	H
	Optimisation	Increasing performance and efficiency by using better and cleaner technology. Consider predictive actions for maintenance and the extension of the life. From conception and design stages to the improvement of procedures/regulations (e.g. building codes, incentives) that accompany/encourage such efforts.	M	H	H	H	H	L
	Looping and Adaptation	Keep components, materials and resources (except emergy-related which are covered in bio-regeneration) in a closed loop, both physically (e.g. dismantling and using components) and functionally (e.g. changing and adapting use). Recycling, reusing, repurposing, repairing, remanufacturing and refurbishing against underutilisation.	M	H	H	H	H	M
	Localisation	Reinforcing local systems of services, flows and activities (e.g. supply chains) to leverage symbiosis and foster a manageable urban metabolism by localising and spatialising the stock and flows to inform decision-making.	L	M	H	H	M	L
	Colaboration	Incentivising synergies between actors, not all the initiatives need to come from the government, exchange of knowledge and grassroots projects are key catalysts. Also, collaboration can be seen in a large scale (the connections inter-systems i.e. neighbouring cities and regions) and micro-level (the behavioural changes).	L	L	M	H	H	H

L: Low M: Medium H: High

P1: Planet P2: Places — ENVIRONMENT; P3 Prosperity — ECONOMY; P4: Private P5: Public P6: People — SOCIAL

Level of correspondence between the strategic elements of the circular economy and sustainable urban planning components

4.2 Planning the circularity of Glasgow

Following the creation of the *Sustainable Glasgow* group in 2010 as a permanent partnership, Glasgow's urban and strategic planning was led into greener approaches that covered some aspects of the circular economy. Although not all the local projects, plans and/or strategies that have emerged during the period 2010-2020 are labelled as 'sustainable' or 'circular', the results from a cross-sectional matrix of connections between these initiatives and the key strategic elements of circularity previously defined (Table 3) showed that some of Glasgow's efforts have been supporting 'Collaboration' and 'Optimisation' actions, with 'Localisation' also having a significant presence within urban and upper-level policies. Most of these initiatives are related to visions and projects aiming to the local production of energy and the use of technologies as it is evidenced in the content of the *Energy and Carbon Masterplan (2014), The Resilient Glasgow Strategy (2014)* and the *Economic Strategy 2016-2023* - which explicitly considers circular economy as part of its scope - and most recently, examples such as the *Zero Carbon Communities Programme (2019)* and the *Glasgow City of Science and Innovation*

(2020-2023) which aims to foster knowledge transfer, new practices in manufacturing and low carbon technologies.

Although there are plans like the *Air Quality Action Plan 2009-2019* that sets some zero-carbon zones where car and bike sharing schemes are promoted or the *Digital Glasgow Strategy (2020)* that encourages big data, remote working and other advantages of virtualisation, lower attention was found for 'Functional dematerialisation', as fewer initiatives were identified in support of this transitional element that is focused on sharing economies, digitalisation and service over products to reduce consumption and waste generation.

On a similar note, for 'Looping and Adaptation' of urban resources, although partially present in older initiatives such as *Stalled Spaces (2011);* which promotes the interim use of available spaces for community entrepreneurship, these kind of projects might be reinforced by the brand new *Property and Land Strategy (2019-2029);* which will guide a better use of the land and built assets in the city. Similarly, an increasing attention towards 'looping' initiatives can be noticed in the recent *Recycling and Renewable Energy Centre (GRREC)* fully operating since 2019 with a section that covers energy from waste production. The updated editions of previous plans like the *City Centre Living Strategy and Vision for 2035*, mentions the circular economy concept but it requires more practicability and an actionable definition of the way it addresses the built environment, as the city is wasting a lot of resources, especially in the construction sector, according to the interviews.

Table 3: Mapping the local planning initiatives of Glasgow against sustainability and circular economy elements (Soto-Nieto 2020)

NAME OF THE INITIATIVE (LEVERS)	TYPE	SUSTAINABLE DEVELOPMENT ASPECTS				STRATEGIC ELEMENTS FOR THE TRANSITION TO CE					
		People (Wellbeing)	**Prosperity** (Economy/ Growth)	**Planet** (Nature/ Resources)	**Places** (Built Environment/ Infrastructure)	Bio-Regeneration	Functional Dematerialisation	Optimisation	Looping & Adaptation	Localisation	Collaboration
Sustainable Glasgow Board, Since 2010 -ongoing	Board/Parttnership	●	●	●	●	As a aboard it promotes projects and plan on a broad range of aspects					
Air Quality Action Plan 2009 - 2019	Plan/Reports	○		●	○		High	Medium		Low	
Stalled Spaces since 2011 - ongoing / Spaces for Growth	Project/Programme	●	○	○	●	Low	Low		High	Medium	High
Open Data Glasgow	Website/Plaform	○		○	○		Medium	Low			Medium
Understanding Glasgow 2011 - Glasgow Indicators Project	Website/Plaform	●	○	●	○		Medium	Medium		Low	High
Energy and Carbon Masterplan (ECM) 2014	Master Plan	○		●	●	High		High	Medium	High	Medium
Carbon Management Plan, Phase two 2013-2021	Management Plan		○	●	●	High		High	Medium	Low	Low
i Tree Glasgow 2013	Research/Project	○		●	○	Medium				Medium	
Future City Glasgow and Open Glasgow 2013-2018	Project	●	○		●		Medium			Low	High
Resilient Glasgow City Strategy and Framerwork 2014 - ongoing	Framework/Strategy	●	●	○	●		Low	High	Medium	High	High
Waste Strategy Action Plan 2015-2020	Plan/Actions	○		●	●			Medium	Low	Low	Medium
Glasgow City Centre Strategy Action Plan 2014-2019	Strategy/Action	○	○	○	●		Medium	Medium	Low	High	High
Economic Strategy 2016-2023 and Leadership Board	Strategy/ Board	●	●	○	○	Medium	Medium	High	Low	Medium	High
City Development Plan 2017 - ongoing	Plan/Policies	●	●	●	●	High	Low	High	Medium	Medium	High
Strategic Development Plan 2017 - ongoing	Plan/Policies	●	●	●	●	Medium		Medium	Low	Low	High
Connectiong Nature 2017-2022	Project	●		●	●	High		Medium	Medium	Low	Medium
Community Action Plan 2018-2020	Action Plan	●	●		○			Low		High	High
Local Biodiversity Action Plan 2017-2027	Action Plan			●	○	High					Low
Strategic Plan for Cycling 2016-2025	Strategy/Action	○		○	●		Low	Low		Low	High
Housing Strategy 2017-2022	Strategy	●	○		●	Low		Medium		Medium	Medium
Circular Glasgow 2016 - ongoing	Partnership/Agenda	●	●	○	○	medium	Low	High	High	medium	High
Recycling and Renewable Energy Centre (GRREC) 2019 -	Project/Facility		○	○	●	High		Medium	High		
Climate Emergency Working Group 2019 - ongoing	Board/Partnership	○	○	●	○	As group it promotes projects and plan on a broad range of aspects					
Zero Carbon Communities (ZCC) Glasgow 2019-ongoing	Project/Programme	○		●	○	High	Medium	High		Medium	Medium
ParkPower (National Project with city-level Data) 2020	Project	○		●	●	High		High	Medium	High	Medium
Glasgow City of Science and Innovation 2020-2023	Programme	●	●	○	○	Medium	Medium	High	Medium	High	High
Property and Land Strategy 2019-2029	Policy		●	○	●			Medium	High	Low	
Vacant and Derelict Assets Plan 2019-2029	Policy	○	●	○	●				High	Low	Medium
City Centre Living Strategy Vision 2020-2035	Vision/Strategy	●		●	●	Low	Low	High	High	High	High
Digital Glasgow Strategy 2020 - ongoing	Project	●	●	○	○		High	High			High
Open Space Strategy 2020	General Strategy	●		●	●	High		Medium	Medium	High	High

Connection with circularity: Low | Medium | High

Direct ●
Indirect ○

4.3 Stakeholders views

According to the interviews, the understanding of the CE concept in Glasgow is primarily based on the scope of waste and recycling strategies as seen from the lens of the applied resource management in industry (with an emphasis on the construction and manufacturing sectors) and the business/retail sectors, as they present opportunities for scaling up processes towards improved business models with an impact on behaviour, which some interviewees also related to 'financial benefits' and progressive positive 'structural changes' of urban activities. However, issues regarding the understanding of and engaging with the circular agenda were raised amid the 'blindness' or 'fuzziness' caused by the diversity of labelled 'sustainable' approaches.

When asked about the processes to scale up the structural changes required, most respondents highlighted that incentives were on top and some rhetoric questions such as 'What is the motivation for sharing instead of owning? And others related to the barriers for engaging multi-agency actors were raised by the interviewees. Secondly, the regulations, monitoring and disclosing processes were found to be relevant for the CE as '*a transition needs to be measured and controlled in order to succeed'*. Other stakeholders mentioned the importance of having funding and proper collaboration for research and knowledge transfer, not only with partners but with other sectors of the community for further engagement. The Figure 3 shows a thematic summary of responses, highlighting the most common key words.

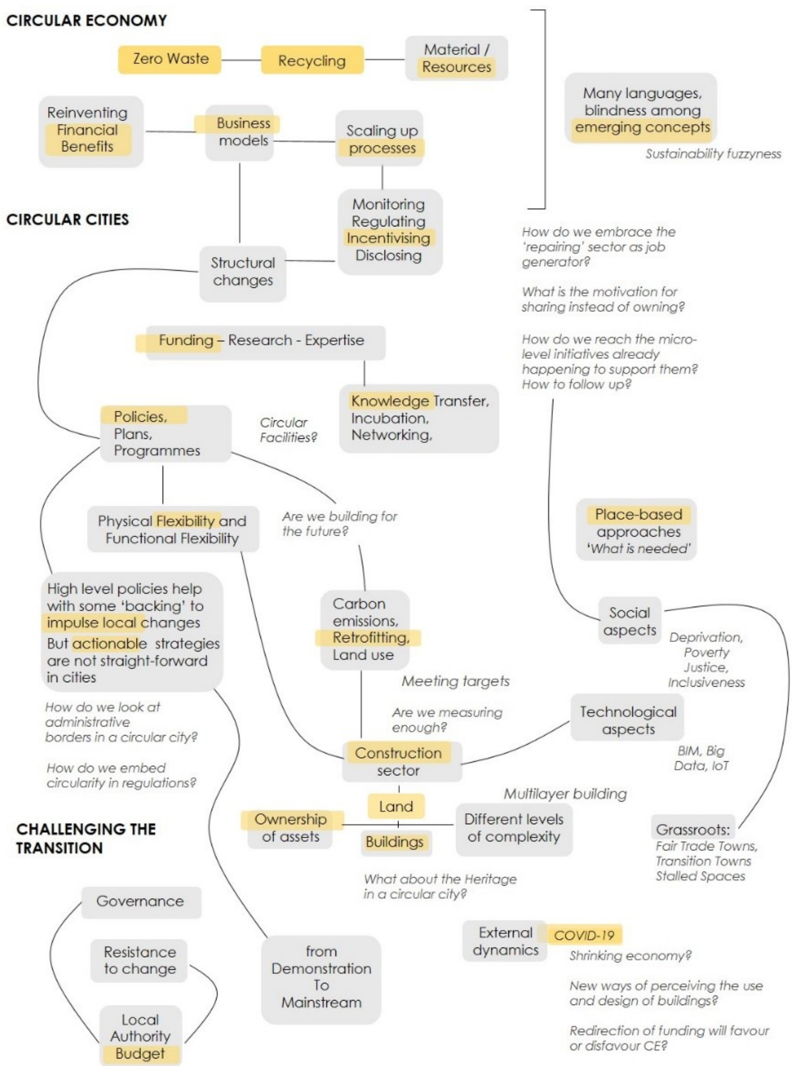


Figure 3: Thematic diagram of interviews with key stakeholders in Glasgow (Soto-Nieto 2020)

The most important levers to bring CE to cities, as acknowledged by almost all the interviewees, were the policies and plans, stressing the relevance of those dedicated to the built environment, calling for changes in the construction sector and the planning/design approach into a more 'flexible' one, both physically and functionally. '*Are we building for the future?*' said one of the stakeholders from the private sector, as a reference on how the construction is currently being managed not only in Glasgow but in other cities of the UK, citing cases where '*It is too easy to demolish*' without managing waste and other embodied impacts. Whereas one respondent from the Circular Glasgow team on behalf of the City Council added that '*the amount of material lost is significant in Glasgow*' and the way the built environment is managed has an influence on it, something that can be solved by '*collaborating with* developers *to share data and resources*' and let the local authority act as an '*administrator to match up material needs and requests'*.

As an advantage for the implementation of the CE in Glasgow it was stated that there is some sort of 'backing' from the national level of government in promoting a circular economy. Scotland has a national strategy and the local authorities are following the example. The interviewee from Zero Waste Scotland ZWS also mentioned that apart from Glasgow, Edinburgh and other cities are part of different programmes, ZWS offers support through funding and knowledge-based guidance, but '*sometimes the challenge comes when trying to connect and let stakeholders know'* about what they offer and that slows down the process of taking demonstrations from particular groups to the mainstream, because of the limitations in terms of synergy, budget, political will, governance and resistance to change from certain sectors.

Finally, some external factors or threats were acknowledged, emphasising the latest pandemic (COVID-19) and how this situation could interfere in the process of adopting not only the circular but other agendas; the re-direction of funding, and the uncertainty about a healthy economy amid an upcoming recession.

<u>4.4 Spatialising the stocks of resources</u>

As an exercise, the work conducted for the thesis included the analysis of the spatial distribution of several variables across the city (Figure 4), but for this article some key findings can be highlighted as follows: It was estimated that Glasgow has around 48,9 million tonnes of materials in the building stock sampled (90% of the buildings in the city). The City Centre, some parts of the West End (Hillhead, Woodlands, Hyndland, Partick East, Dowanhill) and the Southside (Langside and Battlefield) concentrate the highest amount of material that could be mined in the future. The City Centre alone has approximately 7 million tonnes of material in buildings (14,3% of the total) with up to 430 thousand tonnes of material per each 9 hectares of urban surface (the size of the grid used for the analysis). Steel and glass are more prominent in the City Centre, whereas copper and aluminium are clustered around.

Glasgow City has a well-known amount of wastescapes, 9% of the vacant and derelict land of Scotland is in Glasgow, the largest area among the local authorities with 954 hectares declared in 2019 (Scottish Government 2019), which according to the latest register available and used for this project: Ordnance Survey from January 2020, ascends to 1007 hectares, with 460 hectares (45.6% of the total) being of public property. These wastescapes are scattered all around the city.

The number of non-residential buildings in the city that were found to be vacant, derelict and/or at risk, reaches 440 units. But, in a recent report of Glasgow City Heritage Trust it was identified around 2,600 long-term empty homes in 2018 and circa 1,000 empty commercial and industrial premises in Glasgow. Similarly, the 'Dross from infrastructures', which mostly accompanies highways and junctions do not provide an actual use or service, and represents around 828 hectares of areas that could be used for a more productive purpose. Some of this Dross is categorised as 'Green Corridors' in the OS Green Space maps, but in practice they are mostly underutilised grassland. Most wastescapes are located to the centre-north. Opposite to this, around 100 initiatives have made interim use of vacant land and there are successful cases of repurposed buildings into versatile and productive uses, 18 examples were identified and mapped/overlaid together to get an idea of the activation and de-activation dynamics of these assets, with hot-spots around the central area.

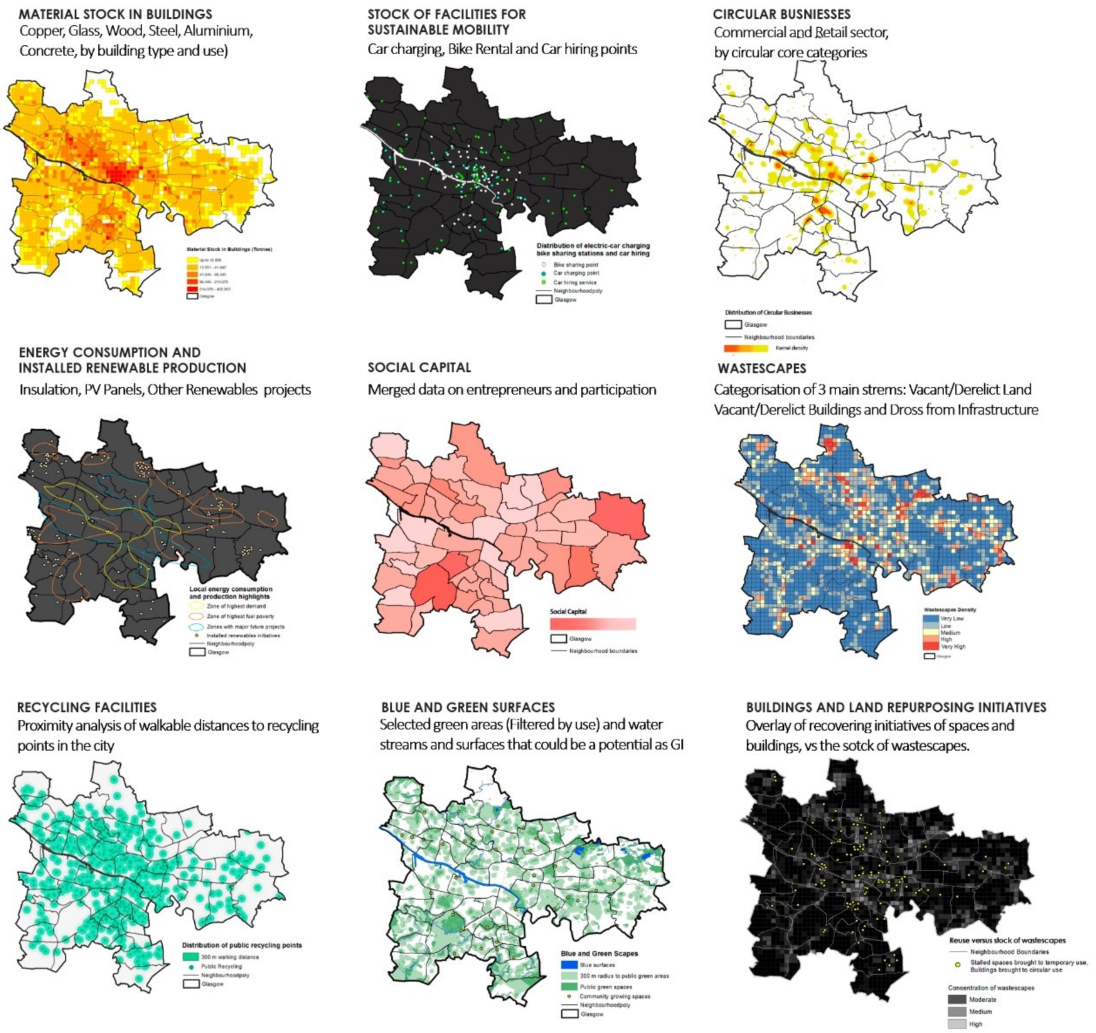


Figure 4: Themed mapping of selected variables/stocks (Soto-Nieto 2020)

Glasgow has a total of 12,845 registered commercial services and retails of which only 5.9% percent could be considered circular according to selected core categories that were identified out from the last update of 'Point of Interest' from Ordnance Survey by March 2020. Similarly, apart from circular businesses in the retail sector, it was found in secondary sources that in terms of circular jobs; 21,000 out of 375,000 jobs (6%) account with activities involving repair, leasing, and waste management in the manufacturing, digital technology, engineering, design and creative industries. Within the quota of 6% of 'circular jobs', 37% follow core circular strategies, whereas the rest of 63% are classified as enablers and indirectly circular (Circle Economy 2018).

Other variables were estimated using secondary information, for instance, information on participation, car ownership, natural assets, energy use and future projects was retrieved from technical reports. After mapping all the variables for which data was reliable, a selection of metrics was considered for illustrating the zonal potential of Glasgow in terms of the presence of a group of practices that might contribute to urban circularity. The map in Figure 5 portrays it at the city and neighbourhood levels, based on the weighting of variables such as proximity to facilities for recycling, Wi-Fi hotspots, location of community halls, growing spaces, public/equipped green areas, among others features within walkable distances and the presence/density of wastescapes, repurposing initiatives, allocated spaces for pedestrians in the streetscape, digitally crowdsourced data on litter reports, installed renewables, circular businesses (17 variables in total were weighted, re-classified in thresholds and pointed).

The areas of Calton, Bridgeton, Hilldhead, Woodlands, Ruchill and PossilPark obtained the highest mean score for their circularity zonal statistics, followed by areas around the centre and south of the city. It is important to mention that the highest mean scores obtained for all the neighbourhoods were still medium to low scores (circa 2 points out of a maximum of 4 points). Thus, the contribution of the selected variables to the potential circularity at the neighbourhood level is still very low overall.

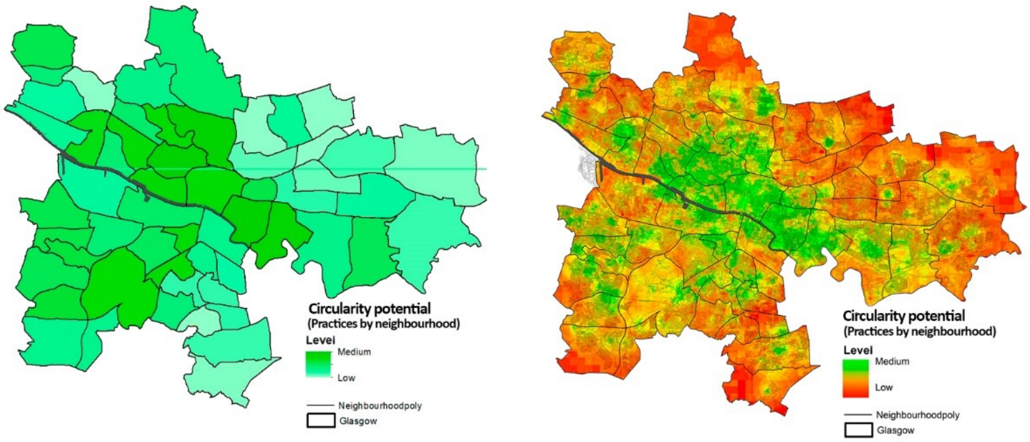


Figure 5: Themed mapping of selected variables/stocks (Soto-Nieto 2020)

In the original document of this thesis (Soto-Nieto 2020) it is shown in detail the multi-layered analysis and also draws a compendium of levers, pilots and monitoring metrics per themed areas that might be further evaluated towards establishing a proper measurement of urban circularity in cities.The mapping carried, for the scope of this thesis work, was limited to a mapping exercise to understand the geographies and implications of the socio-spatial dimension of the circular economy in cities.

5. Implications and conclusions

The circular economy is a developing concept that has received increasing contributions from both academia and practitioners in the last 10 years, evolving into a multi-sector and system level approach. Circular cities are a recent application of this concept which has gained more exposure in the industry/practice than the academic contributions; with international organisations guiding the knowledge transfer and demonstrations and an increasing amount of cities self-defining and promoting circular action. Therefore, urban circularity is a dynamic and contextualised concept that varies according to local realities, local economies and the characteristics of the urban settings where this is implemented.

The idea of urban circularity is not dissociated from urban sustainability, the first contributes to the latter but in a more specialised and tailored way, focusing on the resources (natural+urban) a city uses to sustain its settings. Whilst a sustainable city remains as an umbrella concept from which other concepts emerge, a circular city is a more practical and grounded model that incorporates aspects of sustainability, offering a vision for climate-sensitive planning aiming to a better response to the global resources crisis by tackling context-led strategic processes in cities regarding production and consumption. However, the diversity of concepts and labels that we have nowadays was found to be perceived as a barrier to communicate and spread the understanding of the circular agenda as one aligned with - and not in substitution of - the sustainable agenda.

There is a fair diversity of frameworks and principles for the circular economy, with an emphasis on business models and actionable strategies to rethink the procurement and the production of goods and services. Yet, there are many silos for its application in urban areas, a gap that this research work builds on, facilitating the construction of a socio-spatial perspective of the strategic elements of circularity to inform policy making, urban development planning and the design of local regulations and actions.

This work identified basic levers and variables to help policy makers pilot and monitor circular initiatives by weighting the potentialities of urban planning as a driver for circular solutions. This work shows how the lens of urban circularity help to re-define urban settings and the way urban components can be perceived as resources with cycles, stressing an emphasis on 'where' these resources and practices are distributed, especially those affecting the built and infrastructure assets and the socio-productive networks that are at the heart of circular cities. Similarly, it was confirmed that engagement and collaboration are structuring aspects of the circular agenda in Glasgow which relates to how individual choices merge with broader systems.

The premises of a circular city are based on ecological and metabolic cycles: the outputs of one part are the input of another (Figure 6), and this can be transferable not only to the design of future facilities, buildings, industrial parks and neighbourhoods, but also to the planning processes of both intra and interconnections at the city-level for localisation of resources. Multi-scale plans and policies are levers that facilitate circular practices and these practices enhance urban resilience and contribute to sustainability. But there is a recognition of a series of challenges and barriers that depend on long-term changes of the current cultural and normative structures to incentivise and mainstream the circular demonstrations.

Glasgow started its circular journey in 2016 and has been raising awareness within the business and public sectors. Because of its post-shrinking characteristics, the built environment of Glasgow has a high potential to be better re-cycled in a circular way, taking into account aspects related to reutilisation of vacant land for ecosystem services, timber, solar or rainwater harvesting, as well as urban mining of disused buildings for substitution of non-structural elements.

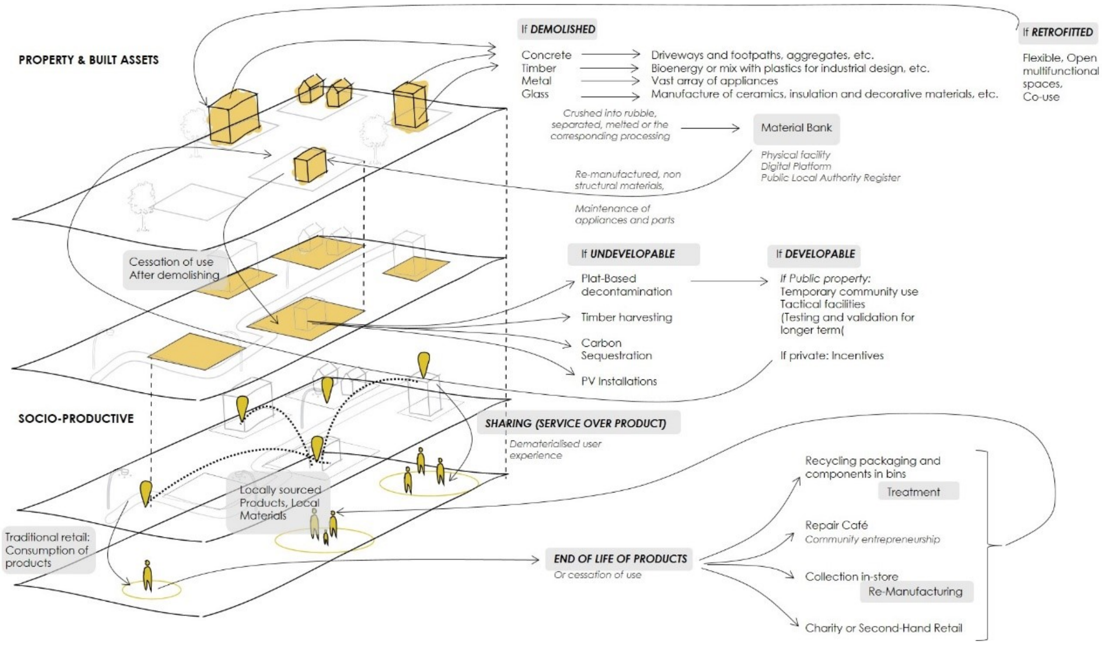


Figure 6: Visualisation of flows associated to circular actions in the property and socio-productive systems of cities (Soto-Nieto 2020)

In terms of the socio-productive system, the local businesses that already rely on circular practices in Glasgow should be leveraged as catalyst agents, and the ones that are harder to turn into circular ways could be engaged to provide basic practices that enable the general transition. Similarly, the local communities and networks that exist, e.g. the urban gardening and permaculture groups, could receive more support to escalate the localisation of certain productive activities, as demonstrators towards a circular society based on initiatives similar to the *Transition Towns* movement. This could have an impact on the kind of social entrepreneurship that will emerge in the future, influencing the path towards a circular city.

Finally, regarding future research, this work identified some suggestions that might take the circularity concept to a broader understanding; an analysis of the urban systems as circular systems with a deeper emphasis on the flow instead of the stock of resources in different contexts is needed. Similarly, the connections between pollution associated to specific urban waste-streams and wastescapes, or the impact of these on the micro-climate of the neighbourhoods and cities can draw other interesting evaluations, as well as the consideration of other variables like the concentration of certain stream of material in the building stock and the spatial distribution of bare soil, vacant land and derelict spaces as potential influencers of a varying local climate, following the premises of Local Climate Zones.

Moreover, the identification of a taxonomy of circular urban activities and land uses e.g. the use of incremental-tactical planning techniques as well as a formal metrics for measuring circularity at different levels need to be better explored, especially in the building sector, towards the evolution of a climate-sensitive planning and design.

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ECOSYSTEM
SERVICES

Re-valuing Canals: Valuation of ecosystem services provided by the Smart Canal project, Glasgow, UK

Ala' Al Dwairi

Abstract

This dissertation aimed to highlight the different roles canals can play in cities by mapping the provision of Ecosystem Services (ES) provided by the Smart Canal project in the north of Glasgow city. Furthermore, ES mapping was performed by adopting a Multi Criteria Decision Analysis using Geographic Information System based on available spatial data for land use and land cover classes combined with other criteria. The results indicated that the Smart Canal area has considerable potential for offering regulating and cultural services in comparison with provisioning services. The highest ES provision was for enhancing water quality and carbon sequestration followed by evaporative cooling. As well, the Canal showed intermediate potential for the delivery of biodiversity. Moreover, the north-western part of the Canal proved to be a 'hotspot' for the delivery of multiple ES, making it a highly sensitive area in need of sustainable planning. Thus, the results of this analysis fortified the role of the Canal as an adaptation tool to face climate change threats as well as its potential for forming an ecological corridor creating a refuge for urban wildlife. The outcome of this analysis can be used as a decision support tool for developments around canal networks in Glasgow city.

1. Introduction

Historically, civilizations thrived near water bodies. Shores, rivers, and lakes shaped the urban form and environment (Galil et al. 2008). Constructing hydrological structures such as canals began as early as 2200 B.C, to be used in navigation, agriculture and flood management (Bandaragoda 1999; Echols and Nassar 2006; Galil et al. 2008).

Scotland aspires to hold status as a hydro nation, responsible for disseminating best practices related to sustainable water management under a changing climate (Muscatelli et al. 2020). The main effects of climate change over Glasgow city include extreme weather, changes in temperature and precipitation, and flooding (Adaptation Sub Committee 2011; Kazmierczak et al. 2015; ClimateXChange 2016; England et al. 2018). The most significant flooding risk in Glasgow city is associated with surface water flooding due to a high percentage of impermeability (caused by the removal of vegetation and building over greenspaces). Therefore, Glasgow city is one of the ten most flood disadvantaged local authorities in the UK (Sayers et al. 2018).

Climate change comes with a high risk towards water based transport and infrastructure (ports, canals), increasing the levels of erosion and silting in waterways, increasing maintenance costs and jeopardizing vulnerable historical structures such as Forth & Clyde canal (England et al. 2018; Scottish Canals 2017). Since reopening and regenerating the Forth & Clyde canal in 2001, the Canal has been in a rebirth phase (McKean and Lennon 2017), where The Millennium Link project aided the restoration of the Forth & Clyde canal status as a cruising canal (Transport Scotland 2013). The North Glasgow Integrated Water Management System (NGIWMS) project came to life in 2013, mainly Glasgow City Council, Scottish Waters and Scottish Canals signed into a sixty-year drainage partnership to deliver infrastructure works aiming to regenerate 260 hectares of North Glasgow area (AECOM 2013; Allan et al. 2016; Robinson 2013). The base of the drainage partnership is to transform a section of the Forth & Clyde canal to become a 'smart canal.' The Smart Canal scheme alters part of the

Forth & Clyde canal to become an innovative drainage solution for surface water management (Brears 2018; Scottish Canals 2018). Basically, in case of heavy rainfall, the canal water level will be automatically lowered to take in extra volumes of water drained through Sustainable Urban Drainage Systems (SUDS) installed within future developments in the NGIWMS area, which drains naturally towards the Canal (AECOM 2013; Robinson 2013). It is evident through the Scottish Canals environment strategy (2015 2025); that SC aims to further fortify the status of the Canal as an indispensable asset to Glasgow's adaptation efforts towards climate change and environmental degradation by tapping into the Canal's value in sustainable water management, supporting biodiversity and environmental protection (Scottish Canals 2015).

Through this dissertation, I aim to answer the following research question: what are the ecosystem services the Smart Canal project can deliver to foster adaptation to climate change threats and create environmental and social benefits within the urban environment?

The answer will be obtained by achieving the following objectives:

- Identify key ecosystem services in the Smart Canal project.
- Map ecosystem services provision.
- Detect synergies and tradeoffs between ecosystem services.
- Define the new role of the Forth & Clyde canal.
- Highlight opportunities for adaptation to climate change threats.

2. Background

The study of the interplay between humans and nature dates back to ancient times (Barr 1972). However, Marsh's research is considered the start of a continuous wave of exploration in the topics of environmental degradation, natural resource depletion, and what role do humans play in it (Lowenthal 2000). Daily's powerful book Nature's Services defines "Ecosystem services as the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life." (Daily 1997). Numerous definitions followed daily's, focused on creating precise and consistent terminology for Ecosystem Services (ES), to have comparable classification systems across different contexts (Wallace 2007).

Multiple ES frameworks were used to evaluate the changes in ecosystems and the consequences of human activities (Leemans and De Groot 2003). Starting with the Millennium Ecosystem Assessment (MA; Leemans and De Groot 2003) in 2001, followed by The Economics of Ecosystem Services and Biodiversity (TEEB) in 2007, focused on estimating the cost of the loss of biodiversity and incorporating the cost of effective conservation into international policy work (Ring et al. 2010). On a national level the UK National Ecosystem Assessment (UK NEA), in 2009 aimed to track and generate data on the status of ES in the UK and to safeguard natural resources for future generations (UK NEA, 2011). The final framework is the Common International Classification of Ecosystem Services (CICES) founded on the works of MA in 2005; this framework focuses on identifying, assessing and accounting for ecosystem services, (CICES, 2013). CICES is ubiquitous in research focused on mapping and management of ES (Czúcz et al. 2018).

Urban ecosystems are defined as "those areas where the built infrastructure covers a large proportion of the land surface, or as those in which people live at high densities" (Pickett et al. 2001). Although cities take up approximately 3% of land's surface, projections indicate that around 68% of the world's population will be living in urban areas by the year 2050 (United Nations 2019). Urbanization is a dominant factor in global land use change driven by population growth and economic development (Pickett et al. 2001). As of 2018, 83.4% of the UK's population live in urban areas (ONS 2019). Urban ecosystems are dependent on other ecosystems located outside the limits of the urban areas, to deliver essential needs (e.g. food, water, materials), and to process the waste created in urban settings (McGranahan et al. 2005). Gómez Baggethun et al. (2013), highlights that urban ecosystems come to exist through a set of interactions between the 'built infrastructure' (i.e. any human made elements in urban areas) with the 'ecological infrastructure' (i.e. water and vegetation in or near the built environment). These interactions take place in all green and blue spaces in urban areas (e.g., parks, cemeteries, gardens, urban allotments, urban forests, single trees, green roofs, wetlands, streams, rivers, lakes, and ponds), and are considered significant because it delivers 'direct' benefits for humans living in cities (EEA 2011).

Urban canals are a perfect example of this interaction between the built and ecological infrastructure, aiding in urban temperature regulation, promoting species biodiversity and providing recreational areas (Middleton et al. 2004; Angold et al. 2006; Žuvela Aloise et al. 2016; McKean et al. 2017).Urban ecosystems are capable of offering essential services and benefits that can positively affect human wellbeing and reduce urban areas' dependence on external ecosystem services (Gómez Baggethun et al. 2013). However, ES provided by the urban environment is still prone to damage due to urbanization, changes in demographic trends, and economic development (Elmqvist et al. 2013). These changes can negatively affect cities by increasing the percentage of impermeable surfaces and pollution, especially in highly dense city centers (Davies et al. 2011). So far, there is not a single inventory directed towards understanding urban ecosystem services potential in the UK; for Scotland, urban ES inventories only exist at an aggregate national scale (Aspinall et al. 2011).

First publications on ES mapping were around 1996, since then mapping ES proliferated corresponding to advances in technology (e.g. GIS and modeling), which fortified the use of ES maps in establishing a connection between ES and the surrounding landscape (Jacobs et al. 2017). ES maps could be used to facilitate sustainability based decision making (Söderman et al. 2012), raise public awareness (Niemelä et al. 2010), serve as a base for ES accounting and assessment (Rocha et al. 2015), minimize the gap between supply and demand (Ashley 2014), illustrate ES bundles (Dittrich et al. 2017), identify tradeoffs and synergies (Fernandez Campo et al. 2017) and recognize ES stakeholders at different spatial scales and time intervals (Jacobs et al. 2017; Syrbe et al. 2017). Urban environments are relatively complicated, and mapping urban ES does not come under a general framework, as each case has its requirements (Martnez Harms and Balvanera 2012). Key ES in cities stems from trees, parks, private and community gardens, urban forests, and urban water bodies (Davies et al. 2011).

Canal systems are considered to be vital but equally sensitive elements of urban ecosystems (McKean et al. 2017). Scotland's canals are an illustration of past and present events, a timeline for the country's history (Canal and River Trust 2015; McKean et al. 2017). In Glasgow, the Forth & Clyde canal serves as a representation of the industrial past of the city, and since its revival as a cruising canal, it provided a destination for local and national recreation (e.g. Falkirk Wheel, paddle sports center, festivals) (Transport Scotland 2013). The historical status of the canals makes its management and development a delicate matter, implementing an ecosystem based management approach is a step in the right direction to understand the Canal's potential to deliver direct benefits for people and to enhance land planning around the canals (Ashley 2014; Scottish Canals 2015). Identifying and mapping ES coming from the Smart Canal project area will help in understanding the new role of the Canal as an adaptable ecological infrastructure, responsible for the delivery of a set of provisioning, regulating and cultural services (EEA 2011; Gómez Baggethun et al. 2013; Maes et al. 2012).

3. Method

The Smart Canal project area was chosen as an example of a complex urban environment with multiple ecosystems, undergoing extensive regeneration work (Brears 2018; Robinson 2013; Scottish Canals 2018). The methodology set forward by Fernandez Campo to analyze and map ES within two Norwegian municipalities represents a practical approach towards mapping and identifying ES in the Smart Canal project area (Fernandez Campo et al. 2017). The approach is easily adaptable, straightforward and can be used as a decision support tool in current and future regeneration/development projects around the Forth & Clyde canal to ensure sustainable management of natural resources (Fernandez Campo et al. 2017).

The first part of the approach focused on producing a list of key ES present in the study area by thoroughly reviewing previous research on ES frameworks (CICES 2013; Leemans and De Groot 2003; Silvis 2012; UK NEA 2011), identifying urban components responsible for delivering ES (Forest Research 2010; EEA 2011; Davies et al. 2011; Gómez Baggethun et al. 2013), contrasting the list with similar case studies (Ashley 2014; Fernandez Campo et al. 2017; Kabisch 2019; Sheate et al. 2008); and associate the final list with the targets and areas of interest set by Scottish Canals environmental strategy (Scottish Canals 2015). After that, collected data covered landuse types, vegetative cover, topography, greenspace functions, and sustainable drainage systems, amongst others (EEA 2017; Greenspace Scotland 2018; Moss 2014).

The selected criteria for analysis of each ES had to be spatially explicit, based on previous literature different weights were assigned for each ES before being analyzed through a GIS based multicriteria decision analysis (MCDA) to produce Ecosystem Service Provision Units (ESPU), followed by further analysis with GIS to detect ES bundles in the study area (Fernandez Campo et al. 2017; Rocha et al. 2015). Finally, comparison maps between ES highlighted tradeoffs and synergies in the area (Fernandez Campo et al. 2017), Figure 1.

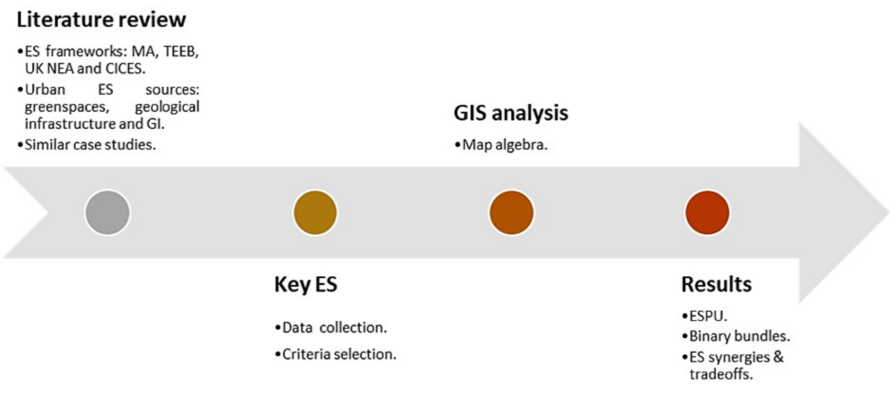

Figure 1: Methodology summary (partially adapted from Fernandez Campo et al. 2017) (Al Dwairi 2020)

4. Results

4.1 Key ES in the Smart Canal project area

Based on the explored ES frameworks (CICES 2013; Leemans and De Groot 2003; Silvis 2012; UK NEA 2011), the nature of urban ecosystems and its components (Forest Research 2010; EEA 2011; Davies et al. 2011; Gómez Baggethun et al. 2013) and similar case studies (Ashley 2014; Fernandez Campo et al. 2017; Kabisch 2019; Rocha et al. 2015; Sheate et al. 2008), a preliminary inventory of key ES in the Smart Canal project was prepared, Table 1.

Table 1: Preliminary inventory of key ES offered by the Smart Canal project (Al Dwairi 2020)

ES Category	*ES*	*Benefit description/example*
Provisioning	water supply	Drinking water/the canals have private drinking water supplies on its estate (Davies et al., 2011; Gómez-Baggethun et al., 2013; Scottish Canals, 2015)
		Water for industrial, agricultural, and recreational uses (Davies et al., 2011; Gómez-Baggethun et al., 2013; Scottish Canals, 2015)
		Energy/ possibility of renewable energy regeneration from the canal water (Davies et al., 2011; Scottish Canals, 2015; Muscatelli et al., 2020)
	Material	Dredged sediments/ used to improve agricultural land, deliver ecological benefit at several locations across the canal, used in road surface material and bricks production (Davies et al., 2011; Scottish Canals, 2015; Muscatelli et al., 2020)
	Plants	Ornamental (e.g., flowers), rare plants (e.g., Tufted loosestrife, Bennett's pondweed) (Davies et al., 2011; Scottish Canals, 2015)
Regulating	Climate regulation	Urban heat amelioration/ cooling effect of the canal, (Forest Research, 2010; EEA, 2011; Gómez-Baggethun et al., 2013; Žuvela-Aloise et al., 2016; Codemo et al., 2018)
		Carbon sequestration/ urban vegetation, soil, and water of the canal aid in sequestering carbon (Cruickshank et al., 2000; Davies et al., 2011; Z. G. Davies et al., 2011; Gómez-Baggethun et al., 2013; Chen, 2015)
	Hazard mitigation	Flood protection/runoff mitigation by storing surface runoff in the canal, (Forest Research, 2010; EEA, 2011; Davies et al., 2011; AECOM, 2013; Gómez-Baggethun et al., 2013; Robinson, 2013; Brears, 2018; Scottish Canals, 2018)
	Purification	Clean air/ vegetation around the canal expected to reduce PM10 concentration in air (Forest Research, 2010; EEA, 2011; Davies et al., 2011; Pugh et al., 2012; Gómez-Baggethun et al., 2013; Scottish Canals, 2015).
	Waste treatment	Nutrient retention/use of bioretention ponds as part of sustainable drainage systems in Smart Canal projects and installation of active ecosystems (floating wetlands) in the canal, (Forest Research, 2010; EEA, 2011; Davies et al., 2011; Gómez-Baggethun et al., 2013; Winston et al., 2013; Scottish Canals, 2015)
	Pollination, pest regulation, and seed dispersal	Green assets of the canal (e.g., towpaths, grassland, hedgerows, woodland, and scrub) promote species biodiversity, (Middleton et al., 2004; Forest Research, 2010; EEA, 2011; Davies et al., 2011; Gómez-Baggethun et al., 2013; Scottish Canals, 2015)
Cultural	Recreation	Activities around/in the canal: Boating, Trim trail, wave boarding area, and Paddle Sports Centre, (Forest Research, 2010; EEA, 2011; Davies et al., 2011; Gómez-Baggethun et al., 2013; Robinson, 2013; Scottish Canals, 2014, 2015; McKean et al., 2017)
	Aesthetic value	Improved physical and mental health (Forest Research, 2010; Davies et al., 2011; Gómez-Baggethun et al., 2013; Scottish Canals, 2015)
	Cognitive development	Educational destination/ sites of special scientific interest (SSSIs) (e.g., Dullatur Marsh site) (Davies et al., 2011; Gómez-Baggethun et al., 2013; Scottish Canals, 2015)
	Place value and social cohesion	Canals foster a sense of place and emotional attachment (e.g., Forth & Clyde canal society charity), (Forest Research, 2010; Davies et al., 2011; Gómez-Baggethun et al., 2013; Scottish Canals, 2015; FCCS, 2019)
Habitat	Increasing habitat area	The canals serve as a refuge for bats, otters, and badgers/ most reported wildlife are: Mute swans, mallards, frogs, damselflies, dragonflies, bumblebees, butterflies and foxes), (Middleton et al., 2004; Forest Research, 2010; Davies et al., 2011; Gómez-Baggethun et al., 2013; Scottish Canals, 2015)

4.2 ESPU maps

The Smart Canal project area depicted a high to a very high potential for the delivery of regulating services, such as water quality enhancement, carbon sequestration, evaporative cooling, and biodiversity at 11%, 10%, 5%, and 4% of the area consecutively. The study area offered limited delivery of provisioning services, where only 3% of the area had the potential for delivery of water for non-drinking purposes. Additionally, cultural services showed limited presence and were focused in the north western part of the canal, which means only 2% of the area is capable of delivering high to a very high provision of cultural services. Value of 1 indicates very low provision and vale of 5 indicates very high provision, Figure 2, Figure 3.

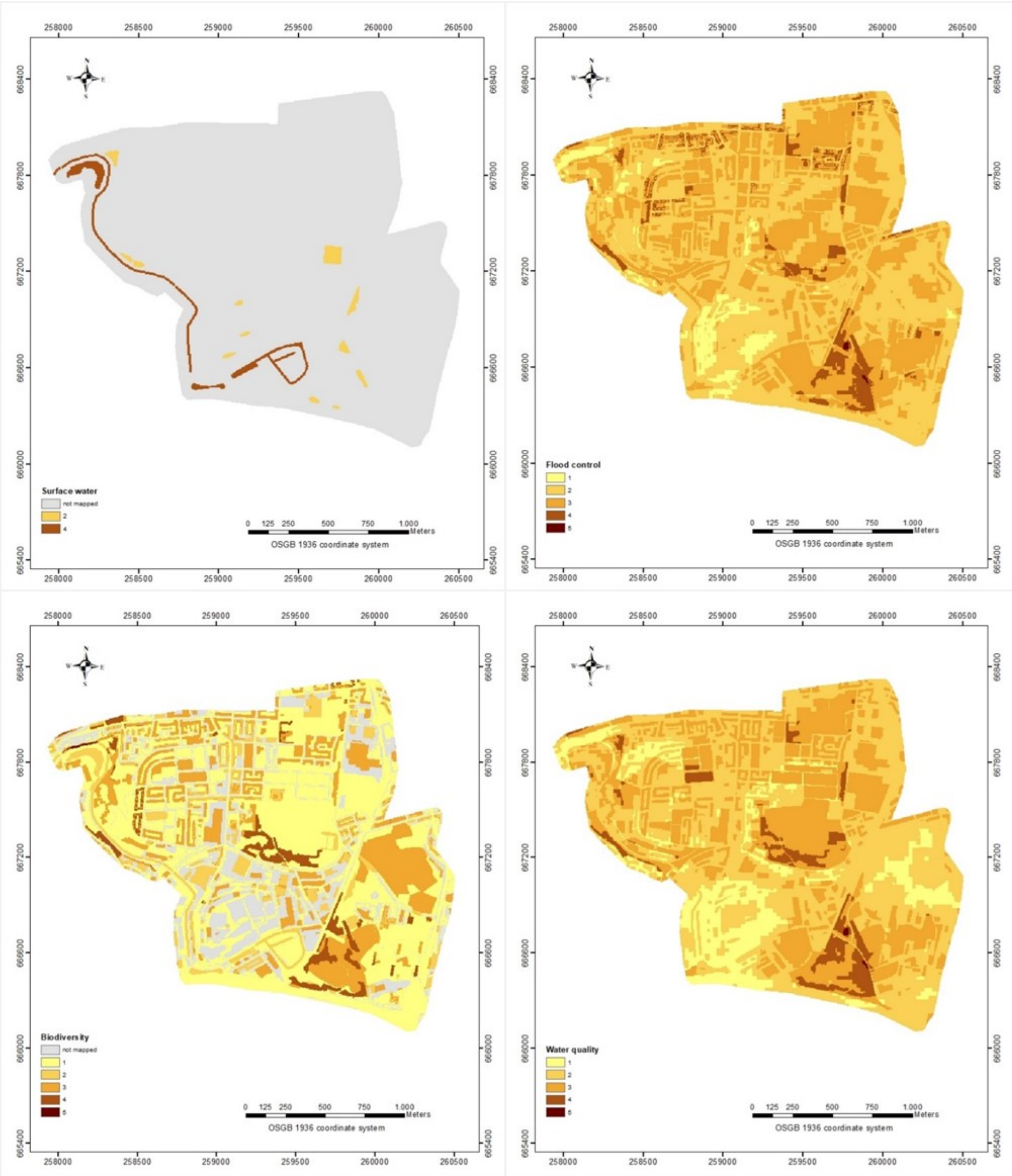

Figure 2: ESPU for surface water, flood control, biodiversity, and water quality (Al Dwairi 2020)

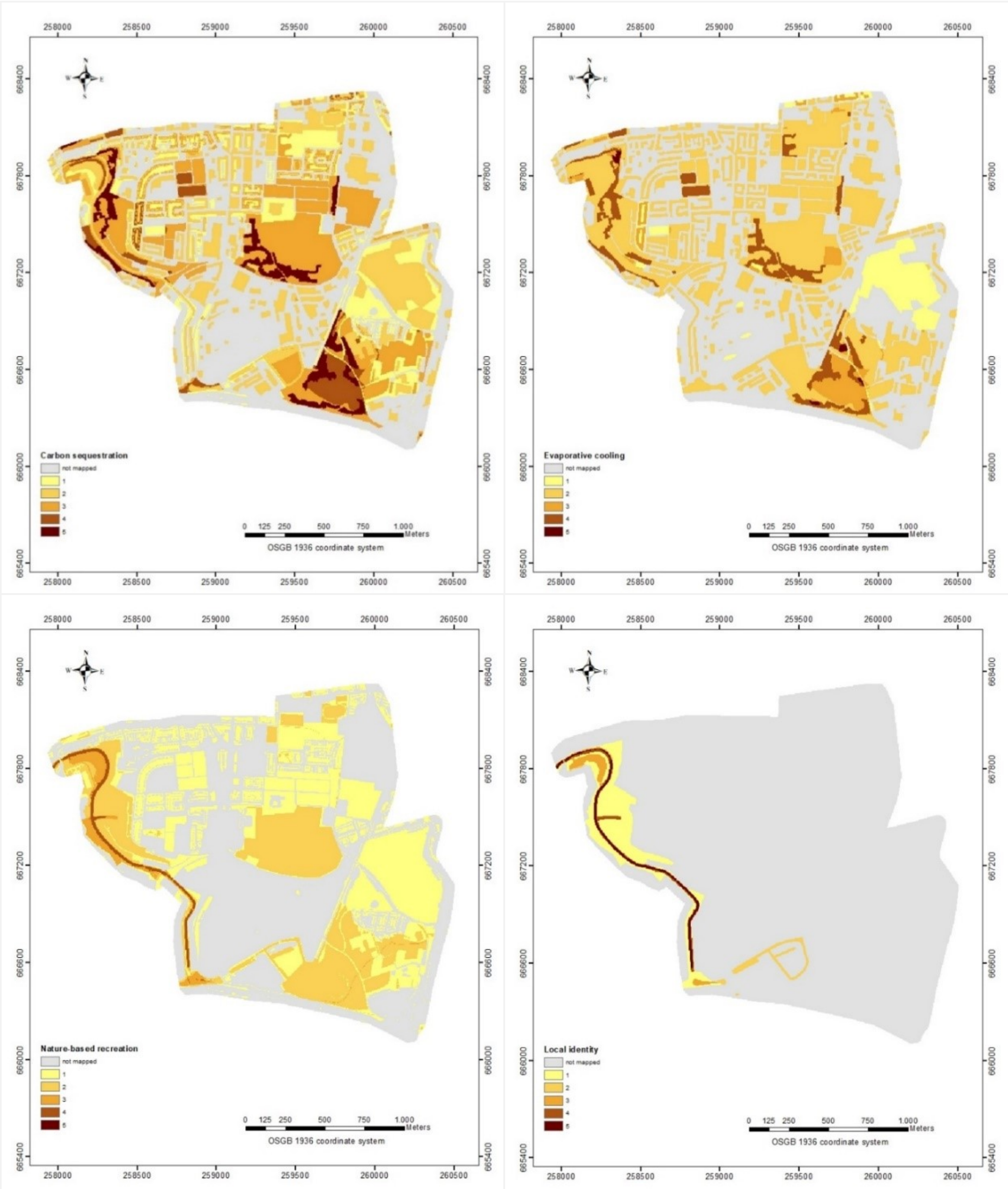

Figure 3: ESPU for carbon sequestration, evaporative cooling, nature based recreation, and local identity (Al Dwairi 2020)

The ecosystem services inventory provided a comprehensive list of possible services in the smart canal project area (Table 1). The inventory aimed to provide a transferable set of ES, based on several assessment frameworks and covering multiple elements of urban ecosystems present in the study area. Although the results conveyed a higher potential for the delivery of regulating services, there was still an almost equal opportunity for the occurrence of provisioning and cultural services in the area. For instance, the north western area of the canal can be used as a hub for starting small scale urban agricultural projects focused on reusing the canal water to produce both ornamental and edible plants while educating residents on the rare plants in the Canal area. Thus, increasing the delivery of provisioning and cultural services (Hajzeri and Kwadwo 2019; McLain et al. 2012; Russo et al. 2017). Finer details can be obtained through consultations with involved stakeholders and the public to understand the possible services of the Smart Canal project and draw investment opportunities towards the Forth & Clyde canal (Klain and Chan 2012; Raymond et al. 2009). Stakeholder opinion analysis and community involvement can provide essential information to better value the services of the Canal and ensure its continued success (Buckman 2014, 2013; Sheate et al. 2008). The selection of the eight mapped ES depended on data availability (Rocha et al. 2015; Jacobs et al. 2017; Syrbe et al. 2017).

ESPU maps (Figure 2 and Figure 3) were meant as in indication of the potential of ES in the Smart Canal project area, mainly based on the ability of landuse and landcover classes to deliver ES (Cruickshank et al. 2000; Maes et al. 2012; Cabral et al. 2016; Fernandez Campo et al. 2017). ESPU can only be considered as an indication of the presence of particular ES in the site area, without giving any further information on the actual supply of the service (Fernandez Campo et al. 2017). The ESPU maps confirmed that there is considerable potential for the delivery of regulating services in the Smart Canal project area.

4.3 Detection of bundles

A map representing the level of spatial coincidence between ES was produced by overlaying the ESPU maps for the eight mapped ecosystem services. Around 38% of the Smart Canal project area indicated high to very high coincidence levels between ES, especially in the northwestern part of the canal which indicates the importance of management decisions in balancing ES. Furthermore, 24% of the area represented intermediate levels of coincidence, especially in greenspace areas, in the north eastern parts of the project area. Finally, around 38% of the area represented low to very low levels of coincidence between ES, Figure 4.

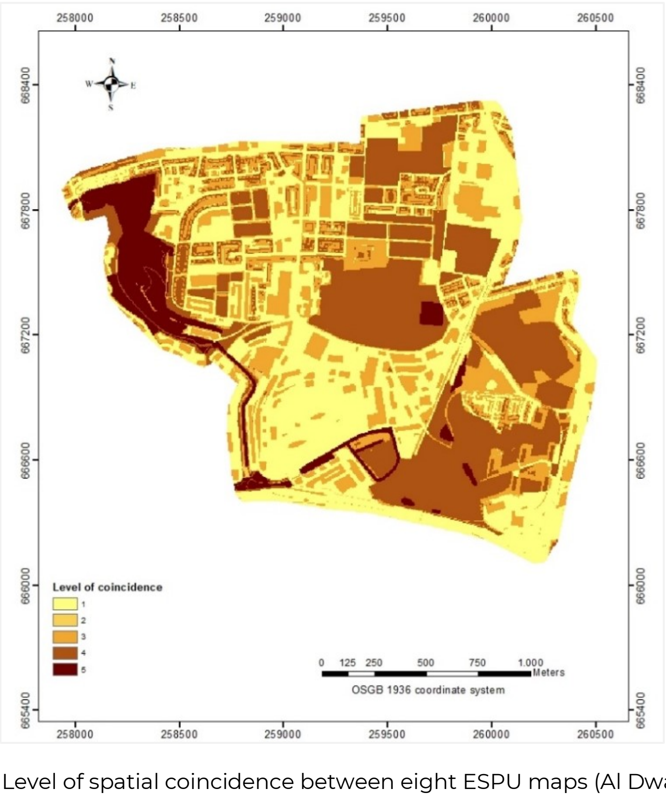

Figure 4: Level of spatial coincidence between eight ESPU maps (Al Dwairi 2020)

4.4 ES synergies and trade offs

The following maps provide further details on the level of interactions between biodiversity/carbon sequestration and other ES in the study area. Category A indicates areas with no provision for biodiversity or carbon sequestration, category B includes areas where the provision of biodiversity/carbon sequestration is higher than other ES, and category C represents areas where both ES have high provision, depicting high levels of vulnerability, Figure 5.

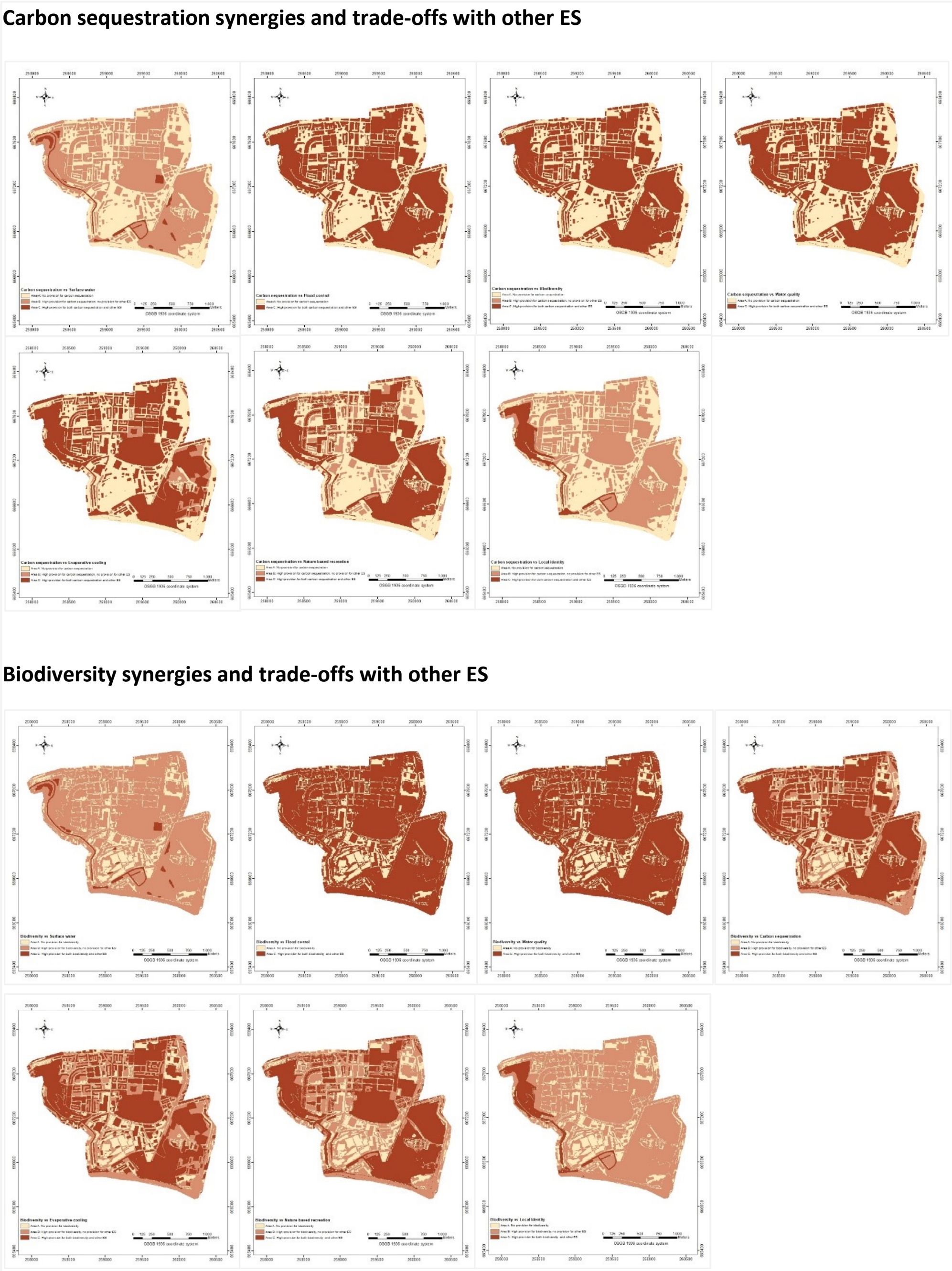

Figure 5: Tradeoffs and synergies between ES (Al Dwairi 2020)

5. Implications and Conclusions

The main aim of this research was to provide a new perspective on revaluing canals and defining its role in the urban environment. The analysis focused on mapping the provision of ecosystem services in the Smart Canal project area and highlighting the occurrence of possible synergies and tradeoffs between ES. The Canal proved its ability to support the provision of multiple ecosystem services. Some of the ES were provided directly by the Canal, such as the provisioning services (e.g. surface water for non-drinking purposes), other ES were a result of interactions between the Canal and surrounding ecological infrastructure such as the regulating and cultural services (e.g. the presence of the Canal and surrounding vegetation increased the potential for the evaporative cooling effect of the Canal and use of the Canal water for recreational activities).

It was evident that natural landscape elements (e.g. canal water, riparian routes, and old oak woodland) present around the Canal and Hamiltonhill nature reserve in the north western part of the study area, had a higher potential for ES provision delivery, compared to other landscape elements such as greenspaces in the central part of the study area (e.g. private gardens, lawns, and parks) because the greenspace functions might change depending on the human activity in the area. Also, areas where blue and green landscape elements intertwine the most, showed the highest potential for the delivery of multiple ES (e.g. the north western area delivered intermediate to high provision for six out of the eight mapped ES). Hence, indicating the multifunctionality of these landscape elements and its potential for ES delivery within urban ecosystems.

The delivery of multiple ES creates an environment for the occurrence of synergies and tradeoffs. Taking into consideration that the primary purpose of the Smart Canal project was to enhance flood control allowing for the regeneration of north of Glasgow area. Bringing focus into a specific ecosystem service will result in a tradeoff situation with other ES in the area. Having flood control as the main aim might result in changes in the functions of greenspaces, types, and allocations of vegetation in the area, which consequently affects its ability to sequester carbon or form new habitats around the Canal. Thus, areas of tradeoffs and synergies require careful planning.

The Forth & Clyde canal is able to transcend beyond its role as a transportation route into delivering a set of essential ecosystem services through the Smart Canal project. Regulating ES indicate the Canal's potential to be used as a climate adaptation tool in the city (e.g. alleviating flood pressure and enhancing microclimate). Mapping biodiversity provision confirmed the importance of the Canal as an integral open water body in a highly urbanized surrounding, responsible for providing feeding and resting areas for urban wildlife, the implementation of sustainable drainage systems to collect surface water runoff in the Smart Canal project area (e.g. bioretention ponds and bioswales) serves as an extension of the Canal's role as an ecological corridor focusing on creating new habitat patches and attracting various species. Furthermore, the north western part of the Canal holds a considerable potential for the delivery of cultural services, the presence of the old canal structure, recreational attractions (e.g. water based sports) and proximity to Hamiltonhill reserve encourage the occurrence of physical and intellectual interactions amongst people. Hence, the role of the canal can be taken further to account for the potential of ES delivery along the entire length of the canal, not just within the study area, validating the Canal's future potential in creating environmental and social benefits within the urban environment.

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Biomimicry approaches to mitigate the urban heat island

A case study of Toulouse, France

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Abstract

Mitigating Urban Heat Island Intensity (UHII) requires a comprehensive understanding of its relationship with global climate change, the underlying reasons, and adoption of all sorts of ideas from multidisciplinary fields. The biomimicry approach can be a remarkable option to this global concern, which has been emphasized by many scientists, researchers, and experts since the nineteenth century. However, it is yet to be acknowledged and widely practiced, especially in urban planning and design to safeguard a sustainable urban environment. The purpose of this study is to introduce a descriptive guideline on biomimetic urban design process, based on climate analysis at a neighbourhood scale. The study area, Paleficat of Toulouse in France, is a prospectus development area, a mixed-use area. Urban planners seek for a design that will cause the least environmental effect from the development. Both qualitative and quantitative study approaches are used in this study. Primary information is collected through field observation and secondary data is collected from The Laboratoire Interdisciplinaire Solidarités, Sociétés, Territoires (LISST). The climatic analysis is done in the laboratory by using R-Language and QGIS for wind and temperature at city scale. Primary analysis done on vegetation, hydrological courses, building topology, building material, topography, UHII, heat stress, and wind has been carried out. Later, from both field study and literature review, this study stresses on formulating a guideline, which describes what component the neighbourhood should consider while designing the area such as: vegetation and hydrological courses, existing built structures, vehicular accessibility, heat stress and wind analysis, and height of the building. The guideline will enhance thermal comfort for the residents. Besides, the study has inferred that if the street network is built by following a naturally existing pattern like a leaf structure the area will cause minimum heat island in the future. Overall, identification of right biomimetic approach can help to reduce local heat stress. This approach gives the ability to creatively design an adaptive built environment that acknowledges that a city grows and evolves over time. Biomimicry helps planners to deal with the complexity of city planning in a multidisciplinary approach that aligns with the natural systems.

1. Introduction

According to the United Nations (2018), 68% of the world's population is projected to be living in urban areas by 2050. As a result, urban areas are expected to have much tighter spatial interrelationship among buildings that may raise several urban environmental issues. Rapidly increasing urbanization is the main cause of urban heat islands (UHI), which is reaching epidemic proportions. There are examples of approaches to mitigate urban heat Island intensity in micro scale urban physical infrastructures using the concepts of biomimicry. The notion of biomimicry is the idea that the natural world has been doing research and development for 3.8 billion years refining responses to environments that humans as recent species have only begun to understand. The biomimicry approach is to learn the lessons of nature and understand how nature has designed itself in response to environmental conditions and design the world accordingly.

Globally cities are being regenerated and readjusted according to visionary ideologies to accommodate necessities for achieving thermal comfort and ensuring the wellbeing for urban dwellers. These cities can benefit by adapting solutions embedded in nature which can be implemented in an urban neighbourhood scale to mitigate several climatic issues like urban heat island effects.

1.1 Aim and Objectives

Urban heat island is a phenomenon, which is mainly caused by densely constructed surfaces that absorb solar radiation more than the natural surfaces and anthropogenic cooling mechanisms. Another significant cause of UHI is due to the buildings blocking wind that stops cooling by convection. Urban heat island is a significantly large urban area or metropolitan area that is warmer than its surrounding rural areas (Solecki et al. 2005). The initial part of the research is to analyse the climatic conditions of neighbourhood scale of an urban area that have significantly increased solar absorptions and the existing wind conditions.

Brown and Kellenberg (2009, 60) mentions that biomimicry at a broad spatial scale might be more effectively confronting ecological degradation and climate change adaptation. These encourage designers to envision urban built environments based on principles of biomimicry. In the realm of academia, it has been encountered that almost all current ecological solutions applied to suffice the criteria of sustainability aligns with concepts of biomimicry. Even in the professional field of urban design, there are several attempts to derive solutions of urban climate related problems, using biomimicry approaches. Although biomimicry is counted as a new approach in the field of architecture and urban design, there is still no adequate access for architects and urban designers to utilize biomimetic design strategies in projects (Chayaamor-Heil et al. 2017). Snillen (2019) states that biomimicry suggests looking into nature to explore possibilities through investigation of natural and environmental features of a specific site. One of the core objectives of this research is to produce a rich resource for urban design professionals to make use of biomimetic work processes in building climate sensitive urban design projects

1.2 Scope of work in an existing urban development project

For the aid of research involving climatic data possible site for analysis, there was a unique opportunity to work at *The Laboratoire Interdisciplinaire Solidarités, Sociétés, Territoires* (LISST), which is a public research laboratory under the supervision of the Centre of National Scientific Research (CNRS) and the Toulouse University. In addition to that, LISST is also a research team belonging to Centre for Interdisciplinary Urban Studies (CIEU), which deals with housing, relationship between the economy and urban spaces, urban sustainability (Masson et al. 2015). Their research questions the interface between city and environment such as the urban climate and the adaptation of cities to climate change.

The initial internship task was regarding wind analysis for urban planning recommendations in Toulouse. The research work was supervised under Dr. Julia Hidalgo, the proponent of the CNRS/LISST wind analysis for urban areas projects. As mentioned earlier obstacles that block wind flow majorly contributed causing urban heat island. Thereby, this project helped to identify a specific problem caused by wind. It was crucially insightful to collaborate with other interdisciplinary urban researchers involved in other relevant projects.

During the internship at LISST there was scope to be involved in a new urban development project in Toulouse. Inside the Toulouse metropolitan boundary, the remaining places allocated for a new urban settlement is an area called Paleficat. There was a scope to be involved in a research exercise to conduct a primary feasibility analysis of the area and later prepare a proposal. The project is handled by the Toulouse Metropole, which is a public planning agency that supports the French ministry in charge of town planning. An urban professional from Toulouse Metropole, Benoit Brandon was the personnel who provided all the available information about the project. Beniot also practiced and propagated biomimicry approaches in design and planning processes. Several analysed graphical data and recommendations were presented to Toulouse Metropole. The presentation and discussions were held in person and during the later phases the online meeting and email correspondence were the only means of discourse. Based on the feedback received; helped construct the design and planning guidelines using a biomimicry approach.

2. Background

In 1997 Janine enyus published the book " iomimicry: Innovation inspired by Nature" which is still devoted as the origin of most of the literature on biomimicry. One of the torch bearers Baumeister (2014) mentions in her publication the various ways that design lessons can be derived from nature. CEEBIOS is the European centre of excellence in Biomimicry Senlis, their aim is to facilitate and encourage the development of bio-inspired French territory habitats, their primary activity is to assist actors involved in a sustainable development project in building scale or that of the eco-neighbourhood.

The "Habitat, Bio-inspired summary report 2018" is a compilation of many up to date advancements where biomimicry contributed in building sustainable cities of the future and evoke rethinking of cities as a living ecosystem. The publication highlights the idea about how the association of inspiration from nature to design built environment so not a new such as vernacular architecture, Japanese, green architecture. All these concepts converge to biomimicry (CEEBIOS 2018). This report is a great resource to know about the pioneer researchers in the field of bio-mimicry working in various different fields of biomimicry.

Antonio Gaudi (1852 - 1926) is one of the first architects known for replicating biological organic forms into building design. Later Richard Buckminster Fuller and Frei Otto also presented us with marvellous structural innovation derived from nature. Satoshi Sakai, professor at Kyoto University designed a shading roof structure that contributes to reducing urban heat island effects. His inspiration came from establishing similarities between concentrated cities and dense forests. (CEEBIOS 2018).

Architectural researchers like Estelle Cruz and Dr Natasha Chayamor-Heil are working in CEEBIO and CNRS respectively. They are leading several research teams for the transposition of biological principles to architectural design and urban planning. Estelle Cruz participated in research of biomimicry and architecture in four renowned universities around the world for a span of one year. Since this field of subject is still emerging, such an un-orthodox research method is important to establish the role for biomimicry in the future of planning our cities.

3. Method

3.1 Methodological Approach

Urban climate maps are graphical representations of climate data, which are increasingly essential tools for sensitive urban design and planning. The initial phase of the methodological approach was to understand the state of the art urban climate maps and how different climate phenomena are graphically presented from a meteorological perspective. Later a neighbourhood scaled site was chosen for the exercise.

The urban climate data relevant for the site and its scale were extracted and analysed to prepare a microclimate study. The case studies aided in identification of relevant design solutions were derived from a biomimicry approach. As shown in figure 1, a later phase was intended to make a performance assessment to strengthen the proposed solution.

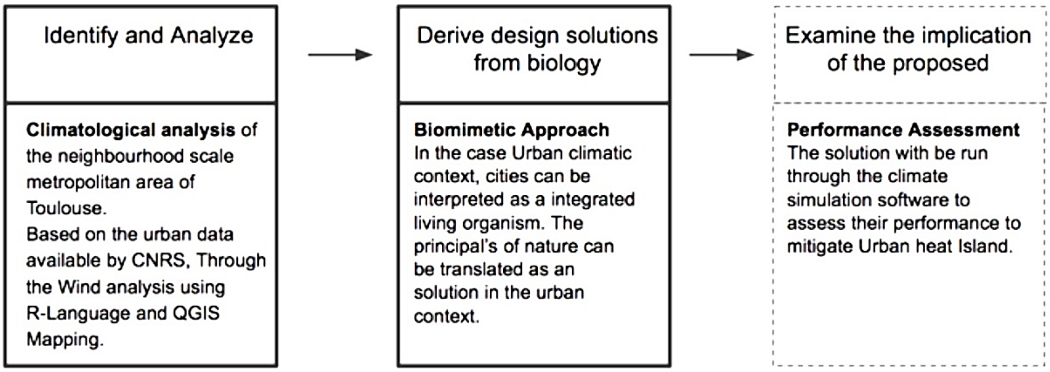

Figure 1 Research method analysis diagram (Chowdhury 2020)

3.2 Exemplary Climate analysis and representation

In order to suggest a wholesome climate sensitive solution to the city-scales area; it is essential to analyze and take into consideration all the climatic forces acting upon the region. It is equally important to represent the finding that will be comprehensible to all relevant stakeholders that participate in the planning, designing and feasibility phase of the project. Climatic attributes like air temperature easy to portray but graphical representation of wind analysis is rather difficult. Many important phenomena of wind analysis visualization are an unexplored territory that urban designers do not take into account.

4. Analysis

4.1 Microclimate Study of Paleficat

Paleficat sector which is located in the north-east of Toulouse, France is the site selected for a micro climate study. This area of 96 hectares is the remaining piece of land within Toulouse metropole that will be transformed in the following years for large neighbourhood development to accommodate the urban migration. Figure 2 shows the demarcation of the site allocated for the new development and a secondary boundary showing the area in between which is denoted as “Urban integration zone”. Three climatic indicators produced using numerical simulations of climate for those meteorological situations presented on the “Guide de recommandations sur la prise en compte du climat dans l’Aménagement du territoire à destination des services de Toulouse Métropole, 2019” and the atlas “Intensité de l’ICU sur le territoire de Toulouse Métropole, 2015”. (Toulouse Metropol 2019, AUA 2015.)

- *The thermal stress* during the day time because it strongly impacts the comfort of citizens and must make the use of air conditioning in many industries.

- *Air temperature at night* because it influences the ability of buildings to cool during the hours of night rest and thus the health of residents. This information is characterized by the intensity of the urban heat island.

- *The air flow conditions* because they can identify favorable areas for natural ventilation and those with an air gap. They are characterized from the prevailing wind corridors, generating areas slope breezes, areas for producing fresh air (or vegetation water for example) or hot air (highly mineralized areas or which employ air conditioning by example) and areas which hinder the wind.

From the perspective of the evolution of long-term climate, France expects a high probability of an increase in minimum and maximum temperatures. Higher frequency, duration and intensity of heat wave episodes will occur throughout France and especially in the Mediterranean. Locally, this has been confirmed by the Climate Profile Toulouse Métropole which was established in 2015. The annual average temperature has already risen by 1.2 ° C with a marked rise in temperatures in the mid-1990s (2003, 2011 and 2014 were particularly hot). Looking at the evolution of seasonal temperatures, this warming is very clear for spring, summer and fall. The precipitation standpoint, there is little or no change, but rising temperatures promote evaporation and extended drought effects are increasing. These facts point to an interest to focus specifically on the issue of summer comfort for this territory (Hidalgo & Jougla 2018).

In order to deal with the problem of summer thermal stress, the analysis focused on three local weather types. The local weather types are used to describe the climatic context of this urbanized area that explains the plurality of weather. This classification method has been coded in an R script and is used for climatic analysis, which is believed to be a good practice for performing climatic contextualization (Hidalgo et al. 2018). The three local weather types are selected for their situations conducive to high daily temperatures and to the development of a consequent night heat island or both. The three weather types are explained below:

4.1.1 Local weather type 7: Typical sunny summer day with southeast wind (22% of summer days). This is a type of summer weather situation whose temperature can reach 40 ° C. It is characterized by a large temperature difference between day and night and a persistent but weak south-easterly wind (2 - 3.5 - 2.5 m/s in the morning, in the afternoon and in the evening respectively).

4.1.2 Local weather type 8: Typical sunny summer day with northwest wind (37% of the days). Although present in other seasons, it is the most frequent type of situation in summer. The temperature remains relatively high in summer, the maximum temperature is 30 ° C, but it is softer than in the previous situation. The northwest wind can be relatively strong and humid, with peaks of 4 m / s in the afternoon.

4.1.3 Local weather type 9: Sunny day, very hot in summer, with northwest wind (22% of the days). It is also a very common type of weather situation. In summer, the temperature can rise to 40 ° C. The wind blows from the west in the morning to northwest in the afternoon and then southwest in the evening. The wind speed also varies between 2 m/s in the morning, 4 m/s in the middle of the day, and 2 m/s again at the end of the day. This type of situation is very favorable to the formation of an important night heat island on the territory.

4.2 Basic information about the project at Paleficat

Project: Development with establishment of necessary public facilities of new housing, economic activities, public spaces and public facilities for the neighbourhood.

Location: Paleficat Sector, Toulouse, France. The site is located at the northern-east boundary of Toulouse Metropolitan. And is it surrounded by municipal boundaries of L Union and Launaguet communes on the east and west side of the site consecutively. This site is restricted from the north and south by the Natural Plains of Hers and the ring road

consecutively (Figure 2).
Area: 96 hectares
Provisional structures to be built: 6720 household units
Possible users: 19,200.
Project Time Frame: Two years between 2019 to 2020 is allocated for the feasibility of the projecting the selected site

Figure 2 Photographs of the site and surrounding long side the newly constructed road (Chowdhury 2020)

5. Results

5.1 Urban heat island intensity and Heat stress

The site selected for the project falls n between two different communes of Toulouse Metropole – Laynaguet and L'Union. The urban heat intensity inside the site area is remarkably less than the surrounding islet of the city, as most of areas within the site experiences moderate heat stress. Which is significantly lower than the surrounding areas which are facing extreme heat stress. The demarcated site has less built structure and predominantly covered with dense vegetation, which locally decreases the urban heat Island effects. The level of heat stress is signified in 4 primary classifications: low, medium, high and extreme. In comparison to all the three selected weather types; the thermal heat stress illustrated Figure 3 during local weather type 7 shows the maximum thermal heat stress.

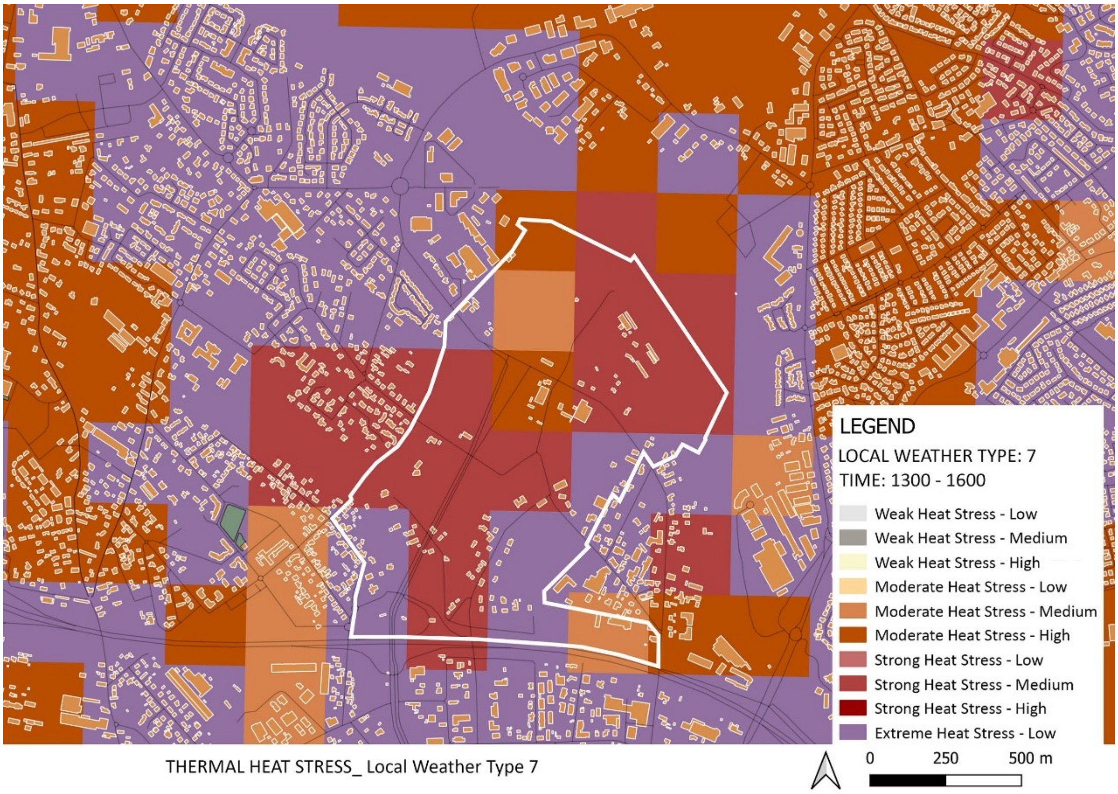

Figure 3 Map of different level of heat stress recorded in local weather type 7 (Chowdhury 2020)

5.2 Wind Analysis

By comparing the wind conditions during Local weather type 7,8 and 9 it can be seen that there is a constant presence of wind flowing in from North-western and South-eastern directions (Figure 4). Therefore, it can be deduced that this particular diagonal path passing through the site should be emphasized while designing the new development in Paleficat. Figure 3 shows that in local weather type 7 when the heat stress is extreme among all the summer days; the strength of wind is stronger at night than daytime. If the new development in Paleficat is designed in a manner where the strong wind can flow through the diagonal corridors with minimal built obstacles; it will hugely contribute in reducing temperature due to urban heat island.

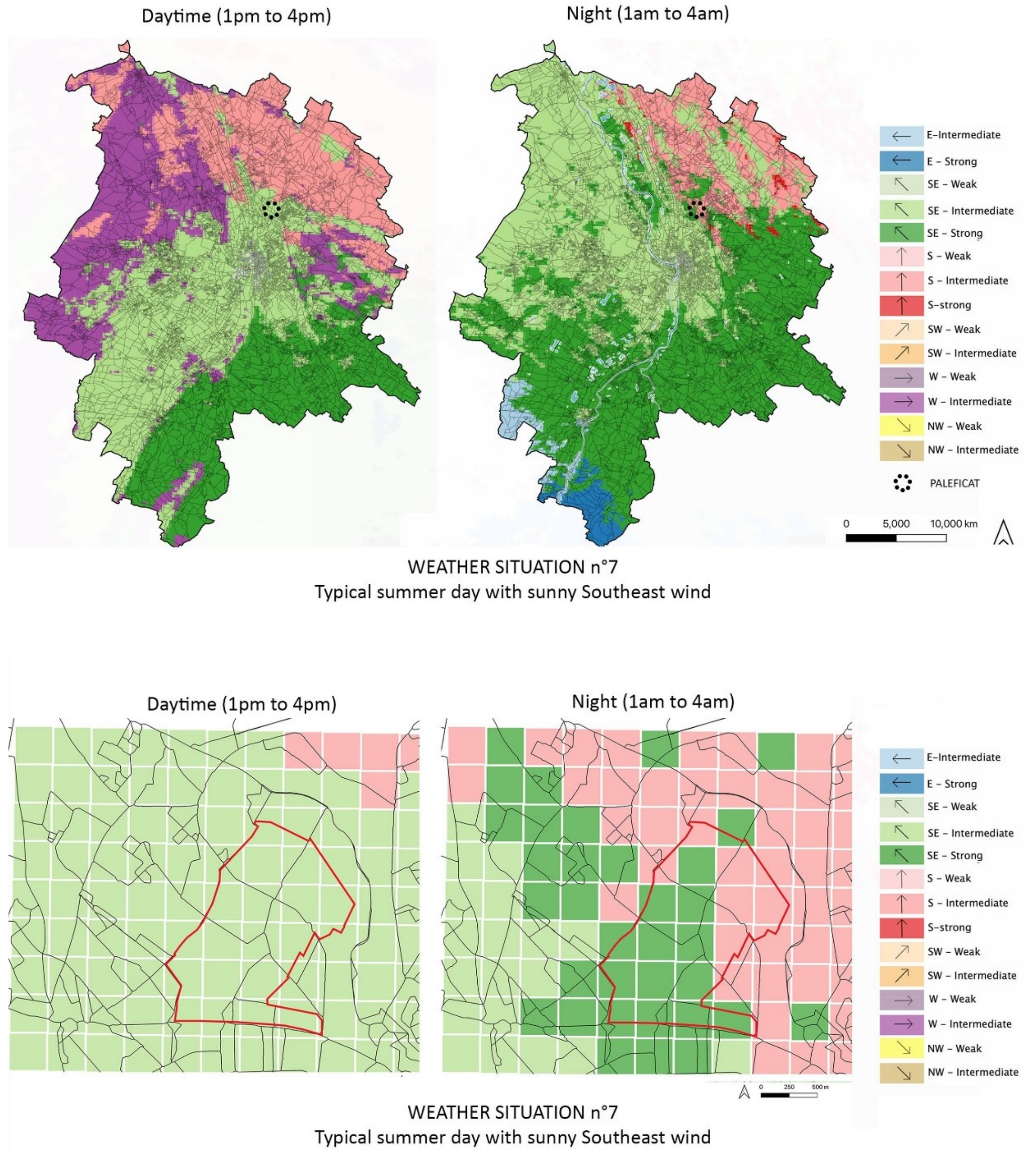

Figure 4 Maps comparing between day and night wind condition in weather type 9 (Chowdhury 2020)

5.3 Guideline for the planning of urban project in Paleficat, Toulouse.

5.3.1 Initial planning and design decisions

- *Vegetation and hydrological courses*: as vegetation plays a big role in mitigating the urban heat Island issues; the existing vegetation should be used or accentuated. These patches of lush greenery guide the new urban development and hold priority in the plan. The dry hydrological sources present on site are potential open spaces of swallow water bodies that can invite biodiversity and help reduce the air temperature during hot summer.

- *Existing built structure:* compared to the whole site there are very few existing buildings in the area. They are mainly used for residential purposes and few of the buildings are used as old industrial purposes. Most of these buildings are built in privately owned lands and they do not have a cohesive spatial connectivity.

- *Vehicular accessibility:* the new road that has been constructed through the middle of the site has encroached a significant amount of vegetation. Yet, this road has dedicated bus routes and bicycle routes that promote sustainable mobility. The positioning of this main vehicular accessible road plays an integral role to formulate the plan of the neighbourhood.

- Heat Stress and wind analysis: according to the microclimate study it is observed that maximum heat stress inside the site occurs during weather type 7. Simultaneously there is an advantage that among the three weather types when there is more probability of thermal discomfort due to heat stress; the wind with the maximum speed approaches the site from southeast direction.

- *Height:* the height of the buildings also plays a big role. Variation of the height can be explored for the incremental growth of the project over various phases. The guideline can narrow down to the clusters of the neighbour where the design and planning interventions can affect the thermal comfort. The clusters in the neighbourhood can be arranged in a manner that approaching wind flows over the cooler area with vegetation and the water body before reaching the clusters.

5.3.2 Biomimicry approaches to planning and designing of the urban development in Paleficat

After the primary design decision, biomimicry approaches started with biolization of the site and its contexts. Where existing ideas about how nature would solve the problem are explored that give connections with the system. As shown in the illustrated map in Figure 4, a new prominent vehicular road has been built within the site boundary that runs through the middle of the site. This road is well connected to the public transportation, which makes it accessible to travel all over the Toulouse city. Moreover, this road divides the site into two halves, which have resemblance with a structure of a leaf.

The biological mechanism of the leaf structure was relevant to the site for two characteristics. The plot sizes of the neighbour settlements matched the in-between spaces of the veins. And the veins resembled the meandering street network. This pattern of street network is suitable for wind to reach all the households and provide comfortable outdoor space for pedestrians navigating in the neighbourhood. As shown in figure 4 the vein structure of the leaf is extracted and it is replicated in other areas of the site.

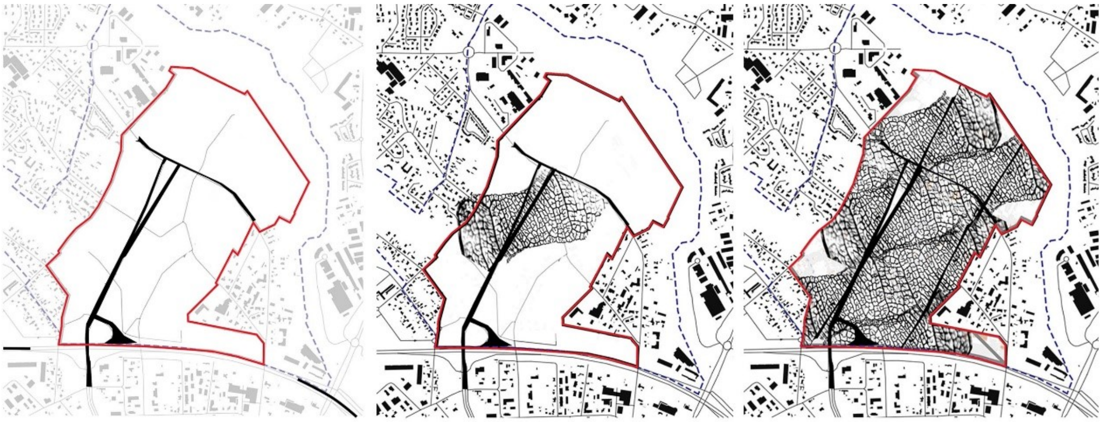

Figure 5. Illustrated map where the structure of a leaf is extracted and the prototype is replicated throughout the site (Chowdhury 2020)

The existing vegetation and hydrological courses are juxtaposed over the leaf structure. And the remaining leaf structure is extracted. The new development should be well connected with the surrounding road networks. The proposed road network branches out to join the existing roads in the surroundings. The development should be implemented in phases. The initial physical infrastructure should be built next to the predominant roads and streets.

After abstraction, the next step was the proposing design that fits into the system. Where the abstracted version of natural models was translated into human adaptation. The in-between plot sizes for each household are adequately drawn which fitted the scale and usability. Aim was not to make an exact replica of a natural form but to extract the design principles that aids in formulation of the problem solving.

Figure 6. The illustrated map showing the final planning phase of the new development in Paleficat (Chowdhury 2020)

Figure 6 shows the final planning outcome of the development. The preserved green spaces can ensure the thermally comfortable outdoor spaces that become pockets of spaces that allow cooler wind to flow through the street and the meandering narrow streets (Figure 6). Designing the street orientation is not enough for stagnant warm air to be pushed out of the site. It is also important to think about the three-dimensional aspects of the design outcome. The height of the building next to the primary wide roads are restricted to lower height buildings as it creates less obstruction for the wind to easily enter and exit the site. The buildings situated further from the wide roads allocated for buildings with maximum heights, which accommodate tall mixed-use residential apartments.

6. Implications and Conclusions

The result presented a possible approach to design a new neighbourhood where biomimicry has been chosen as a prime inspiration to reduce the possible effects on urban heat island. Climatic and existing natural environmental aspects governed the proposed design where socio economic aspects were not overlooked as well. The proposed new development also addresses the inclusive nature of different housing typologies that need variation in plot sizes and other attributes. The maximum height restrictions were set that accentuates and enhances the wind flow.

During early January 2020, a congress called " Faire la Metropole io-inspirees" was held at Jean Jaures University of Toulouse regarding biomimicry approaches in urban thinking. One of the participatory exercises was on Paleficat where students took inspiration from a concept called "Tiny forest". Tiny forest is a method used by the Japanese botanist Dr. Akira Miyawaki who experimented on forest creation based on potential natural vegetation theories. The students used these theories to adopt an incremental growth of the building where vertical extensions of the buildings can take place to maintain and support the increasing population without "artificialization" of vegetative permeable surfaces in the site. These ideas aided in determining the three dimensional visualization of the project.

Moreover, two design competitions were held previously in adjacent areas of the site. One of the locations is in the Paleficat castle and the other is situated on the banks of the Hers. " The first is named Agriville, which allows the park to be renovated in order to welcome families, workers and residents around an ecosystem linked to urban agriculture. Equipment and services will make it a new centrality of the future Paléficat eco-district. The second, named Agriparc, highlights a hybrid space crossing agricultural land, housing, public space and green spaces preserved along the banks of the Hers" (QUARTIER PALÉFICAT 2020). The submitted proposals from this competition focused more with urban integration of the existing socio economic conditions and public interaction.

For the first time in Toulouse Metropole, the concept of Biomimicry has been incorporated during the initial phase of the new neighbourhood scale urban planning and design. The importance of an urban designer with expertise in Biomimicry that has been established at the Toulouse Metropole for the Paleficat project, due to this research and other previously designed proposals by students and urban professionals. Several unique features of the site in Paleficat were analysed to provide a climate sensitive design solution derived from the principles of biomimicry. The proposed solution of Paleficat was intended to run through climate simulation software like ENVI-met to ensure its effectiveness in mitigating the adverse climatic conditions. It requires long time and high computer configuration to make comprehensive climate simulation of the proposed complex scenario. Even then few "Hotspots" could be extracted from the whole site to be separately analysed. An estimated collective understanding of the overall proposed design could be pictured from all the segregated small tests. In addition to deduce the effectiveness of opting a suitable biomimicry approach; repeated ENVI-met tests would have been necessary to refine the design over time and be more climatically appropriate.

6.1 Limitations of the approach

The spatial attributes were more emphasized as the research was more inclined to address the climatic aspects and the built infrastructures. Although the restrictive height of the buildings was suggested but apart from housing other functions were not allocated. The open spaces can be converted to integral public spaces where the city dwellers can engage in social interaction. The valued aspect of this research project is the partially participatory process, which was held between local urban professionals, meteorologist and architect. Inclusion on the local's feedback on the proposed design and planning is also a valuable input to formulate a sustainable solution.

6.2 Concluding Statement

New neighbourhood developments like Paleficat are being built in almost all cities to accommodate the increasing urban population. Simultaneously city dwellers are also more conscious about the ecological benefits of the unbuilt areas of cities. Adopting biomimicry approaches can be a key area of discourse while involving all stakeholders from multidisciplinary professions including ordinary city dwellers to conduct an interactive urban planning. The emerging tools like GIS and ENVI-met enable climatologists and urban professionals to collaboratively analyse huge amounts of climatic data. This analysis and their graphical representation makes it more justifiable for biomimicry experts to incorporate radical ideas to creative design decisions. Urban interventions of such planning and design in neighbourhood scale can collectively have a positive impact in building a sustainable city.

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BEHAVIOURAL CHANGES

Roadmaps: a platform for stakeholder connectivity towards decarbonisation of the buildings sector

Thais Glowacki

Abstract

Decarbonising the buildings sector is critical to achieving the Paris Agreement commitment as it is responsible for almost 40% of final energy use. However, the sector is not on track to meet the targets. Recent debates call for better coordination of agencies and stakeholders across organisational and sectoral boundaries, arguing that this would ultimately help accelerate the process. Through action research, this study demonstrates that improvements to the stakeholder engagement process in policy design, reflected in the energy efficiency roadmaps, are an entry point for transformative changes. Supported by the social network and transitions theory, the discussion suggests that co-creation can be added to the framework as an instrument to enhance connectivity, weaving scattered stakeholders. In practical terms, it aims to create a roadmap community and, at the same time, in the long-term, a resilient network with stakeholders more aware and willing to implement the roadmap targets, thus helping the sector meet the climate targets. It reverberates in the conception of the roadmap itself that turns out to be a normative document as well as a platform for amplified connectivity and collaboration between stakeholders using multiple benefits of energy efficiency as mediators.

1. Introduction

With the Paris Agreement countries have agreed to a common goal of maintaining the global temperature increase to below 2 degrees by the end of the century. According to the International Energy Agency (IEA), as the buildings and construction sector accounts for almost 40% of energy and process-related carbon dioxide (CO2) emissions, they have a significant part in achieving this vision. However, in 2018, buildings-related CO2 emissions rose for the second year in a row. Rapid increases in floor area and demand for energy-consuming services are driving this growth, outpacing efficiency improvements (Global Alliance for Buildings and Construction, International Energy Agency and The United Nations Environment Programme. 2020, 4).

Noticeably, the buildings sector is a highly fragmented industry, and there is a lack of a shared vision from disparate stakeholders in the sector which slows down innovation processes. Succeeding these outcomes at pace and scale requires greater collaboration among stakeholders (urban planners, architects, developers, investors, construction companies, utility companies and building owners and occupants).

In this context, energy efficiency buildings roadmaps have been developed to support a common language and vision for the complete decarbonisation of buildings across their life cycle and to support the development of national or subnational strategies and policies.

This study understands that co-creation can be an instrument used in policy design, reflected in the roadmap, to mobilise some ingredients in the stakeholder engagement process, i.e. collaboration, networks and innovation that can help the buildings sector get on track for the climate goals. Therefore, this research aims to explore how co-creation can contribute to roadmaps for the buildings sector decarbonisation.

The research is tied to my experience as an intern as an analyst in the Emerging Economies programme (E4) at the International Energy Agency (IEA) in the Energy Efficiency Division

(EEfD). Working on the development of buildings roadmaps, I took over the role of embedded researcher and through action research assisted the organisation by reflecting on the process of the stakeholder engagement done in the regional buildings roadmaps and proposing improvements to the national ones. The first-person narrative was chosen because the study is a construction based on my own experience as an embedded researcher.

2. Background

Currently, policymaking is opening the top-down hierarchical model to others that involve the public and non-state actors (private sector and not-for-profit organisations). This movement acknowledges the vital role that stakeholders from different institutional settings can contribute to addressing climate change (Akhmouch & Clavreul 2016, 32).

Akhmouch & Clavreul (2016, 32) refers to Freeman (1984) when defining engagement as an umbrella term to the organisation's efforts to ensure that individuals and groups have the opportunity to take part in the decision-making processes that affect them or in which they have an interest.

Sherry Arnstein conceived in 1969 an original conception pointing out to the relevance of power redistribution in citizen participation. Her perspective was represented as eight levels in a ladder pattern from, the bottom corresponding to nonparticipation, followed by degrees of tokenism (informing, consultation and placation), and on the top, the citizen power.

Connor (1988, 257) points out in his interpretation of the ladder, that at times several approaches should be used simultaneously in order to meet the needs of the parties involved. Consequently, sometimes, a combination of rungs can coexist in a project.

The AA1000 Stakeholder Engagement Standard (Accountability 2015, 6) sees the engagement as a journey and envisions the process in four stages: plan; prepare, implement, and act and review. In determining levels of engagement, facilitators define the nature of the relationship, they aim to develop for or with their stakeholders.

2.1 Energy efficiency multiple benefits

Energy efficiency means achieving the same level of service (measured as economic output, production quantity, or distance travelled) while consuming less energy. It is a cross-cutting theme and can benefit many sectors (buildings, industry and transport) and a variety of stakeholders.

If robust energy efficiency policies are designed, they can connect the three pillars (3Ps) of sustainability (people, planet and profit), e.g., tackle decarbonisation as well as support local job creation and thus, economic stimulus (IEA 2020). However, it is vital to develop the right narratives to make it appealing to stakeholders other than only energy savings. A way of doing this is looking at the constellation of indirect and positive impacts labelled as multiple benefits (IEA, 2014, 9).

The multiple benefits aim to capture a reality that is often overlooked, revealing that energy efficiency can provide many different benefits to various stakeholders. Nonetheless, curiously, the link between stakeholder and multiple benefits is yet to be done. This integration can be critical to reformulate the role of stakeholders in a project.

2.2 Understanding the co-creation concept

The concept of co-creation can help stitch that link. The very literal meaning of co-creation is together (co-) make or produce something (new) to exist. The concept of co-creation can be seen as a bricolage of ideas coming from very varied fields, including marketing, public service management, urban planning, and design and innovation (Lund 2018, 5).

De Koning et al. (2016, 267) points out that co-creation is still a maturing concept. The authors compiled models of co-creation in the existing literature. One of the models is the spectrum of co-creation that accommodates the overlapping of terms such as open innovation and participatory design. The spectrum also helps visualise the existence of different levels of influence the stakeholders can have on the output.

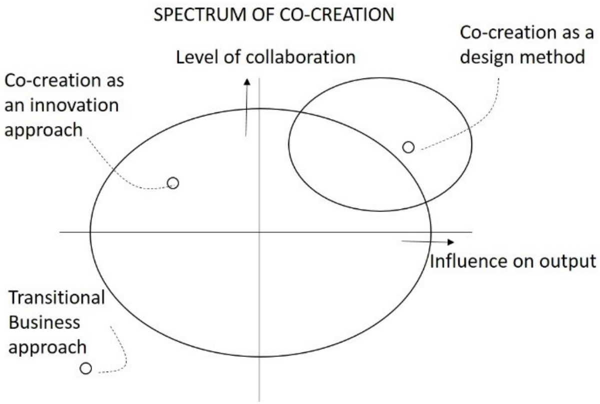


Figure 1: Spectrum of co-creation (De Knoning et al. 2016)

Lund (2018, 6) explains that whereas, from the 1970s onwards discussions on participation centred on rights and power - following Sherry Arnstein, participation conceptualised as co-creation instead focuses on including diverse forms of knowledge in urban processes to create innovative solutions to complex problems. Consequently, democratic legitimacy now relies to a much greater extent on output, rather than input legitimacy. It represents a significant shift in the criteria for evaluation and the purpose of participation because it moves the discussion from representation and empowerment to the ability to solve problems.

Associated with co-creation comes the penta-helix approach that categorises stakeholders in 5 types (businesses, public administration, local community, knowledge sector and capital) and represents them at different levels (local/micro), regional/meso, and national/macro). It points out the valuable contribution each stakeholder has and how hybridising elements from university, industry and government can generate new social formats for policy, programme and projects.

In conclusion, co-creation is an in-progress concept with no definite boundaries. It embraces notions ranging from community empowerment (design) and collaboration between the company and consumers aiming at better goods and services (business) to, more recently, the innovation perspective. The last emphasises the multi-stakeholder variety as an ingredient to better produce solutions for wicked problems.

3. Method

The embedded researcher role shaped this study and the way of investigating because by promoting co-creation in the development of the India roadmap, I took dual identities - the researcher bringing academic knowledge and practitioner working with the organisation to deliver this process. McGinity and Salokangas (2014, 3) describe embedded research as a mutually beneficial relationship between academics and their host organisations on the production of knowledge.

3.1 Action Research

Therefore, having a crucial connection with my role as a practitioner, the action research methodology allowed me to intervene within the organisation and reflect on it. Vaccarino et al. (2007, 13) claim that the fundamental principle underpinning action research is identifying a problematic area, imagining a possible solution, trying it out, evaluating it (did it work?), and changing practice in the light of the evaluation. In other words, a problem-solving process.

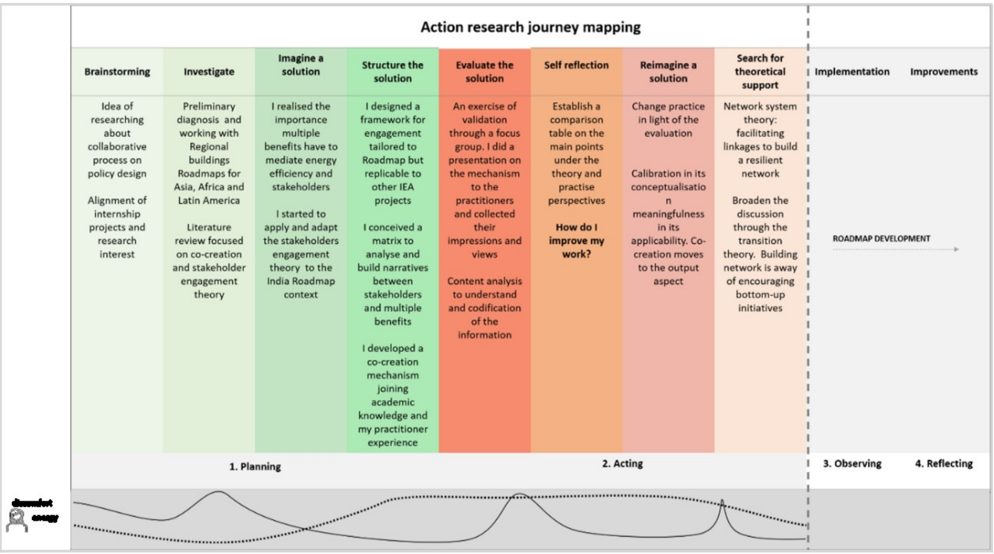
Altrichter et al. (2002) reiterate that action research involves a self-reflective spiral of activities: planning, action, observation, reflection, re-planning, and action. I was not able to observe the implementation of improvements proposed for the India roadmap in time to discuss them in this study. Hence, I have partially completed the cycle, including planning and action.

In action research, there is the aspiration for a social change and improving shared social practices and understandings behind practices (Kemmis 1993, 8). McNiff (1995,7) raises that action research does not begin with a fixed hypothesis. It starts with an idea to be developed and needs to be continually evaluated: 'How do I improve my work?'

3.2. Action Research Journey

To illustrate the process, I went through conducting the research, I used the idea of journey mapping (Figure 2). The mapping was designed taking the advice given to new action researchers by McNiff (1995) on structuring the topic investigation in a cyclical process: imagining a solution, implementing the solution, evaluating the solution and changing practice in light of the evaluation (McNiff 1995, 11).

Table 1: Action research journey mapping (Glowacki 2020)



I added a graphical representation to the bottom with two categories: discomfort and energy spent during the process. They are part of my self-reflection in conducting the research. Gibbons (2018) underlines that one feature of a journey mapping is exploring the experience and uncovering moments of both frustration and delight of a process.

A set of multi-methods was used to gather data and information. Desk research provided a deeper understanding of the themes discussed. An interview was conducted with a practitioner involved in the work with the roadmaps project to get insights on lessons learned from the previous process. Empirical qualitative data was collected through a focus group formed to validate the process. I was able to capture insights from practitioners and discuss the co-creation instrument applicability after a theoretical presentation.

The empirical data was analysed by doing a simplified exercise of axial coding and interpretation. Axial coding is a qualitative research technique that involves relating data together to reveal categories within participants' voices collected. It is one way to construct linkages between data (Allen 2017). The technique allowed me to identify main topics for reflection and improvement of the work, as requires an action research methodology.

4. Results

The stakeholder engagement framework (SEF) designed for the energy efficiency residential buildings roadmap in India was based on literature review, stakeholder engagement handbook consultation and insights I got from a structured interview with the practitioner responsible for previous regional roadmaps. Differently from the former process, SEF covers different levels of engagement to make the process more meaningful and strategic.

SEF introduces three steps for conducting the engagement process. The results presented cover only activities involved in steps 1 and 1.2.

Table 2: Stakeholder Engagement Framework (SEF) synthesis (Glowacki 2020)

Step by step						
Identify	Prioritise	Understand	Co-creation	Plan	Act	Evaluate
1. List 2. Categorise	3. Power/ Interest 4. Add other context-specific classifications	5. Correlations SH x MB and narratives	An instrument to enhance participation	6. Selection of engagement level(s) and methods 7. Kick off webinar	8.Implementing activities and obtaining outcomes	9. Indicators to learn and improve 10. Report
	STEP 1: Analysis		STEP 1.2:	STEP 2: Strategy		STEP 3: Assessment

IDENTIFY AND PRIORITISE: Encompasses to gather information necessary to start picturing the existent actor's landscape in the buildings sector and create categories to help prioritise the constellation of stakeholders: power, interest, link with roadmap themes, description of mandate, among others.

This first map (figure 2) shows stakeholders divided into 11 broad categories. Different nodes size represents the power of influence that each stakeholder has in the buildings sector. The map also reveals how energy efficiency crosses different disciplines, raising the importance of multiple benefits as there are different motivations and interests from various stakeholders.

To design a strategic approach for the engagement not only based on extensive consultation, I used the spectrum of public participation developed by the International Association for Public Participation (IAP2). It proposes five types of engagement: inform, consult, involve, collaborate (Figure 3).

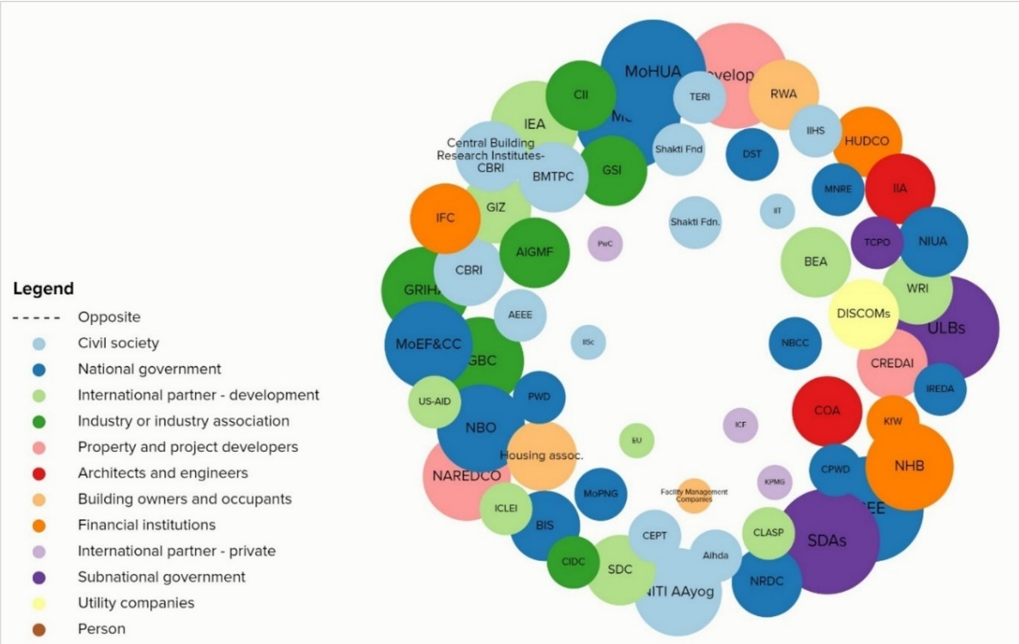


Figure 2: The constellation of stakeholders x influence in the building sector (Glowacki 2020)

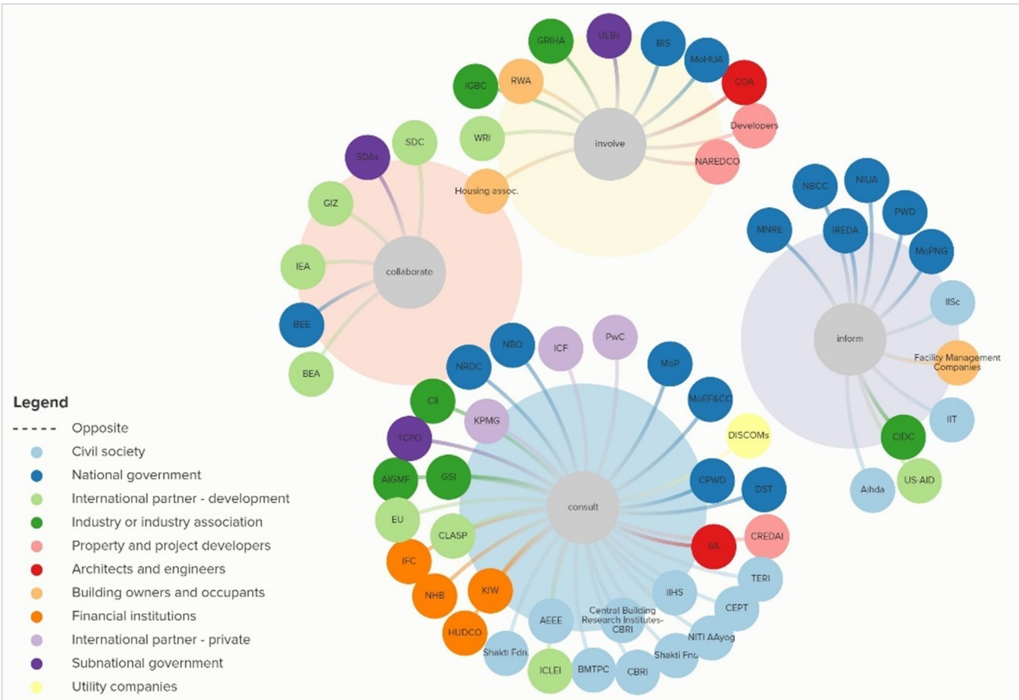


Figure 3: Stakeholders x level of engagement (Glowacki 2020)

UNDERSTAND: For this session, I developed the matrix of multiple benefits (MOMB). It was designed to improve the dialogue with stakeholders through:

1. Building narratives

- Establishing correlations among multiple benefits and stakeholders to help build context-specific narratives on gains from implementing energy efficiency measures
- Presenting key data to stakeholders (emissions reduction, air quality improvement, energy savings, resource efficiency, job creation, poverty alleviation, health benefits, safety, and security) illustrating the potential benefits but in a tailored manner.

2. Refining the target-audience for reports, webinars, workshops

Table 3: Matrix of multiple benefits x stakeholders – MOMB (Glowacki 2020)

Type	Multiple Benefits/ Stakeholders	Project developers	Architects /	Industry association	Financial	Sub-national govt	National govt	Utility companies	Civil society	Building owners	Building occupants
Energy system	Increased Energy Security										
	Reduced Energy System Costs										
	Increased Integration of Renewables										
Economic	Increased Energy Productivity										
	Creation of Jobs										
	Increased Affordability of Services										
	Freeing up of Public Budgets										
	Increased Competitiveness of Industry										
	Higher Asset Values of Real Estate										
Social	Increased Energy Access										
	Better Health and Wellbeing										
	Increased Safety and Security										
	Increased Resilience to Extreme Weather										
Environmen-tal	Reduction of GHG Emissions										
	Improved Air Quality										
	Increased Material Efficiency										

This association results in progress on the process of, first, making the multiple benefits more evident, revealing to the stakeholders what energy efficiency can provide and second, understanding how better engage with them in a project.

A two-way FLOWER represents this linkage moving from the classical approach where energy efficiency means only energy saving to the unidirectional FLOWER reaching the two-way in which stakeholders (SH) are part of the constellation and the multiple benefits (MB) act as mediators between them and the energy efficiency.

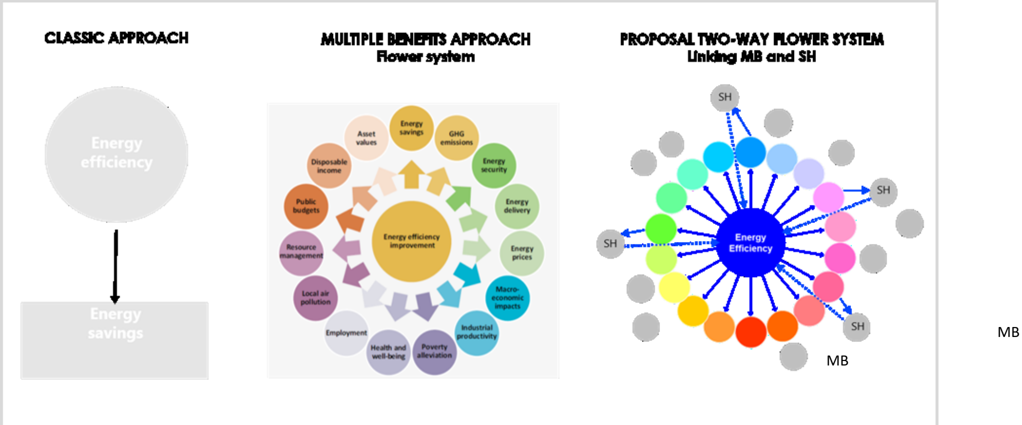


Figure 4: A progress process approach to energy efficiency (Glowacki 2020)

5. Discussions

While having proposed improvements to the engagement process by developing a framework this section explores how the engagement can be enhanced when utilising the co-creation instrument. This section is made up of three parts. First, a presentation I made to colleagues showing the theoretical conception, second, a validation of the process, when I collected their perspective as practitioners on the applicability of such instrument and, finally, an analysis that allowed to calibrate the instrument making it more suitable for the roadmap purposes.

The main aspect of the presentation was to explain that although SEF is designed in a more strategic way assigning stakeholders to different levels of engagement, the focus remains on consultation. In order to enhance collaboration, I revisited De Koning et al. (2016) spectrum to propose the co-creation instrument seeking to promote the inclusion of stakeholders and foster innovation. The instrument has different degrees according to the influence stakeholders have on the input.

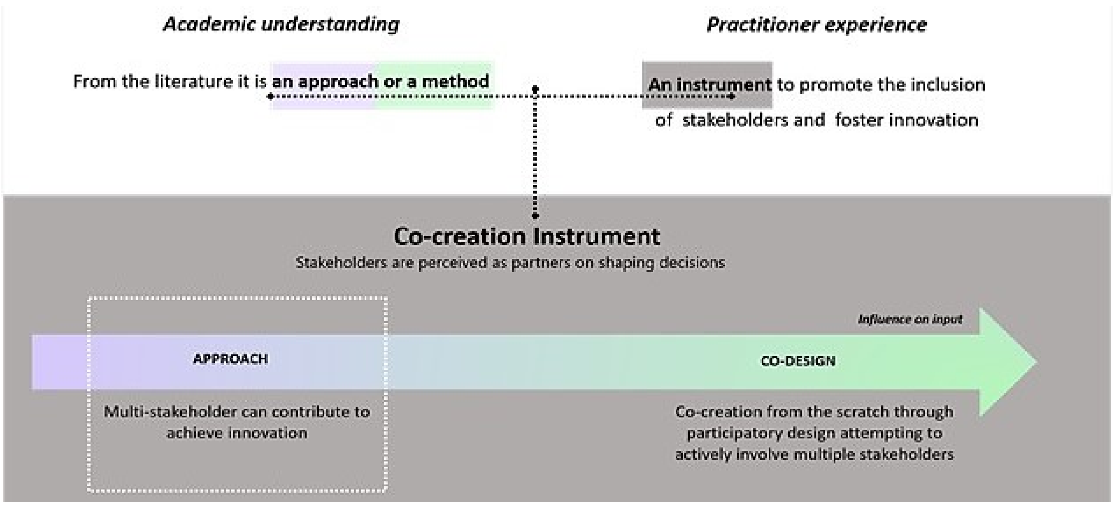


Figure 5: Conception of co-creation instrument (Glowacki 2020)

Approach represents the most moderated way of conceiving co-creation. It is based on the notion that multi-stakeholders mean a variety of knowledge, and this can lead to innovative solutions. On the other hand, co-design is the most extreme approach, requiring participation from scratch. It is related to the 'right to participate' and Arnstein conception.

Approach is based not only on salient stakeholders (government, i.e.) but seeks for embracing a diversity of stakeholders in the collaborative level. Penta-helix sessions are considered the forum of co-creation and multiple benefits mediators to shape common interests and facilitate knowledge sharing.

The second part refers to the validation process where I collected the perceptions of the practitioners on these ideas. The discussion was guided by a few questions such as: How could this idea be incorporated into practice? Could co-creation add value to the E4 programme? In the context of the India roadmap: raise possible challenges, barriers and benefits. To illuminate the data collected I created categories and organised the data.

Table 4: Codifying perspectives raised by practitioners in the validation process (Glowacki 2020)

Challenges	Barriers	Benefits	Opportunities
Too many stakeholders	Time-consuming EE closed community Common language	Calibrate target-audience MOMB a great tool for internal and external exercise	Enable a network Expand closed circle Mainstream EE in project other main objectives

4.1 Calibrating the co-creation instrument

After the analysis of the data collected from the focus group session with practitioners, I started a process of critically reflecting on the model and the co-creation instrument I have conceived and presented. Alluding McNiff (1995), in his inaugural paper 'Action research for professional development: Concise advice for new action researchers', I started to question myself - How do I improve my work? The table below summarises some points on the co-creation discussion to help build an answer to the question.

Table 5: Summarising themes for the instrument calibration (Glowacki 2020)

A	B	C	
THEME	THEORETICAL INGREDIENTS	PRACTITIONER FEEDBACK	
1. Multi-stakeholder approach	Key to foster innovation	Time-consuming	Find a balance and prioritise with whom collaborate
2. MOMB	Key tool to two-way FLOWER - linkages among stakeholder and energy efficiency	Useful tool for an internal exercise so that the organisation understands what precisely the benefits represent to each stakeholder	An important piece to deliver the right message to the stakeholders in the right language
3. Penta-helix sessions	Forum of co-creation. It is key to integrate penta-helix using multiple benefits as mediators	EE is a closed community	Enable the right network and the IEA can play the facilitator bringing people that usually do not talk to each other

McNiff's question can be rephrased as how comments from the column [C] can improve the applicability of themes in column [A], having into consideration that there is the will of putting co-creation somehow into practise?

As time passes working there, it becomes progressively clear the enormous potential that the IEA has on facilitating conversations and interactions among stakeholders. Moreover, this is one of the most powerful values the E4 programme has. Hence, to take advantage of such critical position the previous theoretical model needs to be calibrated at the themes (1) penta-helix approach, and (3) sessions to accommodate these ingredients of the approach level in a better way.

Lund's thought on co-creation as including diverse forms of knowledge in urban processes to build innovative solutions to complex problems is the hook to come up with another type of scale for the instrument. It means that the focus is not on influence on the input, where only direct collaboration in a moderated or extreme version is legitimate. Instead, a qualitative scale for the level of collaboration desired in a project and its impact on the input and output can be more significant, reuniting Arnstein's (input) and Lund's (output) perspectives.

In other words, it embraces a spectrum of collaboration from ways of making part of the decision to the ability to solve problems and find innovative solutions collectively.

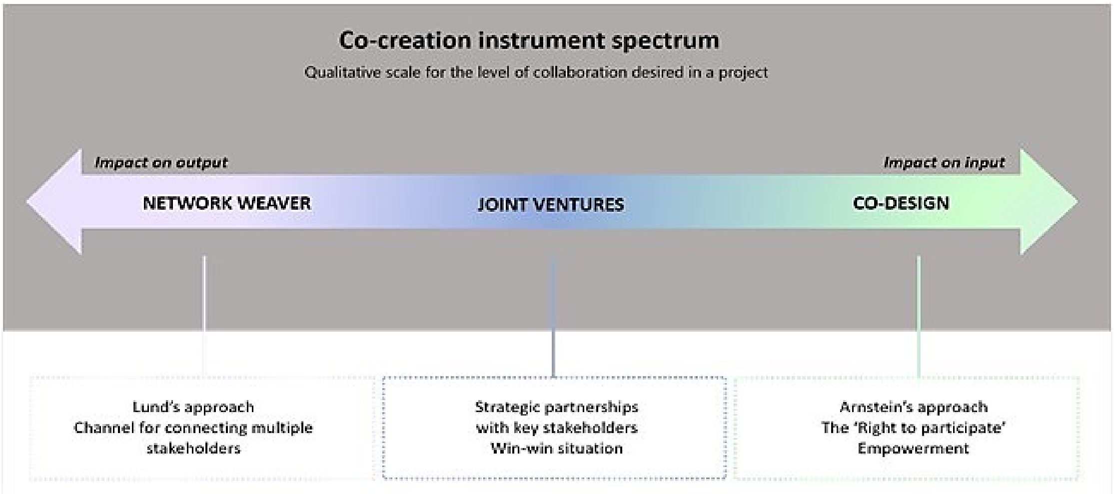


Figure 6: Calibrated co-creation instrument spectrum (Glowacki 2020)

The calibrated instrument ranges from the network weaver, joint ventures and co-design. The network weaver enables connections and synergies to happen, and ultimately it helps flourish bottom-up initiatives. In the network weaver, the IEA does not collaborate directly with several stakeholders but facilitates and creates a channel to an emerging and intentional network (penta-helix) be formed. In this way, it becomes a more strategic and less time-consuming process.

Joint ventures seek to make partnerships based on the idea that, especially in developing countries, projects may have other priorities rather than pure energy efficiency, even though they represent an opportunity to mainstream measures and address the climate agenda.

Aligned to this calibration, theme (2) matrix (MOMB) keeps being an essential tool. Nevertheless, instead of enhancing collaboration, it can be used for possible linkages to improve stakeholder connectivity.

In a short-term, the network weaver level can be a channel that makes stakeholders as part of a roadmap community, promoting cohesiveness to the sector. At the same time, in the long-term, it turns out to be a resilient network with stakeholders more aware and willing to implement roadmap targets, thus helping the sector get on track and meet climate targets. Besides this, the network weaver can facilitate knowledge sharing and generate data around the multiple benefits, building more pieces of evidence.

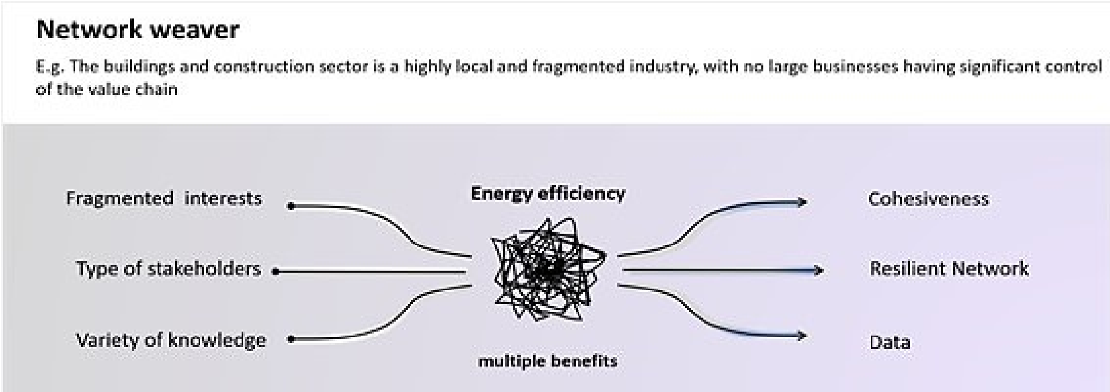


Figure 7: Visual synthesis of network weaver for the buildings sector.
Based on the OSMOS scheme. (Glowacki 2020)

As per such reinterpretation, also reviewing the role of a roadmap itself helps set co-creation accordingly. In addition to providing guidance, targets and time for policy adoption, a roadmap can stimulate the growth of a network. In other words, it can be at the same time normative while a platform to implement the network weaver level of co-creation.

The platform can come in various forms and scopes, ranging from volunteer-based alliances to formalised structures. Regardless of the format, it should encompass good practices dissemination, policy proposals, discussions, dialogue, awareness-raising, and even training around the multiple benefits.

Given this conceptual calibration in the co-creation instrument and its applicability, it makes sense to return to the literature and substantiate some ideas presented.

4.1 Back to the theory – Insights from social network and transitions theory

Actors organised in networks are considered essential for changes. Research on networks highlights their vital role in the adoption and implementation of reforms and the development of innovative practices (Therrien & Normandin 2020, 2). Networks of actors working together are seen to be especially useful in dealing with complex multi-level problems, such as those related to the environment and adaptation to the climate crisis.

The social network theory views social relationships in terms of nodes and ties. Nodes are the individual actors within the networks, and ties are the relationships between the actors. The emphasis lies on the relationships and the ties between actors within the network, and the structure and the quality of the relations are the main determinants of its usefulness to its participating individuals (Caniel and Romijn 2008, 614).

Therrien & Normandin (2020, 4) point out that the heterogeneity of actors in a network reflects the sharing of information and resources, access to specialised resources and interorganisational learning. Connecting actors fulfil a crucial strategic function, helping to build consensus and enabling the transfer of information and ideas. A particular type of linking actors is called bridging organisations (Kampelmann et al. 2016, 2) whose objectives are overcoming barriers to cooperation and they occupy a special role in the network structure as they serve as 'glue' between actors (Chassagnon 2011).

Kazadi et al. (2017, 527) cited in Reypens et al. (2019) says that innovation network theory can shed light on how organisations may integrate multiple stakeholders during the innovation process. In many activities, the locus of innovation is not the individual organisation but rather its network. Innovation networks combine dispersed resources, knowledge, and capabilities. Broadening the discussion, it is relevant to bring to the discussion the transitions theory that sees social networks a relevant process. Many scholars have been arguing that to counteract path dependence, inertia, and lock-in genuinely transformative change must be the result of alterations at every level of the system simultaneously (Sovacool 2016, 3).

Geels (2014, 4) explains that, according to the transitions theory, changes occur through interactions between three levels: the niche (the locus of radical innovations), the regime (the locus of established practices and incumbent actors concerning existing systems), and the landscape (exogenous developments or shocks – such as climate change). Concerning niches development, three internal processes are identified crucial: (1) the articulation and subsequent convergence of visions, (2) learning and experimentation and (3) the building of social networks. The convergence of actors' perceptions refers to the degree to which their strategies, expectations, beliefs, and practices go in the same direction (Hermans et al. 2012).

In a nutshell, Sovacool (2016, 3) explains that niche-innovations build up internal momentum (through learning processes, price/performance improvements, and support from influential groups) that lead to changes at the landscape level, creating pressures on the regime. The destabilisation of the regime creates windows of opportunity for the diffusion of niche-innovations. The theoretical dialogue between stakeholder management, network system and transitions theory help extend the focus beyond a focal organisation. Thus, the stakeholder management gains a more critical role in the context of decarbonisation pathways, by expanding its scope of influence (scattered stakeholders) to the management of network structures that, ultimately, is a component of niche-innovations development.

6. Implications and Conclusions

Recent debates in the field of energy transition call for better coordination of agencies and stakeholders across organisational and sectorial boundaries, arguing that this would ultimately improve to accelerate the process (Huck et al., 2020, 3).

Overall, the study is aligned with this debate and claims that improvements to a stakeholder engagement process in policy design, reflected in the roadmaps, are an entry point for transformative changes. As an embedded researcher, these improvements to the energy efficiency buildings roadmap consist of two main aspects. First, using a stakeholder engagement framework makes the process more strategic and ensures involvement in the project appropriately by assigning levels according to their characteristics. This process is focused on the work between the organisation and stakeholders (nodes).

Second, using the co-creation instrument to enhance relationships between the buildings' sector stakeholders and improve their connectivity (ties). By facilitating a shared channel, the instrument weaves scattered stakeholders and structures a network, making stakeholders as part of a roadmap community and nurturing a future resilient network. Also, while strengthening linkages between stakeholders, it encourages bottom-up initiatives to happen.

Nonetheless, theoretically, while an in-progress concept, co-creation requires some boundaries to be defined, but it also accepts increments, and both will make it get more meaningful over time. Indeed, this is the idea behind the design of the instrument. By establishing a scale on the type of collaboration desired, either an input or output, co-creation instrument accumulates pre-existent definitions (design and business) and integrates a new layer (social network) that confers the *zeitgeist*[1] (sustainability) to it.

Practically, the instrument offers the possibility for organisations like the IEA to add value to their programmes, reinforcing the role of bridging organisations (Kampelmann et al., 2016, 2) and strategic function of facilitating the connection between stakeholders and the transfer of information and ideas.

The research was linked to the development of a project, consequently, followed its pace and achievements until July 2020. Therefore, this study had a time constraint concerning the action research development, which was partially completed, covering planning and acting activities. Future research can be dedicated to observing and reflecting activities in order to conclude the action research spiral, investigating the implications of network growth and connectivity and its possible link with the flourishing of bottom-up initiatives in the context of getting on track and accelerating decarbonisation targets.

The literature review points out that the network approach to stakeholder management theory has only been barely touched. It is still under debate how networks and their structure should be used in the management of stakeholders. Therefore, it expands the field of studies beyond the usual focus centred on the relation between the organisation and stakeholders. Analysing and identifying how bridging organisations (Kampelmann et al. 2016) make the work of weaving networks visible and tangible can also be an important contribution to move forward in practical terms.

[1] Zeitgeist is a word used in German philosophy, meaning the spirit of the age. It refers to an invisible agent or force dominating the characteristics of a given epoch in world history.

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Touchpoints and behavioural mechanisms: Strengthening energy conservation in the residential sector

Oliver Carlo

Abstract

Policymakers are leveraging the use of behavioural insights to tackle a myriad of demand-side management issues, including encouraging energy conservation behaviour among consumers in the residential sector. But apart from few large-scale policies, many BI interventions are stuck in the trial phase - because they are not able to pinpoint the underlying behavioural mechanisms that help develop persistent and scalable policy measures. Touchpoints – the part of the user experience journey that is that is key to performing a behaviour – could be pivotal at developing the necessary behavioural mechanisms. Touchpoints also form the interface through which policymakers can interact with energy consumers to encourage energy conservation behaviour. This research analyses the relationship between energy consumers and touchpoints, and then offers suggestions to how policymakers could generate strong behavioural mechanisms through touchpoints. Using several case studies analyses and expert interviews, this research draws out generalisations from the relationship between human and touchpoints that are relevant to the use of behavioural insights for energy conservation policies in the residential sector, and concludes with three mechanisms that could strongly be leveraged from touchpoints – the consumers' perception of the touchpoint, a sense of ownership, and the ability to close the cue-action-reward loop – which could lead to persistent and scalable BI policies.

1. Introduction

Cities consume the larger chunk of energy demand today. In 2013, urban areas around the world accounted for about 64% of global primary energy use (IEA 2016). As this share continues to rise as cities grow, the world is seeking to make more efficient use of its energy resources to improve energy security, curb pollution levels and many others (IEA 2016).

While technologies are an important determinants of energy supply and demand, people's behaviour towards these technologies ultimately determine energy use (IEA 2019), and is an important element in managing the demand-side response.

However, encouraging energy conservation (EC) behaviour among humans is not an easy task. Humans have biases, which can be defined as deviations from rational decision making (OECD 2017). These biases affect our decision-making abilities. Hence apart from traditional policy instruments (such as regulations, taxes, etc), policymakers are increasingly recognising the need to incorporate behavioural insights (BI) to implement more effective policy interventions (OECD 2017).

Behavioural insights denote knowledge acquired from behavioural sciences (behavioural economics, psychology and neuroscience), which can then be applied to policy interventions – including those tackling energy and environmental-related issues (OECD 2017). However, there is currently no platform that collates policymakers' practical experiences applying BI specifically for energy policy (BIE) (IEA 2019). Some reports have attempted to extract key lessons from individual BIE polices (OECD 2017; OECD 2017). However, the analyses were generic, without going into depth in any sector (IEA 2019). Moreover, many of these interventions were experimental, with little influence on large scale policy interventions.

The reason is that moving beyond experiments towards large-scale measures requires behavioural changes (brought about by BI policies) to be persistent and scalable (Marchionni & Reijula 2019; Grüne-Yanoff 2016). However, this is not easy to establish. Many proponents of BI policies seem content with difference-making/ statistical evidence, i.e. the evidence that a putative causal factor makes a difference to the putative effect in a specific environment. But studies have critiqued this approach by stating a need for mechanistic evidence to support difference-making/statistical evidence (Marchionni & Reijula 2019; Grüne-Yanoff 2016).

This paper argues in defence of 'touchpoints' that are critical to any BI policy intervention, and further, explore how touchpoints could offer the mechanisms for robust and persistent BI policies. Touchpoints can loosely be defined as a critical consumer experience that triggers a specific (or multiple) behaviours. However, it is also the interface through which policymakers communicate with energy consumers to encourage/ trigger EC behaviour. For instance, it could be the monthly mail delivered energy report (touchpoint) delivered in a specific format which tries to encourage EC behaviour among consumers.

But touchpoints are more than mere objects, as consumers may form relationships with touchpoints. Exploring the existence and of these relationships should be key to exploring the underlying mechanisms. Since this relationship may vary across different sectors (such as residential, transport, agriculture, etc), the scope of this research has been limited to understanding BI policies that try to encourage energy conservation (EC) behaviour for the residential sector only (BIECR).

This research aimed to analyse the touchpoints employed in the field of BIECR and sketch out mechanisms that facilitate robust, persistent, and scalable BI policies. This was done by:

- Critically identifying as many policies and program types (including tests/ trials)[2] that have leveraged the use of behavioural insights for energy conversation in residential households (BIECR).
- Summarising these 'identified' intervention types.
- Interpreting commonalities/ generalisations observed between residential consumers and touchpoints that facilitated the development of mechanistic relationships.
- Summarizing key mechanisms between consumers and touchpoints that may assist with developing more robust, persistent and scalable BI policies for energy conservation in the residential sector (BIECR).

2. Background

Standard economic principles – such financial incentives and regulatory instruments – sometimes fail in bringing about the desired level of behavioural change. Take for instance an example from the UK; Customers have the choice of actively shopping around each year for a fixed tariff from the energy market which could be around £300 cheaper than the default standard variable tariff, yet they do not. (Tyers et al. 2019). From this example, it can be noted that traditional economic perspectives do not suggest that customers would choose energy deals that maximise their utility or financial well-being (Tyers et al. 2019) – a phenomenon earlier introduced as biases. Understanding human behaviour is crucial to addressing these

[2] Throughout this report, the reader will encounter several words like policy, program, tests, trials, measures, interventions or projects. However, the underlying meaning behind each of these words is the same; they all refer to some BI intervention. It was not possible to replace these with a single word, as this may change the meaning. However, the essence behind the word is to be considered. So for example, if through this report the reader has identified the word 'policy' has been incorrectly called a 'project', then the reader is humbly requested to please ignore any such errors, and instead give cognizance to the essence of the message.

biases and addressing new and complex policy problems (OECD 2019a).–Certain types of biases that BI policies try addressing are loss aversion, status-quo bias, representativeness heuristics, and cognitive dissonance (OECD 2017; Kahneman & Tversky 1972).

This is important to the energy sector because the interaction between humans and the energy systems falls under the umbrella of the socio-technical system (STS), where STS is argued to be the explicit intertwining of society and technology (McMeekin & Southerton 2012). Today, energy is also associated with several perceived negative effects – such as energy poverty, reduced energy security, increased emissions, etc. Besides, the increasing use of energy in urban areas contributes towards the urban heat island (UHI) effect (Giridharan & Emmanuel 2018). Hence STS transitions are viewed as a major interdisciplinary research challenge (Li et al. 2015), and human behaviour plays a critical role for EC in urban areas. As stated by Li et al. (2015), "*…transition of today's energy system to a state with dramatically lower greenhouse gas emissions is not only a technical matter. The behaviour, values and strategies of individual actors as well as policies, regulations and markets also shape energy system transitions*" (Li et al. 2015)." This is where BI policies take the floor.

BIs represents the input to the policymaking process, and can also integrate with other forms of traditional policy interventions such as regulations, information requirement, incentives, and even nudges (Lourenço et al. 2016). Hence while nudges assure a change in the output architecture, BIs are an input approach that may even suggest that no intervention is probably the best solution (Lourenço et al. 2016).

The report by the Joint Research Centre of the European Commission provides a taxonomy for BI that inform the policy process (Lourenço et al. 2016; OECD 2017). These are given in Figure 1.

- ***Behaviourally tested interventions*** are "initiatives based on an ad-hoc test, or scaled out after an initial experiment";
- ***Behaviourally informed interventions*** are "initiatives designed explicitly on previously existing behavioural evidence"; and
- ***Behaviourally aligned interventions*** are "initiatives that, at least a posteriori, can be found to be aligned to behavioural evidence".

Figure 1: Taxonomy of the types of BI interventions
(Lourenço, Ciriolo, Almeida & Troussard, 2016; OECD, 2017)

To address various biases, BI policies make use of policy levers (OECD 2017). Most energy and environmental levers are shaped around the use of seven main types of BI levers, all taken from the OECD (2017) report and shown in Figure 2.

In addition to the levers mentioned in Figure 2, many policies also make use of multiple behavioural levers – which the OECD (2017) report has termed as "hybrid" interventions.

As stated earlier, the underlying issue that this research would like to address is that many small-scale trials do not see their way into large scale policies, despite achieving some degree of success through the evidence-based approach.

Grüne-Yanoff (2016) highlights that the reason is that 'evidence-based' policies should be made up of two types of evidence: difference-making evidence and mechanistic evidence. Difference-making evidence is usually obtained through statistical analysis and typically answers the question of *'how-much'* did the policy intervention change behaviour. On the contrary, mechanistic evidence answers the question of *'how'* did the policy intervention change human behaviour.

- ***Simplification and framing of information***: simplifying complex information can prevent information overload. Framing aims at representing information by consciously activating certain values and attitudes of individuals. The way information is framed can also affect how it is processed by its recipients. For example, energy efficiency labels can be framed to provide a sense of the relative ranking of an electric appliance with respect to the best-in-class one, and the savings that one could enjoy when switching to the latter.
- ***Changes to the physical environment***: the physical environment can substantially affect individual decision-making, especially in contexts in which choices are made spontaneously, on the basis of automated mechanisms and habits. Examples of such interventions are changes in the location and appearance (e.g. colour) of recycling bins, or the installation of automatic (sensor-based) water taps to curb water consumption.
- ***Changes to the default policy***: as individuals are prone to status-quo bias, they often postpone making decisions until or unless it becomes inevitable to do so. Defaults can, thus, have a great impact in contexts in which people are resistant to change. An example of such interventions is a change to the default setting of thermostats (i.e. to a lower baseline temperature in order to foster energy savings).
- ***Use of social norms and comparisons***: as individuals are social beings, not solely driven by their own payoffs, they are affected by the way people surrounding them behave (social norms), by how they compare to their peers (social comparison) as well as by moral injunctions. An example of this type of intervention is the comparison of a household's energy or water consumption to the consumption of a same-sized household in the same neighbourhood.
- ***Use of feedback mechanisms***: several routine behaviours, such as energy consumption or waste disposal, have considerable environmental impacts. However, these impacts are often not sufficiently salient for consumers. Providing them with timely feedback can make such contexts more transparent, increasing awareness of environmental externalities stemming from daily consumption choices. For example, real-time in-home displays connected to smart energy meters can provide real time feedback on energy consumption and costs.
- ***Reward and punishment schemes*** can be used as "carrots and sticks", associating a salient, material payoff to consumers' achievements. For example, rewarding households who have been particularly savvy with water consumption during scarcity periods may generate a positive norm for water conservation.
- ***Goal setting and commitment devices***: as individuals are bound by status-quo bias and inertia, effortful behaviour changes can be encouraged by setting specific and measurable goals and using commitment devices to regularly follow up on progress. One such example involves pinning down an objective of energy savings and following up on the objective with regular feedback and tips.

Figure 2: List of Behavioural Levers (OECD, 2017)

There is a strong interconnected nature between difference-making evidence and mechanistic evidence, as one usually improves confidence levels in the other (Illari 2011). But the argument I am trying to make is that of individual-level causal effects. In an urban population, the diversity of a population hampers the understanding of causal pathway mechanism functions. Adapting from the paper by Marchionni & Reijula (2019), this has been represented in Figure 3.

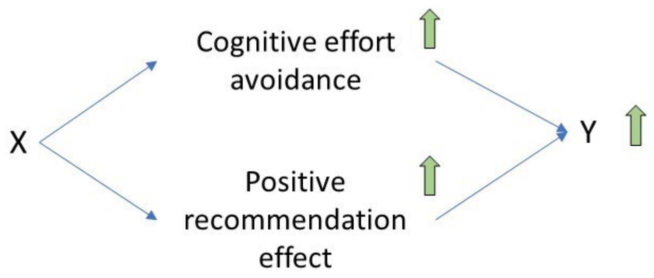

Figure 3: Assumed causal pathway mechanism function. X is the policy intervention; Y is the desired policy objective/outcome. Personal, adapted from (Marchionni & Reijula, 2019)

Figure 3 assumes that these mechanisms contribute positively to policy interventions. But what if one mechanism had a negative effect? What if the individual distrusted the policy measure or the government, such that the recommendation could cause a sum negative effect on the whole policy intervention by nulling the other mechanisms? (see Figure 4). Such was evident from a study in the United States, where it was observed that the political polarisation around environmental protection caused the politically conservative types to be less in favour of energy-efficient technologies than the politically liberal, which resulted in real-world ramifications (Gromet et al. 2013).

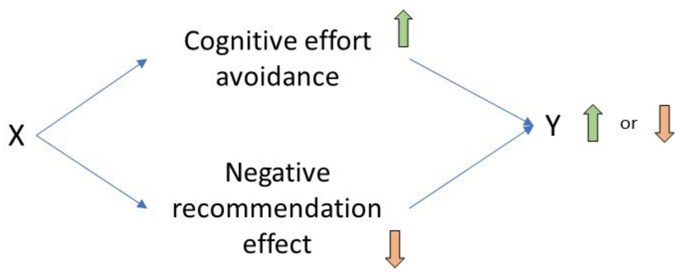

Figure 4: Assumed alternative causal pathway mechanisms function. X is the policy intervention, Y is the desired policy objective/outcome (Personal, adapted from (Marchionni & Reijula, 2019)

Touchpoints could be the key to the solution here, as they are the vehicles/gateways through which policymakers introduce BI levers into a consumer's life. The way these are introduced into a person's life, and the mechanisms which strengthen a consumer's relationship with the touchpoint could be the key to the mechanistic evidence that facilitates persistent and scalable BIECR policies. Ensuring a strong relationship between consumer and touchpoint may be relatively easier for policymakers – depending on how it was designed and introduced into a consumer's life, as compared to trying and testing different behavioural levers for its effectiveness since it takes a much longer amount of time.

Since touchpoints (and the BI lever they carry) are introduced by the policymaker, this research would strongly argue that touchpoints are much more than mere objects in a consumer's life, and some elements can be explored to further implement better policies. This research will not argue against the behavioural levers or the characteristics of touchpoints (like improving salience, prompting consumers, etc.) as it agrees with the underlying principles of these methods (OECD, 2019b). Instead, it factors in the mechanistic relationship between consumers and touchpoints to foster more robust, persistent and scalable BI interventions.

3. Method

The study was inductive and interpretive but leaning towards pragmatism. It adopted an archival research methodology that follows an 'across-case' approach – hence the cases studied were not homogenous. The cases studied were behaviourally tested (Figure 1), since findings from these cases were documented and publicly available. More importantly, reports released/ supported by policymakers (as opposed to academic research) were given higher priority. This is due to the freedom policymakers have in conducting randomized controlled trials to test interventions while reducing bias – freedom which academic institutions do not have.

The reason for studying heterogeneous cases was because finding mechanisms that are persistent and scalable involves assuming commonalities/ generalisations that can be consistently applied across different situations. The only way of establishing or interpreting these generalisation calls for analysis across a heterogeneity of variances – an idea that has been supported by other studies (Botella & Ponte 2011; Hammersley et al. 2000). In this study, there are only a few cases; but it should be noted that each of these cases only alerts the investigator to the presence of key elements within these cases (Ayres et al. 2003). My thesis is hence based on literature reviews suggesting that patterns of events observable across these heterogeneous case studies is what's necessary to identify commonalities, which should also recur in other case studies and hence be persistent and scalable (Ayres et al. 2003; Hammersley et al. 2000). Hence this research is based on an 'across-case' and not a 'within-case' approach.

Apart from this, three semi-structured interviews were conducted with professionals in the industry to complement the archival research study. In the words of Welch (2000), *"A comparison of the main differences between archives and in-depth interviews reveals that the two sources usefully complement each other in case study research"*. Welch (2000) further stated that it is it a form of triangulation – wherein the flaws of one method are strengths of another – and combining different methods should bring out the best of each while overcoming their unique deficiencies.

4. Results

As highlighted earlier, an across-case archival study was conducted. Eleven case studies in the field of BIECR were identified. These have been presented in Table 2.

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Table 1: List of cases studies considered (Carlo 2020)

Case Number	Title	Description
Case 1	Home energy Reports	In 2017, Japan's Ministry of Environment commissioned Oracle Utilities OPower to work with four major utilities across Japan to reduce household energy consumption (Oracle News Connect, 2019). Oracle collaborated with utilities to send quarterly Home Energy Reports (HERs) containing personalised energy usage information and efficiency advice to many households.
Case 2	Framing the health co-benefits of energy savings	In a University study , the benefits of framing energy savings as health benefits instead of cost savings were studied (Asensio & Delmas, 2016).
Case 3	Energy conservation during flexible tariff supply	In 2011, a University level study was initiated with assistance from RWE Effizienz GmbH, as the energy utility, and Miele & Cie.KG, as the appliance manufacturer (Stamminger & Anstett, 2013). This study was conducted among 67 households in Germany, to test whether smart appliances can enhance energy demand flexibility by looking at their impact on consumer behaviour when facing intermittent availability of renewable energy (Stamminger & Anstett, 2013)
Case 4	Default set-point for air conditioners	In early 2020, the Government of India leveraged behavioural insights in a bid to ensure that consumers stick to energy-efficient methods of consumptions. The government, in collaboration with the Bureau of Energy Efficiency (BEE), released a policy mandating all-new room air conditioners manufactured, commercially purchased or sold in India would have a default set-point temperature of 24 deg C (Government of India, Ministry of Power, 2020)
Case 5	CoolBiz': Changing set-point temperature and clothing style for summer	In 2005, the Ministry of Environment in Japan released the CoolBiz policy, encouraging businesses and the public to raise their air conditioning temperature to 28 degrees C, and also promoting a summer business style (CoolBiz) to encourage the business people to wear cool, comfortable clothing that allows them to work efficiently in offices where thermostats are set at 28 degrees C (Government of Japan, Ministry of the Environment, 2005)
Case 6	Reducing peak demand stress through challenges	In 2017, the Jemena Electricity Networks (in collaboration with Ministries and BI teams), an energy utility company that operates in the eastern states of Australia including Queensland and New South Wales, tested a demand response intervention informed by behavioural insights to reduce household energy consumption, especially during the periods of peak demand on hot days (Jemena, 2019).
Case 7	Eco-friendly heating modalities in France	A project similar to Case 2 was carried out by the Inter-ministerial Directorate for Public Transformation in France (DITP, 2020). This project leveraged BI by using health framed messages to reduce pollution linked with heating wood in residential spaces for warmth.
Case 8	Loyalty based smart challenge program	BC Hydro, an electric utility company in the province of British Columbia in Canada, created a voluntary loyalty program that has been running for many years. The program is called 'Team power Smart' (TPS) and works for its consumers by inviting them to participate in an energy-saving challenge and earn rewards (BC Hydro, n.d.)
Case 9	Smart meters and flexible time-of-use (ToU) tariffs	The Commission for Regulation of utilities in Ireland funded and supported the Economic and Social Research Institute (ESRI) to conduct experiments concerning the use of smart meters to explore consumer time-of-use tariff choice by leveraging the use of behavioural insights (Belton & Lunn, 2020)
Case 10	Apps to support flexible tariffs	PEAKApp and leafs are two separate field trials with similar objectives (Cohen, Kollmann, Azarova & Reichl, 2019; Reichl et al., 2019) - to tackle the challenge of developing smart services to better utilise electricity from intermittent renewable sources. This was done by leveraging behavioural insights and ICT devices. To achieve this objective, field trials developed an application for the participants who would have access to their consumption data via smart meter technology.
Case 11	Alternatives to the In-Home Display (IHD)	in 2016, the Department for Business, Energy and Industrial Strategy (BEIS) asked suppliers to offer customers alternatives to the IHD – with research that proves that these devices also offer similar energy-saving potential. Two energy suppliers in the UK undertook the research, to test how smartphone applications (apps) compare with IHDs (BEIS Behavioural Insights Team, 2019)

Table 2: Details of interviewees (Carlo 2020)

INT 1	Dr Kirk (name changed) hold a senior position in the Behavioural Insights Network of Netherlands. He overlooked the implementation of a project in the Netherlands that was similar to Case 1 in many respects, but was met with different results.
INT 2	Dr Lisa (name changed) hold a senior position at the French Behavioural Insights Unit in the Inter-ministerial Directorate for Public Transformation (DITP) in France. She was involved with Case 7.
INT 3	Dr Andrew (name changed), program manager at BC Hydro and overlooking Case 8– BC Hydro's Team Power Smart Challenge. He comes from an academic and professional background using BI.

From these cases, the following observations were made:

4.1 Touchpoint perception

The way in the BI interventions are communicated should preferably match the consumer's original perception of the touchpoint and not the other way around. This was based off a psychological study that discussed how objects and tools assimilate into our extended sense of the body (Carlson et al. 2010), and this perception of a tool's function remains tends to remain static.

For instance, many consumers tend to use their smartphone as a source of instant gratification device when browsing through social media applications such as twitter, Instagram, etc. (Wilmer et al. 2017). A similar observation was made through certain BI cases presented above, where push-notifications, reminders and gamification were necessary to maintain a consumer's strength of engagement with the touchpoint – signalling that the success of these interventions might have been aligned with consumer's regular perception of the touchpoint. To supplement this view, it was observed (through Case 10 and Case 11) that consumers soon became 'habituated' to push notifications – which might have resulted due to the lack of instant gratification rather than the prompt itself – leading to a loss in engagement. An antithesis to this argument could be observed from Case 8, where constant prompts were supported by constant novelty in the types of challenges/ tasks that the project team put out for consumers, leading to a much higher degree of engagement.

On the other hand, sending reports through paper format – in the form of HERs – allow for reading and reflection, since people are accustomed to using papers and reports for such purposes. Case 1 and Case 7 (along with an interview with INT 2) support this by claiming that people may tend not to read 'digital' information for too long. Paper reports, however, can stuck to a fridge and read multiple times, thus reinforcing EC behaviour. The success of HERs (Case 1) is a case-in-point.

This view is in line with representativeness heuristics – where people compare new situations to previously similar situations (Kahneman & Tversky 1972). Understanding how each consumer perceives a touchpoint could involve surveying consumers to understand whether they use their phone more frequently, read papers often, or even look at billboards a lot. A BI intervention should be able to benefit from the awareness of what each consumer perceives, and survey questions that record the responses received from each household could be utilized when designing the intervention. For instance, questions such as "do you read reports and papers you receive in the mail often?" or "do you constantly interact with your mobile phone for following social media trends/ reading news?" could hint at how each consumer perceives a given touchpoint. Since BI policies are often employed by policymakers and energy utilities that have localized operations, such personalized information may not be difficult to obtain and then tested (through RCTs) and could be very effective at scaling BIECR.

4.2 Sense of ownership

Another interesting observation is how touchpoints inculcate a sense of ownership among consumers, which could potentially lead to better and persistent results. This can be done by having the consumer sign up for the touchpoint in some manner, rather than 'defaulting' the touchpoint for the consumer. By saying that the consumer owns the touchpoint (such as a smartphone app or IHD), we can also stretch the idea to the point that the consumer owns his/her relationship with the touchpoint – i.e. energy conservation.

It must be noted that ownership is not to be confused with responsibility (Rae, 2018). While responsibility towards energy conservation behaviour is a necessity, this section argues that is more difficult to inculcate a sense of responsibility towards EC than it is to inculcate a sense of ownership for a touchpoint. Certain case study designs explicitly imbibed a sense of ownership. In Case 6, for instance, consumers had to 'sign up' for the energy challenges themselves – thus claiming ownership of the challenge and EC behaviour. In the end, high satisfaction levels of 91% and 78% (personal reward participants and community reward participants respectively) were expressed by the consumers.

Another case for ownership of a touchpoint can be inferred from Case 8, where people voluntarily sign up for the Team Power Smart (TPS) membership as well as its challenges. INT 3 further claimed that many consumers, after signing up for TPS membership and before receiving any specific challenge or EC tips, started behaving in such a way that they thought a TPS member should act.

These and many other observations noted from the other case studies suggest that, despite the use of 'defaults' as a reliable behavioural lever, a sense of consumer ownership of the touchpoint can have positively higher effect in EC behaviour. Hence, it may be more effective to ensure that the consumer is persuaded (and not simply coerced or defaulted) into owning the touchpoint, else it may weaken the BIECR intervention. More importantly, the touchpoint should be explicitly introduced as a vehicle of energy conservation (EC), and not merely as a display of energy information. This should help establish a concrete relationship between consumer and EC through the ownership of the touchpoint. Reflecting on a comment from INT 3, the consumer may then start "to act like act a little bit more like how they think or how they believe" the owner of an EC touchpoint should act.

4.3 Cue-Action-Reward (C-A-R)

The cue-action-reward system hypothesis presented here, based off neurological and psychological studies that test the effects of dopamine, demonstrates how touchpoints appear to be key agents in triggering rewards (and probably dopamine) (Syed et al. 2016), that could be pivotal in leading to robust and persistent behaviour changes. Also, a lecture video by Dr Robert Sapolsky, an eminent neuroscientist and professor at Stanford University, explains how dopamine surges are higher (in rats) if the reward (for right actions) are received by them only 50% of the time instead of 100% (Sapolsky 2011). This may suggest that the 'urge' to do a task is much higher when the rewards are inconsistent rather than consistent. This view also further built on one of the studies presented by Tomasi et al. (2018), where results showed that both closed task structures and a familiar interface have a positive effect on performance, while an open task structure and unfamiliar interface have a negative effect.

Case 1 appears to meet all these conditions, as the OPower HERs act as a 'cue', triggers a reward through social injunctive norms (emojis), and also contain 'closed-task' tips and actions (Allcott & Rogers 2014; see Case 1). Moreover, the rewards are not necessarily consistent; consumer energy patterns change every month and may not be below the neighbourhood average all the time. This could trigger the 'inconsistent' reward aspect of Dr Sapolsky's findings shared above, that may lead to an urge to perform the right actions.

Hence a question that may be worth asking is whether every consumer has received a reward at some point. It is unclear from the Case 1, but it can be argued that closing the C-A-R loop is necessary for each consumer. This could be explored by changing the scope of neighbourhood comparisons to a fewer/ closer group of households, such that every consumer demonstrates a lower-than-average energy consumption (among this new subset of neighbours) and is rewarded at some point. From a consumer's perspective, maybe he/she tried to perform some EC behaviour; however, the change could have been insubstantial to warrant a 'lower-than-average' social reward message from the existing subset of neighbours. I would argue that if the small actions are never recognised or complimented, the incentive to do more would fade within a short period.

Case 8, too, appears to support this hypothesis. The Team Power Smart (TPS) project by BC Hydro experimented with different types of challenges, and INT 3 claims that communicating single, specific behavioural actions followed by a reward leads to some very promising results. In Case 11, the BIT team noted that the 'traffic light' system of the IHD was passively noticeable all the times since it was always on, as compared to the smartphone app. It can be argued that this passive light from the IHD holds great potential in triggering a reward system.

It must be highlighted, however, that the reward is what makes the cue (Sapolsky 2011). This means that if the reward never existed, then the brain would not be able to associate/ register the cue. Having the touchpoint signal the cue while ensuring the mechanism for a reward should be the signs of an effective touchpoint. Moreover, it can be designed – which is a preferable and controllable scenario compared to letting the consumers figure things out by themselves. From the evidence, this should help build persistence and scalable BIECR policies.

<u>4.4 Chapter Conclusions</u>

Keeping in line with the spirit of what 'mechanisms' truly are – i.e. an arrangement or sequence of steps in achieving a particular end (thefreedictionary, n.d.) – a logic diagram has been constructed (see Figure 5) to capture each of the mechanisms suggested.

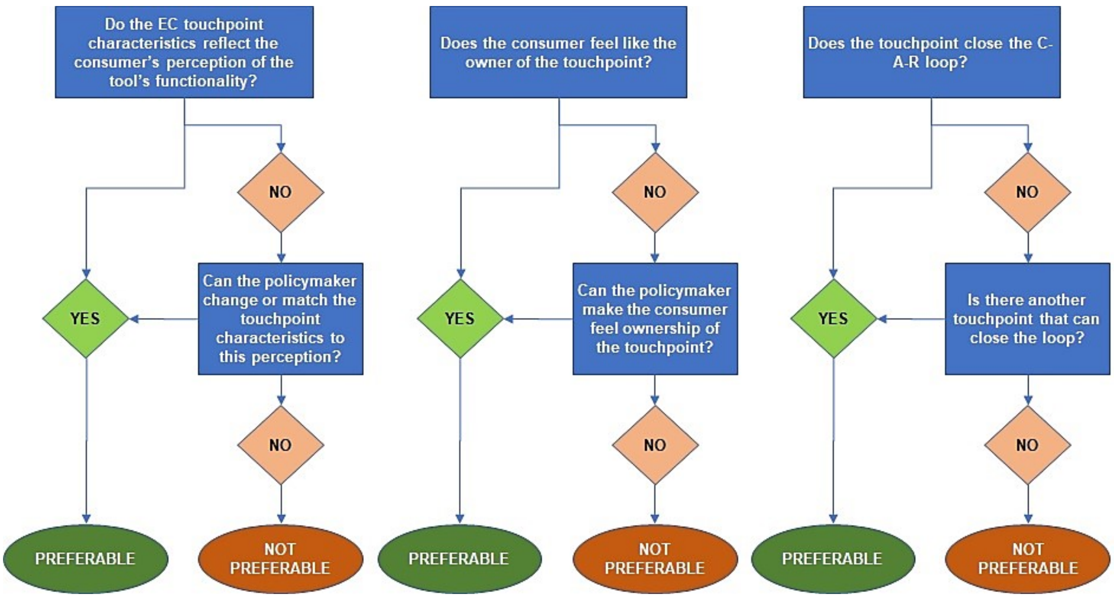

Figure 5: Three logic diagrams that combine the mechanistic evidence; C-A-R stands for Cue-Action-Reward (Carlo 2020)

While the logic diagram frames only single questions for each mechanism, it does not represent the entirety of BIECR policies that could be implemented. Therefore, additional questions that support these mechanisms have been suggested in Table 3. The questions are representative, and policymakers may benefit by aligning questions that are context specific to each type of intervention; the responses could guide policymakers in implementing robust, persistent and scalable interventions.

Table 3: Possible questions to facilitate a policy intervention that employs the mechanisms suggested here (Carlo 2020)

Touchpoint Perception	Sense of Ownership	Cue-Action-Reward
1. Do we know what sort of existing perceptions the consumer has about a potential touchpoint? 2. How well acquainted is the consumer with the potential touchpoint? 3. Is the tool leveraging these 'existing' perceptions of the touchpoint, or trying to create new ones? 4. Is the consumer well acquainted with the touchpoint interface?	1. Can the consumer voluntarily sign up for the touchpoint (or the message that he/she desires on the touchpoint) in some way? 2. Is the consumer fully aware that this touchpoint/ message is intended for energy conservation purposes?	1. Does the touchpoint trigger a reward mechanism for each individual? 2. Is the reward consistent or inconsistent? 3. Is the reward intrinsically or extrinsically motivated? 4. Is the action be initiated correctly? 5. Is the action tailored to the individual? 6. Is the action a closed or open task structure? 7. If the reward is a social comparison, is it local enough?

5. Implications and Conclusions

The archival study methodology – which includes across-case studies supported by interviews – aligns with the literature as a strong method of obtaining commonalities in research. While this method has been adopted for the study of BI towards energy conservation in residential households, a strong database of BI reports used in other sectors could hold similar potential in identifying robust mechanisms. Increased collaboration between policymakers around the world through intergovernmental organisations are key to developing such research.

Also reflecting on the logic diagram, I would argue that these mechanisms should be positive-effect-generating only. For instance, it can be suggested that receiving a reward is always better than not receiving a reward for EC behaviour. Mechanisms that could go either way, as suggested by Grüne-Yanoff (2016) in the case of the recommendation effect causing a positive or a negative effect depending on whether consumers trusted the government or no, could disrupt the overall mechanism; such equations while theoretically useful to know, are a deterrence in policy application and would be difficult to ascertain in a heterogeneous urban population.

Through this research, it has been implicitly noted how touchpoints are not mere objects, but rather share a 'social' relationship of sorts with the consumers through the three mechanisms – namely touchpoint perception, sense of ownership and the cue-action-reward loop. But they are based on interpretations through mixed data and lack clear evidence-based findings. Hence, future tests/ trials (like RCTs) are required to ascertain the role of these findings in increasing the persistence and scalability of BIECR interventions.

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