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Decision support to aid practitioners from a variety of fields

Practical solutions to flood risk reduction

Authors

Abhijith Mathiyathu Sebastian
Architect

Abhijith graduated with a degree in architecture from the National Institute of Technology Calicut, Kerala. He pursued a post graduate fellowship program where he gained critical experience in community engagement and placemaking. He went on to work in academia, where he created unique learning experiences for architecture and design students. MUrCS was an opportunity to broaden his academic curiosity while gaining practical knowledge and skills. During MUrCS he contributed to the OPERANDUM project, exploring nature-based solutions for coastal erosion in Catterline Bay. He currently works as an Active Travel Project Officer with Sustrans Wales. In his master's thesis, he interpreted Henri Lefebvre's Right to the City to evaluate active travel equity in Glasgow.

Anna Mackenzie
Architect and Urbanist

Graduated with a Masters in Architecture (MArch) with-distinction from Robert Gordon University in 2015. She qualified as a Charted Architect in 2019 whilst working on both public and private sector residential and masterplan projects across Scotland. Since completing MUrCS with distinction she has continued to work as an architect, focusing on sustainable and PassivHaus projects. She is interested in socially and environmentally sustainable place-based design and planning. Her thesis focused on the impact of the Covid-19 pandemic on local communities, urban planning, policy, and the opportunities presented by the 20-minute neighbourhood concept in Scotland as a place-based approach to a post-pandemic green and just recovery.

Arooj Humayun

Environmental Engineer and Sustainability Consultant

Arooj graduated as an environmental engineer from NUST, Pakistan and completed an MSc in Sustainable Energy Systems from Queen Mary University of London before joining this course. She has previously worked as a project facilitator for startups in her hometown as well as a government project on supply of potable drinking water in her province Punjab. On completion of this course, Arooj began working as a Graduate Sustainability Consultant across the Real Estate/Infrastructure team at Turner & Townsend in London working to help clients meet their sustainability and net zero goals.

Arooj's research focused on combining her knowledge from previous courses and MUrCS to analyse healthcare infrastructure in the UK and identify areas to improve for future carbon reductions. This study was developed using NHS Greater Glasgow and Clyde and Gartnavel Hospital as a case study.

Fernanda Berlitz

Architect and Urban Planner

Fernanda has a degree in Architecture and Urban Planning from Feevale University, Brazil. For over ten years, she worked as a project coordinator with focus on residential solar heating systems and photovoltaics. Before joining MUrCS, she worked together with residents of informal settlements to evaluate their strengths and vulnerabilities against floods and landslides. During MUrCS, she worked with the Operandum Project as a NbS team leader in Catterline Bay, UK, which provided the firsts insights for her MSc thesis. Her research built a framework and presented base evidence on Live Pole Drains as a Sustainable Drainage System for urban environments facing erosion, landslide, and particularly, flooding hazards.

Maryam Arshad
Environmental Engineer

After completing her bachelors in Environmental Engineering, Maryam spent three years working at WWF-Pakistan as a Senior Research Officer in the Climate and Energy Programme. Her main area of focus was the research and development of projects for climate change mitigation and sustainable cities.

Her MUrCS thesis was completed in collaboration with the Linstone Housing Association. It focused on developing a comprehensive decision support system for social housing within Scotland with the aim of presenting decision-makers with a holistic picture of the current housing situation and potential improvements that can be adopted.

Zarin Tasnim
Architect and Urban Researcher

I am an architect and urban researcher from Bangladesh. After pursuing my bachelor's degree in architecture from BRAC university, I worked under different architects like MTA and profound urban planners in Dhaka. My interest was to learn in a versatile manner and be part of many aspects of the city development field. Bangladesh's urban context led me to work in an exceptional platform Bengal Institute for the last three years. As a research and design associate, I have coordinated canal restoration and urban park projects.

I wanted to learn and experience the possibility of sustainable practices in a broader field through urban management and to incorporate creative features in innovative ways. From the MUrCS program, I have met professionals in diverse fields and gained a quality learning experience in public-enhanced urban management and climatology in diverse cultural contexts.

Chanodi Ratnayake
Architect

Chanodi is a graduate from University of Moratuwa, Sri Lanka, with a bachelor's in architecture. As a chartered architect she has work experience in large scale commercial, educational and administration design projects, with a portfolio on private residential and interior design projects. Having a keen interest to associate architecture with sustainability, she pursued a master's in urban climate and sustainability, where she investigated the role of street tree designs to improve the local air quality - in support of urban planning and policy constrains as her MUrCS thesis. Her interest continues to grow towards bridging policy formulation and implementation in climate adaptation and sustainable growth.

Evelin Elizabeth Bocanegra Ríos
Industrial Engineer

She graduated from the National University of Trujillo, Peru. She has several years of experience in the health sector as a programme manager, developing, executing, and monitoring Disaster Risk Reduction Plans. Besides, she evaluated the resilience of healthcare facilities and trained different communities and health professionals across La Libertad Region on Disaster Risk Management, Climate Change and Resilience.

Due to her interest in climate change adaptation and disaster risk reduction, her research focused on establishing a framework to help subnational-level health organizations develop adaptation plans using the NHS Greater Glasgow and Clyde as a case study.

Sayontani Chateerji
Architect

Sayontani is an architect from New Delhi, India, who has worked towards the implementation of sustainable infrastructure solutions in low-income settlements, under the USAID funded initiative for urban development through WASH (water, sanitation, and hygiene). Her work with the communities and urban local governance has provided her with a comprehensive understanding of informal neighborhoods and its relation to the city. She was able to capitalize on the strengths and capabilities of over 3500 households to have improved sanitation conditions through the design and implementation of low-cost toilets and pit systems, both at the household and community level, visibly reducing the practice of Open Defecation and Urination. Her experience made her want to explore further, the dynamics of a by which they must engage for sustainable development. The MUrCS program allows her to take that evaluation further and acquire the technical know-how needed for the holistic development of cities.

Mushfik Jalal
Urban Planner & GIS Expert

Mushfik obtained the academic foundation of Urban Planning and Development at his bachelor study. He completed Master's in GIS and attended several training programs based on spatial technologies and sustainable development. In the meantime, He has worked in Government and Private sector and gained professional expertise in preparing Risk Sensitive Landuse Plan. Pursuing MUrCS study program helps Mushfik to get exposure at international level and broaden the knowledge about urban microclimate. While urbanization is considered as a major driver of climate change, Mushfik believes the solution lies within cities through implementation of strategic urban development. To establish this notion, he conducted thesis on Heat Risk Mitigation and showed how the factors of urban growth can be managed in reducing the risk of temperature increase at city level.

Jonathan Lieber
Environmental Planner

He holds a Certificate in Urban Forestry and a Diploma in Ecosystem Management from Sir Sandford Fleming College and has over seven years of work experience with environmental planning and engineering projects. Before undertaking the MUrCS program, he worked with the City of Toronto as a Program Standards and Development Officer to assist with the creation of a Parkland Strategy for the city. His MUrCS thesis deployed a hedonic pricing model in Helsinki, Finland to assess how green infrastructure was impacting apartment listing prices. He is now a Ph.D. student in Civil Engineering at the Hong Kong University of Science and Technology (HKUST), specializing in urban climate modelling.

Josué Arrieta Solís
Environmental Engineer

He obtained his degree from the Costa Rica Institute of Technology, being part of the first cohort of Environmental Engineers of the country. He has served both in the public and private sector. During his professional career he has worked on topics spanning environmental impact assessment, waste management, environmental management systems, and carbon footprinting. His latest responsibilities included climate action planning, and providing inputs for the urban planning of San José, the capital of Costa Rica. His Master's thesis focused on how Mobility-as-a-Service solutions could promote a more sustainable mobility, and how their data could be useful for the planning of cities and town.

Lorena Mejia Villegas

Sustainability, Circular Economy and Climate Advocate

Professional in Cultural and Communicative Management, creates synergies and actions to enable sustainable and regenerative development. Identifies high impact solutions and connects them with decision makers and key stakeholders in industries and governments, promoting systemic thinking, and public, product, and cultural innovation, for a whole understanding and implementation of sustainability, transforming organizations and production means. Passionated about inciding in Sustainable and Climate Policy and making them effective. Consultant and Lecturer on topics like sustainable cities, circular economy, extended producer responsibility, corporate leadership and sustainable entrepreneurship. Her thesis was on how Resistance to Change affects Sustainable Management and Low Carbon Transition.

Luke Sebastian Evens

Access Consultant

Luke obtained his BA in Community Development from the University of Glasgow in 2017. After graduating, he held two roles within the UK Government; first with the Foreign and Commonwealth Office in New Delhi, and second with the UK Department for Transport in London. Both roles were focused on a broad range of policy matters.

After MUrCS, Luke began working for Arup's Accessible and Inclusive Environments team in London, as an Access Consultant.

Luke's research brought together environmental sustainability and active mobility, by analysing the microclimatic impacts and opportunities on bicycle infrastructure in Seville, Spain.

Mitia Aranda Faieta
Architect

After obtaining a master's degree in architecture from Politecnico di Milano, Mitia worked for over ten years in the field of infrastructure development and project management in different countries. During MUrCS he had the chance to conduct a research internship at LISST in Toulouse (Fr), where he developed his thesis project focused on metropolitan heat vulnerability and its link with the local authority's climate adaptation and mitigation operationalization needs. His professional interests stand at the intersection of urban development, climate and societal change with a focus on sustainable infrastructure, accessibility and social justice.

New Sha Modjrian
Urban Designer and Planner

Newsha holds a Bachelor of Engineering in Urban Planning from the University of Tehran and a Master of Arts in Urban Design. She has a few years of professional experience as a GIS consultant, designer and planner. As part of MUrCS' collaboration with the City of Lahti, Newsha with her colleagues presented a Development Plan for Nastola Church Village during a summer internship.
She was given the opportunity to take part in the SHAPE Sustainability Impact Projects, which were organised by The British Academy (BA) and Students Organising for Sustainability (SOS-UK). Newsha and four other GCU students received a £5000 grant from the British Academy to implement their sustainability solutions in the 2022-23 academic year. She strives to integrate machine learning into planning to promote sustainability in an urban environment, reach net zero targets and create resilient cities that provide an inclusive high-quality living experience.

Sonali Anusree Patro

Urban Environmental Planner

As an Architect and an Urban Environment Planner, she has comprehensive experience in the field of Urban Development, working majorly in the areas of Urban Water and Sanitation, Urban Strategies, Inclusive Infrastructure, Green Infrastructure etc. Her 5 years of experience in this industry extensively involves examination of scalable and sustainable solutions for urban problems, development of conceptual and implementable frameworks, development of urban tools for decision making, capacity building and training, stakeholder engagement etc. Her keen interest for being a part of creating more robust, efficient, and smart urban areas, has led to the journey of MUrCS program, which provided a rich experience through collaboration and research. To promote the understanding of sustainable and climate resilient urban systems, her master's thesis focused evaluating the impact and linkages between current green certification and assessment systems in relation to urban heat island mitigation and adaptation.

Saloni Paudel

Urban Drainage Engineer

Born and raised in Nepal, Saloni completed her bachelor's in civil engineering from Malviya National Institute of Technology, Jaipur. She had been working as a site engineer for a water supply and sanitation project for a couple of years when her deep-rooted interest in sustainability in the built environment became a catalyst for joining the MUrCS program. Her domain of interest is sustainable urban regeneration, land management, and flood management. Her experiences include a summer internship with OPERANDUM UK which involved the use of Nature-based solutions to tackle hydro-meteorological risks in Catterline Bay, Scotland. Currently, she is working as a Sustainable Drainage Engineer at Peterborough City Council.

Samson Ogunfuyi
Climate Scientist

Samson had his bachelor's degree in meteorology from the Federal university of technology, Akure. His first professional experience was with the NASRDA, where he used GIS and remote sensing technology to address real-world problems. Furthermore, he worked with Eagles orbit for two years before pursuing his master's in Urban climate and sustainability. During his MSC, he interned with GCRF as a research assistant, where he assessed urban heat risk conditions in Colombo, Sri Lanka. The research, as mentioned earlier, inspired him to work on quantifying the effect of anthropogenic and climate parameters on UHI using machine learning for his MSC thesis. Finally, he is excited about using his multidisciplinary skills and experience to find sustainable solutions to environmental crises.

Sumaila Mohammed (Kujar)
Development Planner

In 2010, Sumaila obtain a bachelor's degree in Integrated Development Studies at the University for Development Studies (Ghana). Afterward, he worked as a district development planning officer with the Ministry of Local Government and Rural Development of Ghana from 2012 to 2020. He obtained his MSc. in Development Management at Kwame Nkrumah University of Science and Technology (KNUST) in 2019. His professional expertise lies in development/project planning and management, and community engagement participation. He has worked with different stakeholders and partners to successfully implement projects and programs across various sectors (health, education, agriculture, etc.)

In 2020, he pursued another master's degree program (MUrCS) to broaden his knowledge and understanding of urban planning and its related issues like climate and sustainability.

Khadija Amir

Environmental Specialist

Khadija is an environmental specialist with core expertise and qualification in environmental sustainability. She holds postgraduate degrees in Environmental Sciences (2010, University of Peshawar) and Sustainable Development (2015, University of Exeter), she worked in the academia and development sector for over 10 years in areas of environmental and social impact assessment processes, environmental laws and policies, environmental safeguards, socioeconomic impact assessment, and stakeholder engagement.

After completing Masters in Urban Climate and Sustainability, Khadija is working as Partnerships Manager at Habitat for Humanity Great Britain looking after the Empty Spaces to Homes project addressing housing crisis in the UK. She is involved in developing a sustainability strategy for repurposing empty spaces into affordable housing where she brings her understanding of climate change science and policy in the urban context and help translate policy into local action plans focused on mitigation and adaptation.

Nerxhana Tallushi

Architect & Urban Designer

After earning a degree in architecture and urban design from the Polytechnic University of Tirana, Nerxhana worked for four years mainly with territorial governmental and tangible cultural heritage development programs. She pursued a specialisation in spatial planning and GIS use at Polis University during this period. She had the chance to work with the city of Lahti as an intern in Developing a vision for the Nastola church area as part of her MUrCS experience, during which time she learned a lot about the city's planning procedure and the wide-ranging community involvement. Her thesis focused on exploring the effects of UHI and outdoor thermal comfort on urban cultural heritage sites, as a first step in adapting these typologies of cities towards climate change.

Editorial

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In this third volume of the Thesis Proceedings of the **Master of Urban Climate and Sustainability (MUrCS)** Project (www.murcs.eu) we continue our efforts to link research into the practice of sustainable urban climate management. By continuing with the integration of our three thematic strands of education (Science, Planning and Management) we aim to showcase the possibility of a '*new professional*' able to understand, plan and lead the urban changes needed to tackle climate change in our time.

The most common theme in the present volume is **URBAN CLIMATE RESILIENCE**. **Aranda Faieta** presents a heat risk assessment approach and shows a proof-of-concept application for the metropolitan region of Toulouse (France), while a similar approach with more direct planning applications is championed by **Jalal** for Dhaka North City Corporation (Bangladesh) area. Specific urban heat island mitigation approaches elaborated in this year's proceedings include: **Modjrian** (machine learning applications to better target outdoor thermal comfort enhancement); **Ogunfuyi** (machine learning applications to quantify the heat island effects of anthropogenic parameters) and **Patro** (integrating heat island mitigation into sustainability assessment systems). **Tallushi** on the other hand, explores the heat island mitigation specificities in the context of a heritage city with high tourist footfall (Edinburgh, Scotland).

As was the case with the first two volumes of MUrCS Thesis Proceedings, the local climate functions of open and green spaces is the focus of **Tasnim**'s work.

DECISION SUPPORT TO AID PRACTITIONERS FROM A VARIETY OF FIELDS is the focus of four articles in the present proceedings. **Arshad** provides the theory and a proof-of-concept for a visual decision support system to redevelop social housing in Scotland while **Lieber** develops a hedonic pricing model to value green infrastructure on property prices in Helsinki (Finland). Similarly, **Mohammed** explores the lifecycle performance of waste-to-energy gasification in Glasgow. A further study by **Ratnayake** empirically determines effective street tree planting strategies to manage particulate matter pollution in city centres to support low emission zones (case study: Glasgow). While decision support is the focus of these studies, there is a need to understand how decisions are made, and – more importantly – why they do not lead to sustainable change. This is the focus of **Mejía Villegas**' study in the context of a Latin America.

PRACTICAL SOLUTIONS TO the key hydro-meteorological climate change **RISK OF FLOODING**, forms the next largest section of the proceedings. **Berlitz** proposes an easy-to-build solution to urban flooding by way of 'live pole drain,' while **Chateerji** explores the role of urban agriculture to address the same risk reduction and provides a decision support framework. Linking flood risk reduction to urban re-generation is the focus of **Paudel**'s work.

As can be expected from MUrCS, **CLIMATE CHANGE MANAGEMENT** continues to be an important theme of this year's proceedings as well. **Amir** evaluates climate change considerations in the Environmental Impact Assessment (EIA) framework while **Bocanegra Rios** provides a framework to develop health sector climate change adaptation plans at sub-national levels in Scotland. Health assets is also the focus of **Humayu**n who explores their operational decarbonisation.

A new theme to emerge in this year's proceedings is **ACTIVE TRAVEL**. **Mathiyathu Sebastian** provides a theoretical overview of 'right to the city' and its reclamation through active travel, while **Arrieta Solis** explores 'Mobility as a Service' (MaaS) to drive sustainable planning. **Evens** performs an empirical evaluation of bicycle infrastructure and the opportunities it affords to tackle both the microclimate as well as traffic problems in Seville (Spain). Relatedly, **Mackenzie** explores the 'twenty-minute neighbourhood concept' as the basis for sustainable and equitable communities in Scotland.

We hope these actionable research showcase the kind of possibilities that the 'new' professionals engendered by the MUrCS approach are able to achieve. Our hope is that urban practitioners and policy makers find these practical investigations to be of value in their quest to address climate change in cities.

Urban Climate Resilience

ARANDA FAIETA, MITIA XAVIER

Multicriteria heat vulnerability assessment for the Metropolitan region of Toulouse

Based on key findings of the IPCC's Sixth Assessment Report (AR6), "It is virtually certain that hot extremes (including heatwaves) have become more frequent and more intense across most land regions". Within this context, better understanding the impact of urban heat has become increasingly relevant. This work aims at contributing to this research area by generating an urban heat vulnerability assessment combining environmental, socioeconomic, and demographic data for the Metropolitan region of Toulouse (France). As part of its objectives, the study focuses on the potentials and limitations of composite indexes and heat vulnerability maps as operational tools for urban climate plans. Data collected from different sources was employed to perform a Cumulative Vulnerabilities Assessment (CVA). Results of the CVA were then crossed with other two previous heat vulnerability assessments' results obtained from the application of a Principal Component Analysis (PCA) and an Analytical Hyerarchic Process (AHP). The result of the three assessments was used to produce a combined heat vulnerability map intended to feed the Local Climate Plan of Toulouse Metropole, partner of this study. Results obtained highlighted hotspots of urban heat related vulnerability in the metropolitan region of Toulouse. Furthermore, the study found that composite indexes can be an effective tool to spatially visualize cumulative vulnerabilities tendency over the study area.

1 Introduction

According to the World Meteorological Organization (Douris and Kim 2021), 93% of the natural disaster related deaths in the past 50 years in Europe were linked to extreme temperatures. In the top 10 disasters ranked by deaths, comprised between the period 1970-2019, all the events correspond to extreme temperatures. France has the highest reported number of deaths, linked to heatwaves occurred in 2003, 2006 and 2015 -excluding the European portion of the Russian Federation. Considering the magnitude of these events and the reported trend for the future it is increasingly important to contribute toward the identification of heat vulnerability as a key component in planning, implementing, and monitoring climate change mitigation and adaptations strategies in cities.

If the global warming trend observed continues to progress at the same rates, heatwaves are likely to increase frequency and intensity, incrementing potential population exposure. Due to the phenomenon known as "Urban Heat Island", population in urbanized areas are likely to experience higher temperatures compared to those in non-urbanized areas, and therefore be more exposed to heat stress. Furthermore, studies suggest that within the same city, environmental exposure, demographic and socioeconomic differences among urban population sectors can result in different levels of heat vulnerability. Some groups have been identified as being more heat vulnerable compared to others, such as elderly and very young people, persons with disabilities and health conditions, persons with lower socio-economic status, persons socially isolated and minorities, among others (Leal Filho et al. 2018).

Spatially identifying urban heat-related vulnerability can support decision makers in taking informed decisions about where mitigation and adaptation strategies can be implemented, and/or where interventions should most effectively be deployed in case of emergency. Hence, a better understanding of urban heat related vulnerabilities can contribute toward the process of adapting cities to climate change. For instance, 'Toulouse Métropole', local authority responsible for the metropolitan region of Toulouse (FR), and its partners, have developed as part of their climate services, a network of meteorological stations that collect real time data across multiple locations. This research project is linked with the efforts of the Toulouse Metropolitan authority to develop and improve its climate services.

1.1 Aims and Objectives

This work aims at contributing towards heat vulnerability assessing and mapping in the metropolitan region of Toulouse -France, by integrating urban heat maps with environmental, demographic and socioeconomic data.

The following objectives have been achieved:

- Identification and review of existing literature in the field of heat vulnerability analysis and visualization.
- ecognition of the environmental, geographic, socioeconomic, and demographic data available for the study area.
- Construction of a multi-criteria heat vulnerability assessment based on state-of-the-art heat vulnerability research, available data, and specificities of the study area.
- Production of heat vulnerability maps for the metropolitan area of Toulouse at the finest scale available (commonly understood by urban stakeholders and easily adaptable to other scales) that could be integrated into the authority's climate plan 'Plan climat-air-énergie territorial (PCAET)'.

2 Background

While the potentialities of heat vulnerability (HV) assessments as tool to inform heat related interventions to protect people have been recognized (Bao et al. 2015), defining, characterizing, measuring, and mapping vulnerability remains challenging. Even though studies dealing with HV have evolved in the last decade, there isn't, up to date, a consistent, agreed upon and robust methodology to construct heat vulnerability indexes - HVI (Karanja and Kiage 2021). Albeit the facility with which HVIs can be relatively easily implemented in diverse contexts, Conlon et al. (2020) have identified how Principal Component Analysis (PCA) derived HVIs –the most commonly used methodology—are influenced by inputs data and mapping methods and how small differences in inputs parameters can lead to completely different results identifying different vulnerability hotspots depending on the researchers' choices. Hence, the importance of approaching heat vulnerability (HV) in a context-specific way that is aware of the limits of the proposed methodologies.

The recognition and mapping of different vulnerability factors, following a multi method approach as suggested by Alonso and Renard (2020), can be a useful approach to support local authorities in deploying tailored resources according to the different types of vulnerability. This procedure allows an enhanced descriptive spatial visualization of vulnerability in comparison to unified HVI that aggregates all vulnerability factors, some authors claim (Mallen et al. 2019; Conlon et al. 2020). While not widely diffused, variations of HVIs have been already adopted by some local authorities -mainly in Europe and USA- who have incorporated HVIs and HV maps into their tools and operational documents tackling climate change adaptation and mitigation. Similarly to the corpus of scientific literature, the approaches and methodologies employed by local authorities and their operational applications, vary largely.

Among the cities that have already adopted HVIs and HV maps: the city of Milan introduced HV maps into their '2020 Air and Climate Plan' (2020); Barcelona introduced a heat vulnerability index map in their 'Climate Plan 2018-2030' (2018) ; Sevilla utilized HV maps in their '2017 Climate and Sustainable Energies' action plan (2017) ; Vitoria-Gasteiz produced HV maps based on different climate scenarios within their 'Climate Change Adaptation Action Plan 2021-2030' (2021); New York City incorporated an HVI developed by Madrigano et al. (2015) in their 2017- 'Cool Neighborhoods NYC' (2017) – a document that identifies the heat adaptation and mitigation strategies for the city; Philadelphia has developed an HVI that is accessible online, which has been used to inform their '2021 Climate Action Playbook' (2021), guide community heat relief plans –'Beat the Heat Hunting Park' – (2019) and provide citizens with an open resource they can consult to know if they live in a vulnerable area of the city and what resources to cope with extreme heat are available to them in terms of community assets, like cooling shelters, pools and health facilities. In the latter case, HVI and HV maps works both as analytical tool to inform policy/decision makers and as communication/information tool for the community.

Within this broader context, this study aims at further expanding on the existing UHI mapping network developments achieved in the last five years by the Metropolitan authority of Toulouse crossing climate data from Toulouse's urban meteorological network with other data related to environmental, social, economic, and demographic information, in order to assess and map urban heat vulnerability in the metropolitan region, and identify hotspots were mitigation and adaptation intervention could be most beneficial. Hence, it is within this context that the study worked at the smallest available scale in France (French census IRIS unit), incorporating UHI intensity data and crossing it with other environmental, demographic, and socioeconomic data.

This work was developed in the framework of an internship conducted at the 'Laboratoire Interdisciplinaire Solidarités, Sociétés, Territoires' (LISST) at the 'Université Toulouse Jean Jaures' in France (https://lisst.univ tlse2.fr). The work, which lays under the wide Urban Climate thematic, was developed within the team of the 'Centre Interdisciplinaire d'Etudes Urbaines' (CIEU), under the guidance of Julia Hidalgo –senior researcher focused on urban climatology, climate change adaptation and mitigation in urban environments and operational urbanism –and co-guided by Guillaume Dumas –researcher engineer of the 'Centre National de Recherche Météorologiques' (CNRM) and at the metropolitan local authority 'Toulouse Métropole'

3 Methodology

This study employs the methodology known as Cumulative Vulnerability Assessment (CVA) to assess individuals' heat vulnerability in the urban environment. The methodology is derived from the 'Cumulative Risk Assessment Framework' developed by the U.S. Environmental Protection Agency -EPA- (2003). The CVA version employed in this study was adapted to the French context by Lanier et al. (2019) to analyse environmental inequalities caused by multiple air pollutants exposure in two cities in the north of France. The objective of the methodology is to assess cumulative vulnerability to environmental exposure factors (adapted in this case to urban heat) considering socioeconomic and demographic inequality determinants. The methodology allows to characterize and prioritize geographical units based on a cumulative vulnerability score enabling the visualisation of the areas with the highest levels of cumulative vulnerability. The cumulative vulnerability score is obtained through a tri-dimensional matrix composed of an Environmental score (S env), a Susceptible Population score (S pop) and a Socioeconomic deprivation score (S pop) (Figure 1).

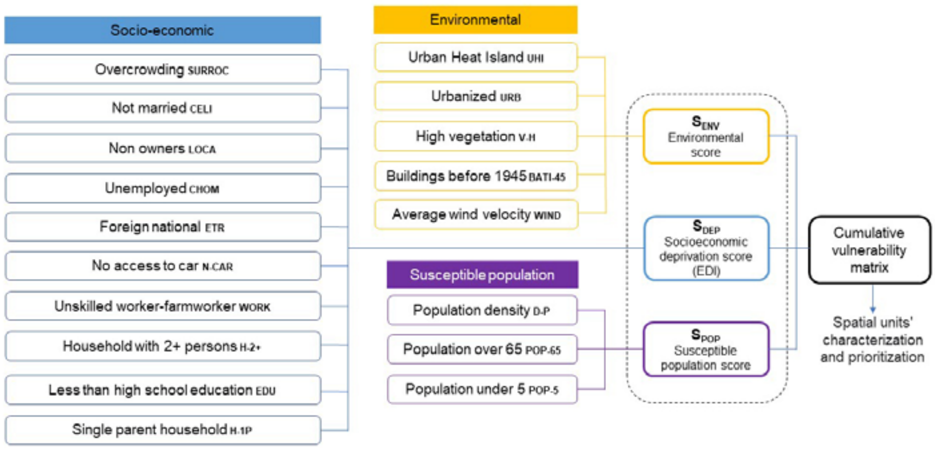

Figure 1. Cumulative Vulnerability Assessment framework adapted to assess heat vulnerability from Lanier et al. (2019)

In addition to providing a Cumulative Vulnerability Assessment for the metropolitan region of Toulouse, this study provides a composite vulnerability index obtained combining the results of three different heat vulnerability assessments conducted over the same area. The first one is the CVA object of this study and the other two are part of a complementary and synergic study conducted at LISST over the same period by Lagelouze (2022). The results of a Principal Component Analysis (PCA) and an Analytic Hierarchy Process (AHP) were combined with the results of the CVA to provide a unified index through a novel methodology specifically developed for this study.

3.1 Study area

The study area selected for this project is the Metropolitan region of Toulouse, located in the south-west of France. Toulouse is the capital of the Occitanie region, its metropolitan area has an extension of 458.2 km^2, this area comprises 37 communes (French administrative division analogue to the terms councils or townships used in other countries) and a population of approximately 800,000 persons according to the 2019 census (Insee 2022). Toulouse is the fourth largest city in France following Paris, Marseille and Lyon; however due to its extension it is also one of the least densely populated with approximately 1738 hab/km^2.

The spatial unit employed for the study is the 'Ilots Regroupés pour l'information Statistique' (IRIS), which correspond to the smallest census tract unit available in the French census (Insee 2022). The IRIS units are employed to administratively partition communes of five to ten thousand inhabitants into smaller units comprised in average of two thousand individuals –251 IRIS units compose the metropolitan region of Toulouse. The IRIS unit is the reference scale employed to spatially localize factors/variables of the three CVA components and characterize and compare spatial units.

3.2 Variables selection

A total of 18 variables (Table 1) were selected to quantitatively characterize individuals' heat vulnerability. The variables were selected based on their contribution to the three components employed to characterize heat vulnerability in this study: Environmental component; Susceptible Population component and Socioeconomic deprivation component. Variables for the Environmental and Susceptible Population components were selected based on existing literature and their previous use to characterize heat vulnerability. The sole exception to this is represented by the variable UHI intensity (UHI) and Average Wind Velocity (WIND) which were available at the scale of the Metropolitan area of Toulouse but are not commonly employed in other studies –presumably due to availability constrains.

Variables in the Socioeconomic component were retained based on their contribution in the creation of the French- European Deprivation Index -EDI- (Pornet et al. 2012; Merville et al. 2022), an index employed to measure context-specific socioeconomic deprivation. Finally, variables selection was eventually limited by data availability over the study area. Due to missing data, out of the 251 IRIS units composing the ensemble of the metropolitan region of Toulouse, only 249 were retained while two were removed from the analysis.

n.	Variable	Code	Impact on vulnerability	Treatment post-acquisition	Source	Reference in heat vulnerability studies
Environmental component						
1	UHI Intensity	UHI	+ (increase vulnerability)	GIS	Toulouse Metropole - CNRM	None of the studies consulted employed this variable directly; other temperatures data such as Land Surface Temperature or average temperatures are employed instead
2	Urbanized % (Build-up surface)	URB	+	GIS	CES- OSO	Conlon *et al.* (2020); Koman *et al.* (2019); Mitchell and Chakraborty (2018); Benmarhia *et al.* (2017); El-Zein and Tonmoy, (2015); Lemonsu *et al.*, (2015); Johnson *et al.* (2012)
3	High Vegetation %	V-H	- (decrease vulnerability)	GIS	CES - OSO	Conlon *et al.* (2020); Koman *et al.*, (2019); Benmarhnia *et al.*, (2017); Inostroza *et al.* 2016; Johnson *et al.* (2012); Chow *et al.* (2011); Reid *et al.* (2009); Vandentorren *et al.* (2006),
4	Buildings built before 1945	BATI 45	+	Variables aggregation	Insee	Hayes *et al.* (2019); Aminipouri *et al.* (2016); Inostroza *et al.* (2016); Lemonsu *et al.* (2015);
5	Average wind velocity	WIND	-	GIS	Ibitolu (2020)	**None of the studies consulted employs wind velocity data directly**
Susceptible Population component						
6	Population density	D-P	+	GIS	Insee -BD TOPO- IGN	Mitchel and Chakraborty (2018); El-Zein and Tonmoy (2015); Lemonsu *et al.* (2015); Wolf *et al.* 2014; Harlan *et al* (2006);
7	Population over 65	P-65	+	/	Insee	Faye *et al.* (2021) ; Alonso and Renard (2020); Koman *et al.* (2019);Hayes *et al.* (2019); Inostroza *et al.* (2016); Johnson et al. (2012); Harlan *et al.* (2006)
8	Population less than 5	P-5	+	/	Insee	Faye *et al.* (2021) ; Alonso and Renard (2020); Koman et al. (2019); Inostroza *et al.* (2016); Bao *et al.* (2015)
Socio-economic deprivation component						
9	Overcrowded households	SUROC	+	/	Insee	Conlon et al. (2020); Hayes et al. (2019); ; Benmarhnia *et al.* (2017); El-Zein and Tonmoy (2015)
10	Non-married	CELI	+	/	Insee	Inostronza *et al.* (2016); Gronlund *et al.* (2014)
11	Non-owners	LOCA	+	/	Insee	Koman *et al.* (2019); Benmarhnia *et al.* (2017); El-Zein and Tonmoy (2015); English *et al.* (2013)
12	Unemployed	CHOM	+	/	Insee	Ebi *et al.*, (2021a,2021b); Alonso and Renard (2020); Hayes and Poland (2018); Benmarhnia *et al.* (2017); Inostronza *et al.* (2016); Rey *et al.* 2009
13	Foreign national	ETR	+	/	Insee	Benmarhia *et al.* (2017); Eisenman *et al.* (2016); El-Zein and Tonmoy (2015); Wolf *et al.*(2014); Chow *et al.* (2011);
14	No access to car	N-CAR	+	Variables aggregation	Insee	Watkins *et al.*(2021); Koman *et al.* (2019); Aminipouri *et al.* (2016); English *et al.* (2013);
15	Unskilled worker-farmworker	WORK	+	Variables aggregation	Insee	Ebi *et al.* (2021a,2021b); Hayes *et al.*(2019); Eisenman *et al.* (2016)
16	Household with 2+ persons	H-2+	+	/	Insee	**None of the heat vulnerability studies consulted employed this variable (EDI)**
17	Less than high school education	EDU	+	/	Insee	Alonso and Renard (2020); Inostroza *et al.* (2016); Johnson *et al.* (2012); Huang *et al.* (2011); Harlan *et al.* (2006)
18	Single parent household	H-1P	+	/	Insee	**None of the heat vulnerability studies consulted employed this variable (EDI)**

Table 1. Variables selected according to the three main components employed to characterize heat vulnerability: Environmental component, Susceptible Population component and Socioeconomic deprivation component. Further details regarding variable selections available in Aranda Faieta (2022).

4 Results

4.1 CVA results

Based on the results of the Cumulative Vulnerability Assessment (Figure 2) conducted in the metropolitan region of Toulouse, the IRIS units classed in the highest vulnerability correspond to:

1. the cluster composed by the IRIS units Raynal, Nègreneys, Concorde, Périole and Raymond IV, a group of geographical units gathered around the train station of Toulouse Matabiau.
2. towards the west, relatively to the above cluster, the neighbourhood of Bourbaki, one of the 'quartiers prioritaires de la politique de la ville' (QP) -socioeconomically vulnerable neighbourhood based on the French government assessments.
3. southwards from the train station and on the east banks of the Canal du Midi, the IRIS of Louis Vitet and Camille Pujol.
4. on the west side of the Garonne river, the IRIS Arénes and Ravelin and toward the south Caserne Niel.

IRIS in the next vulnerability class, in descending order, are also all comprised within the commune of Toulouse, with the exclusion of Cabirol-Ramssiers in the commune of Colomiers and Les Violettes in the commune of Aucamville.

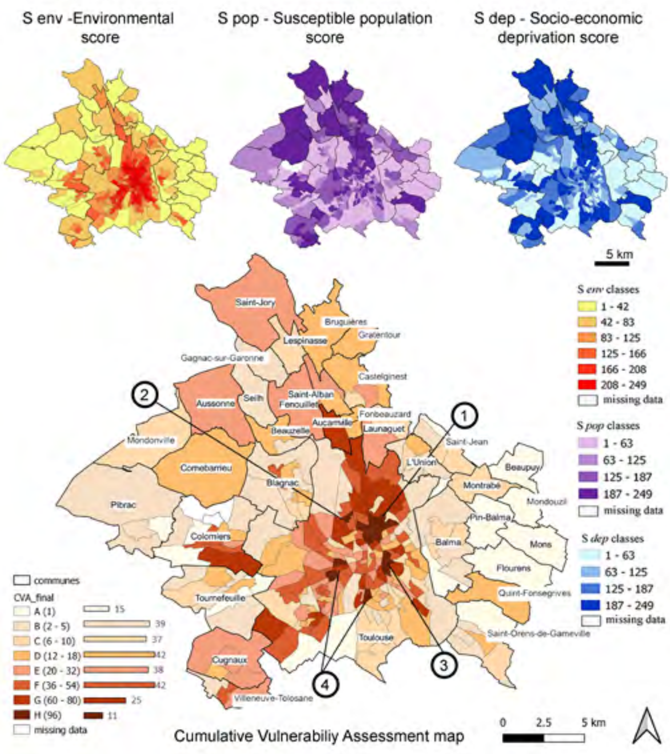

Figure 2. CVA heat vulnerability map including S env, S pop and S dep scores maps (Aranda Faieta, 2022).

4.2 Composite index results

Heat vulnerability assessments' results of a Principal Component Analysis (PCA) and an Analytic Hierarchy Process (AHP) were crossed with the results of the Cumulative Vulnerability Assessment (CVA) to produce an inter-method composite index of heat vulnerability that takes into consideration the three different methodologies. It must be reminded that, while the input variables employed differ to some extent between the CVA and the AHP-PCA, the final aim of the three methodologies is the same. Hence, such composite index allows a more comprehensive cumulative vulnerabilities visualization over the metropolitan region of Toulouse compared to the results of a single methodology (Aranda Faieta, 2022).

Following the first composite classification step (Figure 3), 77.5% (193/249) of the IRIS units were classed in one of the five quantiles of the inter-method composite index. Out of the 193 units, 57 (22.9%) were equally classed across the three methods, and 136 (54.6%) were equally classed across two out of the three methods. The rest, 56 units (22.5%) weren't equally classed across methods. Those units were classed based on their average class

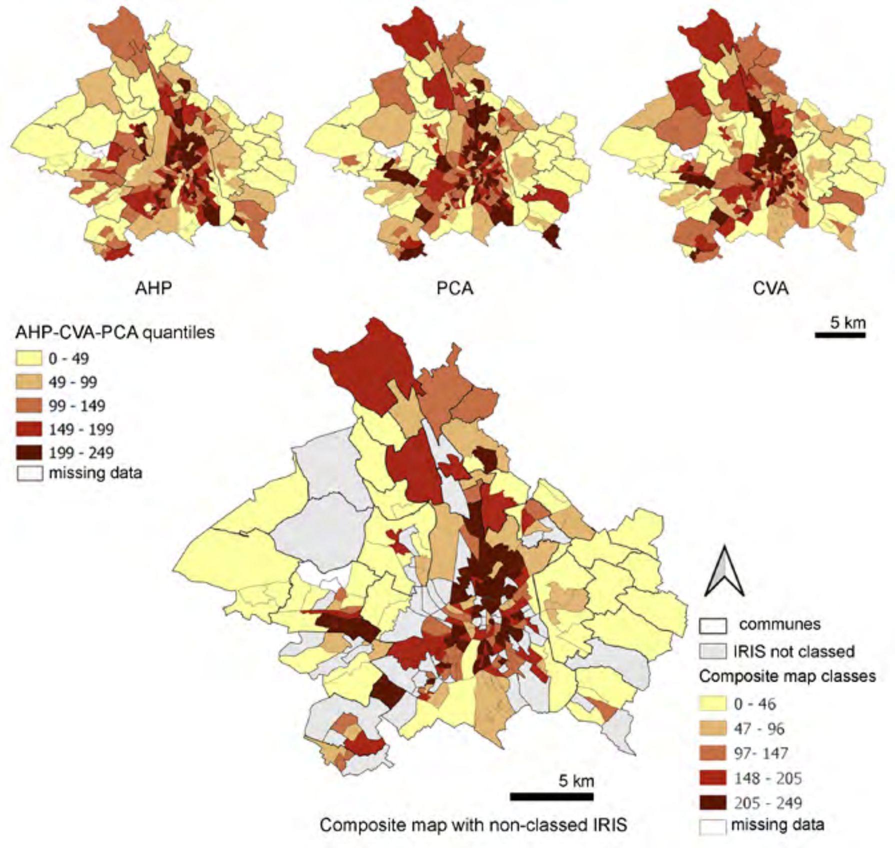

Figure 3. Maps of inter-method composite index construction – above, maps of the AHP-CVA-PCA results—below, composite maps following the first classification step (Aranda Faieta, 2022)

Classification consistency across the three methodologies was higher in the lowest and highest quantiles, achieving 100% and 98% consistency respectively. The percentage is then gradually reduced toward the centre. In class 3 only 59% of the geographical units were equally classed in three or at least two of the methodologies and 41% were classed according to their average rank.

Results of the three-method composite index (Figure 4) show a cluster of geographical units with high levels of cumulative vulnerabilities located in the north-east of the communes of Toulouse. Higher levels of vulnerability in this area were consistent across the three methodologies. Furthermore, within the same commune, IRIS in the previously mentioned 'quartiers prioritaires de la politique de la ville' have emerged. Additional IRIS with higher levels of vulnerability have been fund towards the centre –in lower numbers— and mostly in neighbourhoods in the outskirts and peri urban areas of the city of Toulouse. Other units emerged in the communes of Colomiers and Castelginest.

IRIS classed in the second cumulative vulnerabilities quantile are also mostly contained within the commune of Toulouse. However, a group of units in this class was also identified in the communes located towards the north of the metropolitan region, in addition to the city centers of Blagnac, Colomiers, Cugnaux and Villeneuve-Tolosane. Cumulative vulnerabilities are the lowest in the communes in the east and west of the metropolitan region as well as along the Garonne corridor, crossing south to north, sp

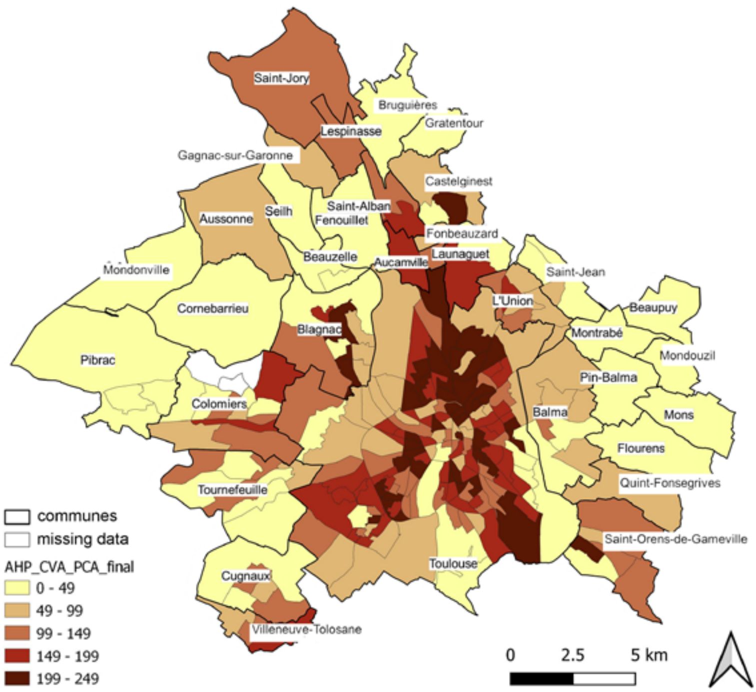

Figure 4. Inter-method cumulative vulnerability composite index map (Aranda Faieta, 2022).

5 Discussion

Following a thorough review of the three heat vulnerability assessment methods included in this study, it can be argued that one of the most important aspects to take into consideration when approaching human heat vulnerability is the identification of the variables that will be employed to characterize and quantify it. Three factors seem to come into play to influence variables choices. First, the conceptual approach or definition adopted to describe human heat vulnerability –meaning the choices the researcher takes based on its own expertise and the subjective affinity with one approach or another. Secondly, once a conceptual framework has been established, a decision on the variables that "better" describe the phenomenon and are most suitable with the conceptual framework chosen must be made. This will be normally informed by previous studies in the field. Thirdly, but not less important, is the factor of data availability over the study area, which will ultimately dictate what variables can or cannot be employed in a study.

Furthermore, once the choices have been operated and the variables selected, additional challenges emerge. One example of this is related to the temporal gap between data acquisition of demographic and socioeconomic data and the moment in which they become publicly available.

The production of a composite index combining the results of AHP-CVA-PCA allows to spatially visualize the convergence or not of cumulative vulnerabilities tendency over the metropolitan region while taking into consideration the three different approaches. As a result, it is possible to identify those areas within the region that would require particular attention. The downside in this process is that, once the composite index is complete, the information describing the vulnerability factors is lost. The combined index is able to communicate where to look but doesn't provide any information on why a particular spatial unit cumulates higher overall levels of vulnerability. To understand the why it is necessary to go back to the composing factors of the single indexes and/or eventually the original variables. While the global visualization can be a very useful tool in understanding where mitigation and adaptation strategies need to be implemented, the final composite index by itself it is not sufficient to support decision makers and practitioners in defining what type of intervention would be more appropriate over a specific area.

Results of the study identified different clusters of heat vulnerable IRIS over the metropolitan region, with the highest concentration occurring with the limits of the commune of Toulouse. These results confirmed the expectations of encountering higher level of heat vulnerability in concomitance with the mostly urbanized areas of the metropolitan region. However, contrary to initial belief, results showed that high urban heat exposure levels not always correspond with the highest levels of vulnerability, suggesting that climate adaptation and mitigation efforts should carefully take into consideration socioeconomic and demographic individuals' conditions, and not only physical exposure, when planning climate adaptation and mitigation interventions aiming at tackling urban heat related vulnerability.

6 Conclusion

The study found that composite indexes combining environmental, demographic and socioeconomic data can be an effective tool to spatially visualize cumulative vulnerabilities tendency over a metropolitan region. While this global visualization can be a useful tool in understanding where metropolitan authorities could focus their urban heat related climate interventions, final composite indexes result by themselves are not sufficient to support decision makers and practitioners in defining the type of intervention that would be more appropriate over a specific area. Local authorities should pay attention to the indexes' composing determinants to plan and deliver tailored solutions according to the specific needs of clusters of geographical units with similar characteristics. This is particularly relevant for the metropolitan region of Toulouse as results suggest that spatial units with high vulnerability values can have different underlying determinants.

Furthermore, results suggest that statistically obtained findings should be accompanied by qualitative field research to validate, complement, better characterize, and describe heat vulnerability tendencies identified over a study area. Results also points out the importance of considering the impact of urban heat on individuals from a perspective that considers its associations with quality of life, capacity to perform work and other activities, social interaction, and influence on individuals' behaviours in addition to the commonly addressed associations with morbidity and mortality. Of particular importance is also the adoption of longitudinal studies to better understand the dynamic component of heat vulnerability and its interaction with environmental, demographic, and socioeconomic determinants linked with the processes of urban evolutions in the context of climate change.

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JALAL, MUSHFIK

Assessing the Role of Landuse Landcover Transition Factors to Mitigate Heat Risk:

A Study on Urban Area of Dhaka North City Corporation

The urban population of Bangladesh has increased by nearly ten times since independence, one third of which has taken place in Dhaka city. On the other hand, the city has witnessed a rise in temperature of around 3 °C in the last 20 years. However, all part of the city does not have a uniform distribution of temperature. Due to differences in spatio-temporal growth as well as variation in physical and socio-economic profile of localities, the risk of surface heat tends to be appeared at dynamic level across the city. This study analyses the pattern of Landuse Landcover (LULC) transition from 2001 to 2021 and addresses type of influence between socio-economic and physical factors at every local administrative zone of the city. The analysis finds three major types of LULC transition which causes increase of surface temperature. The result also shows socio-economic factor has stronger influence in surface heat increase compared to physical factor. Considering the predicted trend of LULC growth and existing contribution of factors, the study provides policy guidelines as necessary to prepare mitigation strategy to reduce the risk of Surface Urban Heat Island (SUHI) effect.

1 Introduction

Tackling the combined effects of global warming and urban heating is one of the biggest challenges to be faced by world sustainable thinkers. Urbanisation causes significant modification of local climates and triggers the phenomena of UHI (Chapman et al. 2017). The percentage of world urban population is increasing rapidly and expected to reach nearly 70% by the year of 2050 (UNDESA 2015). At the same time, there is a continuous change of global climate at an unprecedented rate (IPCC 2014).

Urbanisation processes inevitably replaces impervious surfaces and causes difference in thermal energy balance (Li et al. 2019). Artificial urban fabrics such as buildings, roads, and other infrastructure absorb and re-emit the solar radiation more than natural landscapes like water bodies and vegetation. Which causes comparatively higher temperature in urban area accounting for around 1–7ºF (day) and 2-5ºF (night), as estimated by US EPA. There are several climatic, physical and socio-economic factors which are influencing UHI intensity in particular zone of urban area (Giridharan & Emmanuel 2018; Manoli et al. 2019).

According to The World Bank (2018), average annual temperatures of Bangladesh are projected to rise 1.0ºC to 1.5ºC by 2050, even after maintaining compliance as recommended by the Paris climate change agreement of 2015. Dhaka the primate city and capital of Bangladesh has been experiencing rapid population and spatial growth since its independence (Pranab 2021). The Dhaka Structure Plan 2016-2035 report indicates an increase of 0.5 ° C annual average temperature in Dhaka by the last 100 years (RAJUK 2016). Economist have warned that, Cities might lose up to 11% of economic output due to UHI effect. apart from adverse environmental effect, the phenomena also cause harm to human health and well-being in terms of heat-related morbidity and mortality (Li et al. 2021). Therefore, to control the increasing pattern of UHI effect an immediate action needs to be taken by concerned authorities through strategic and climate sensitive urban development plan.

The aim of this research is to find the pattern of urban growth factors contributing increase of surface heat and how the factors can be utilized to reduce the risk of increasing heat intensity. The objectives are i) to identify LULC transition pattern affecting highest level of surface temperature increase, ii) to find relative influence between socio-economic and physical factors; and iii) To predict location of susceptible land transformation causes rapid surface heat increase. The foundation of methodology is based on quantification of Land Surface Temperature (LST), areal transition of LULC classes and index of factors (Socio-economic & physical). The analysis considers maximum surface temperature scenario for finding underlying pattern of LULC transition and factor of influence.

2 Background

2.1 Form and Aspect of Urban Heat Island

The concept of urban heat island (UHI) refers to the phenomena that an urban area is significantly warmer than its surrounding rural areas due to human activities. This concept of UHI can be considered as one of the most unambiguous and flawless example of climate change due to anthropogenic sources (Hanna et al. 2011). As quoted by Professor Richard S.J. Tol MAE, "Any hard-won victories over climate change on a global scale could be wiped out by the effects of uncontrolled urban heat islands". UHI is usually measured by two form of indicators such as Surface Urban Heat Island (SUHI) and Atmospheric Urban Heat Island (AUHI) (Derdouri et al. 2021). The scope of this study is to investigate effect of LULC transition and influence of factors based on SUHI.

Yuan & Bauer (2007) states SUHI intensity is prominent during daytime, and it is greater during summer while lowest during winter (Imhoff et al. 2010). Dewan et al. (2021) analyses the diurnal and seasonal trend of SUHI intensity for Dhaka city. The result shows annual daytime SUHI of Dhaka (2.74 °C) is highest among all other five major cities of Bangladesh. Furthermore, the study reveals that during dry season SUHI intensity is greater for both day and night. Chakraborty and Lee (2019) also states the similar pattern of SUHI for Dhaka city. Both studies demonstrate an increasing intensity of SUHI for Dhaka regardless of time (diurnal/nocturnal) and season (summer/winter).

2.2 Heat Mitigation Strategy

To achieve heat sensitive urban development, there is no other alternative than implementation of Landuse Planning. Pal & Ziaul (2017). The study finds dense urban characteristics strongly influence an increase of LST and urge for decentralization to release the pressure on urban land. Socio-economic factors explain approximately 10 % to 20 % of the variances of UHI effect (Ying et al. 2020). Therefore, a general recommendations such as conservation of greeneries & waterbody, using cooling surface material for roof & pavement are not enough to combat heat risk in efficiently. Moreover, Causal factors of UHIs vary greatly spatially (Mirzaei & Haghighat 2010) and area-specific information based on UHIs and local attributes, is therefore, very important in supporting local scale mitigation efforts (Alexander 2021, Chun & Guldmann 2018). This study addresses Thana wise LULC trasition trend as well as considers contribution of relative importance between socio-economic & physical factor, to formate strategic policy measure in mitigating SUHI effect.

2.2.1 Linkage between LST and LULC

The major driver behind changing pattern of LST is LULC change. Therefore, finding nature of relation between these two phenomena has drawn attraction to many authors dealing with UHI effect. Several research finds an upward trend of LST over the years, with a significant role of built-up area. There are some Landcover properties causes the changes in heat properties resulting surface temperature increase through different heat storage and conductive capacity. The impact of vegetation and waterbody as form of Latent heat flux is the dominant factor in changing thermal behavior followed by net radiation (Ke et al. 2014). Although LST is highly correlated with Landuse distribution such as LST hotspot in industrial and commercial area, while cold spot is clustered in parks and water bodies (Tran et al. 2017).

With rapid urbanization trend Dhaka has been going through noticeable transformation by built-up class replacing all types of natural landcover. Green space and water bodies have been diminishing in expense of built-up areas in every decade at a rate of 40% since 1978 (Moniruzzaman et al. 2021). It is predicted that there will be a 13% (summer) & 20% (winter) increase in LST by 2030 across Dhaka Metropolitan area (Faisal et al. 2021). The study also shows that LST situation in Dhaka will become worse through simultaneous increase of impervious surface with decrease of vegetation cover.

2.2.2 Factors affecting SUHI Intensity

There are underlying socio-economic and physical factors which direct LULC change of urban and cause variation in surface thermal properties (Tran et al. 2017), during all around the year regardless of season (Pal & Ziaul 2017). Physical factors have dynamic effect on LST change and influence surface temperature of an area based on its properties and morphology such as impervious surface (IS), vegetation, waterbody and urban morphology etc (Xiong et al. 2012). Building geometry has a complex effect in changing surface temperature. For example, higher Sky View Factor (SVF) enhances air circulation and lower SVF helps in reducing incoming solar energy, therefore both contributing cooling effect but with opposite value (Huang & Wang 2019). Furthermore, high rise building increases the possibility of heat absorption but at the same time it counteracts SUHI with shadings effect (Huang & Wang 2019). Dhaka city is an example of organic development where buildings are constructed without following building code regulation. Moreover, there is no applicable rules for building height restriction except some areas like airport zone. Therefore, apart from focusing building density, it is necessary to find the effect of building geometry on changing pattern of LST in the City.

Most of UHI research discuss about population density as a socio-economic indicator and show a strong positive relationship with LST increase (Zhang et al. 2017; Deilami et al. 2016). However, some studies finds that LST changes are more related to socio-economic activities (domestic household and workplaces) of the area rather than total number of populations (Zhang et al. 2013). Other socio-economic factors such as house rent (Chen et al. 2012) and Gross Domestic Product (Cui & Shi 2012) have been evaluated and finds positive relationship with LST increase. Dhaka city comprises of diverse socio-economic characteristics including income group, level of consumption and access to community services. Apart from population density, there is a need to evaluate effect of other related socio-economic variables in assessing its impact on SUHI intensity. This study undertakes relevant socio-economic variables which are available at urban Thana level under DNCC administrative area.

3 Methodology

3.1 Study area

This study is based on urban areas of Dhaka North City Corporation (DNCC). The location of Dhaka City falls under the humid sub-tropical monsoon climate region with an annual average temperature of 25 °C. Urban area DNCC comprises of 18 Thanas including a total of 36 wards (BBS 2011). This study considers Thana as a reference administrative boundary for analysis and mitigative approach.

Data and Information

The study requires information about LST intensity, spatio-temporal change of LULC classes and physical & socio-economic index of respective Thana boundary. LST is the climatic variable used as a reference indicator of surface temperature. Table 1 on the next page describes the principles of each data variables used in this research under four different thematic area.

3.2 Methods

LST Retrieval and SUHI Indicator

Radiative transfer equation (i) has been used to extract LST value for the area (Faisal et al. 2021).

$$\text{LST} = \frac{T_i}{1 + \left(\lambda \times \frac{T_i}{\rho}\right) \times \ln(\varepsilon)} \qquad \text{...... (i)}$$

Here,
LST = Land Surface Temperature, T_i = sensor's brightness temperature,
λ= emitted radiance's wavelength, ε = spectral emissivity of the land surface,
ρ = 1.438 ×10 - 2 mk.

In this process, at first thermal band spectral radiance is converted to actual radiance sensor brightness temperature. The brightness temperature is affected by atmospheric phenomena which is improved using NDVI as emissivity value.

LST is further normalized using Normalized Ratio Scale (NRS) method as given in equation (ii) to reduce the effect of seasonality and temporal variation by smoothing the pixel values (Rasul et al. 2017).

$$\text{LST}_{\text{NRS}} = \frac{(\text{LST})}{\sqrt{\sum (\text{LST})^2}} \qquad \text{...... (ii)}$$

Theme	Variable and Data Source	Parameter	Indicator
LULC (Source: Mamun et al. 2013)	Built-up, Waterbody, Vegetation, Bare land (USGS Landsat Satellite)	Transition of four LULC classes at decadal interval of 2001, 2011 & 2021	Spatio-temporal change of human behavior on land surface at 30 meter areal expansion during 2001 to 2021
Climate (Source: Shastri & Ghosh 2019, Rizwan et al. 2008, Zhao et al. 2014)	LST (USGS Landsat Satellite)	Surface Heat Intensity	Mean Normalized LST at 30 meter spatial resolution as a direct indicator for Surface Urban Heat Island (SUHI) effect
Socio-economic (Source: Parsaee et al. 2019, Magli et al. 2015, Jusuf et al. 2007, Shahmohamadi et al. 2010)	Decadal Growth Rate (BBS 2011, BBS 2001)	Trend of Population Growth	LST increases with an increase of decadal growth rate
	Population Density (BBS 2011)	Population Size of Statistical Administrative Unit	LST increases with an increase of population density
	Density of community facilities (RAJUK 2021)	Level of Community Activity	Concentration of community facilities influence surface temperature as a pull factor for people and transportation
	Percentage (%) of Affordable Household (HH) (BBS 2011)	Level of Land Consumption by Building Type	Affordable and non-affordable HH has varying level of land and resource consumption. The category of affordability has been determined by type of building structure. Permanent structure is considered as affordable while other are non-affordable HH
	Percentage (%) of Household (HH) with electricity connection (BBS 2011)	Level of Energy Consumption by HH Unit	The HH uses electricity implies more consumption of resources. The electricity connected HH have possibility to release more heat in the area
	Average Household (HH) size (BBS 2011)	Proportion of area usage by each HH	Higher HH size indicates less per capita consumption of existing facility and resources within respective Thana
Physical (Source: Oke et al. 2017, Gunawardena et al. 2017, Dare 2005)	Building Density (RAJUK 2021)	Area Coverage (3D) by Buildings	Higher volume of building surface absorbs more short-wave solar radiation and release higher long wave radiation after sunset
	Waterbody Density (RAJUK 2021)	Area Coverage by Waterbody	Because of latent heat properties, areas of higher waterbody density experience less surface heat exposure
	Normalized Differential Vegetation Index (NDVI) (USGS Landsat Satellite)	Density of Vegetation per area	Because of latent heat properties, areas of higher vegetation density experience less surface heat exposure. Because of NDVI value range between -1 to +1, the sum of total NDVI pixels is considered as indicator located in Thana boundary
	Sky View Factor (SVF) (RAJUK 2021)	Level Openness to Sky from ground	If buildings in a area is situated sparsely, the longwave emitted radiation from surface uninteruptedly goes back to atmosphere and hence causes less surface temperature increase
	Percentage of Shadow Area (RAJUK 2021)	Area coverage of Shadow by building height	The coverage of shadow causes inaccessibility of solar short-wave radiation to the shaded area. although it has a cooling effect at micro scale but might indirectly increase surface temperature because of sources of shadow such as building height

Table 1. Description of data and information

3.3 LULC Classification

Landcover classification follows Anderson level I classification system dividing the city into four LULC classes such as Built-up, Vegetation, Waterbody and Baren land (Anderson et al. 1976) for the years of 2001, 2011 and 2021. To extract LULC information, unsupervised classification technique has been adopted (Oyekola & Adewuyo 2018).

3.3.1 LULC Projection

To produce predicted map of LULC for the year of 2031 and 2041, Cellular Automata – Markov (CA-Markov) model has been used (Kafy et al. 2021). Regarding predicting LULC growth, distance from built-up & roads, surface elevation & slope and transition sub-parameters (other to built-up transition) have been used as input parameters.

Socio-economic and Physical Index

Socio-economic and physical index of respective Thana has been calculated using existing parameter value and weight of each variable of both factors. Equation (iii) has been used to calculate index (Larsson 2000).

$$\text{Index of Factors, } F = \sum (\text{Weight of Variable} \times \text{Value of Variable}) \text{ ...... (iii)}$$

Weight has been determined by concentration ratio of correlation between mean NLST change and all the variables of socio-economic & physical factors within respective Thana using equation.

To bring all the variables into a common scale of measurement, minimum maximum standardization method has been applied (Han et al. 2012) ranging from 1 to 100. Although minimum maximum standardization technique performs a linear transformation of original values of variables, but it preserves the relationship among original data values (Han et al. 2012).

3.3.2 Validation and Accuracy Assessment

LST Validation

As the study has limitation of collecting in-situ measurement about surface and air temperature, therefore the process of validation of temperature data depends on the given results of other research papers. A high degree of agreement between the satellite retrieved surface temperature and the ground based LST observations has been established in several research (Sharma & Joshi 2014, Yuan & Bauer 2007, Mallick et al. 2013). Satellite derived long wave upward radiation of Landsat has a bias of 1.9 Kelvin and RMSE of 1.2 Kelvin (Rigo et al. 2006), which is considered as acceptable range of distortion. Moreover, Gawuc et al. (2022) states in their research there is a linear relationship between atmospheric and surface urban heat island.

Accuracy Assessment of LULC Classification

Error matrix tool has been used for LULC accuracy assessment (Kafy et al. 2021). 200 randomly selected ground points have been taken as sample. 70% (overall, user & producer accuracy) and 0.40 – 0.85 (Kappa coefficient) is considered as acceptable accurate level (Basu & Das 2021). To validate predicted LULC maps generated by Markov model, chi square method has been used with degree of freedom 3 at 0.05 level of significance. If the tabulated value is found less than chi square value, the result shows there is similarity between existing and predicted map (Rahaman et al. 2022, Kumar et al. 2013).

4 Results

4.1 Pattern of LULC Transition affecting Surface Temperature Increase

The amount of land where surface heat has increased covers 87.39% of total DNCC area. Of total heat increase area, majority percentage falls under the category of low increase with a percentage of 85%. The rest 15% is divided into moderate increase (14%) and high increase (1%), which refers to the area of SUHI increase over the decades. The underlying spatio-temporal change within this high-moderate SUHI increase zone is considered as a susceptible LULC transition pattern of heat increase.

Three types of susceptible LULC transition have been found from the decadal analysis. Table 2 describes the contribution of above three order of built-up area formation in increasing heat intensity. The statistics shows 1st Order Urban transition has the highest percentage of land occupied within the geographical range of Hi-moderate Heat increase zone. That means the areas which are occupied by mainly built-up class consistently over the three decades has higher influence in increasing surface heat. The areas where built-up class formed at later stage by replacing water or vegetation shows less level of heat increase as explained by percentage of area coverage. Therefore, it can be said that there is a positive relation of heat intensity with the duration of built-up area occupancy.

Transition Category	Phases of Built-up transition			Percentage of Area
	2001	2011	2021	
1st Order Urban	Built-up/ Bare land	Built-up/ Bare land	Built-up/ Bare land	54%
2nd Order Urban	Vegetation/ Waterbody	Built-up/ Bare land	Built-up/ Bare land	21%
3rd Order Urban	Vegetation/ Waterbody	Vegetation/ Waterbody	Built-up/ Bare land	12%
Other	Any	Any	Any	13%

Table 2. Category, phases and area occupancy of LULC transition from 2001 to 2021

4.2 Relative Importance of Factors on Surface Heat Intensity

To assess relative contribution of physical and social factors on surface heat increase in every Thana, indexes of both factors have been compared along with Mean NLST change during 2001 to 2021. Analyzing Moran's Autocorrelation and Pearson's correlation, it is found that there is no spatial relationship between socio-economic and physical factor across the city. Figure 1 represents composite index map of both factors along with mean NLST increase of respective Thana.

Factor Index and Surface Heat Increase of DNCC Urban area

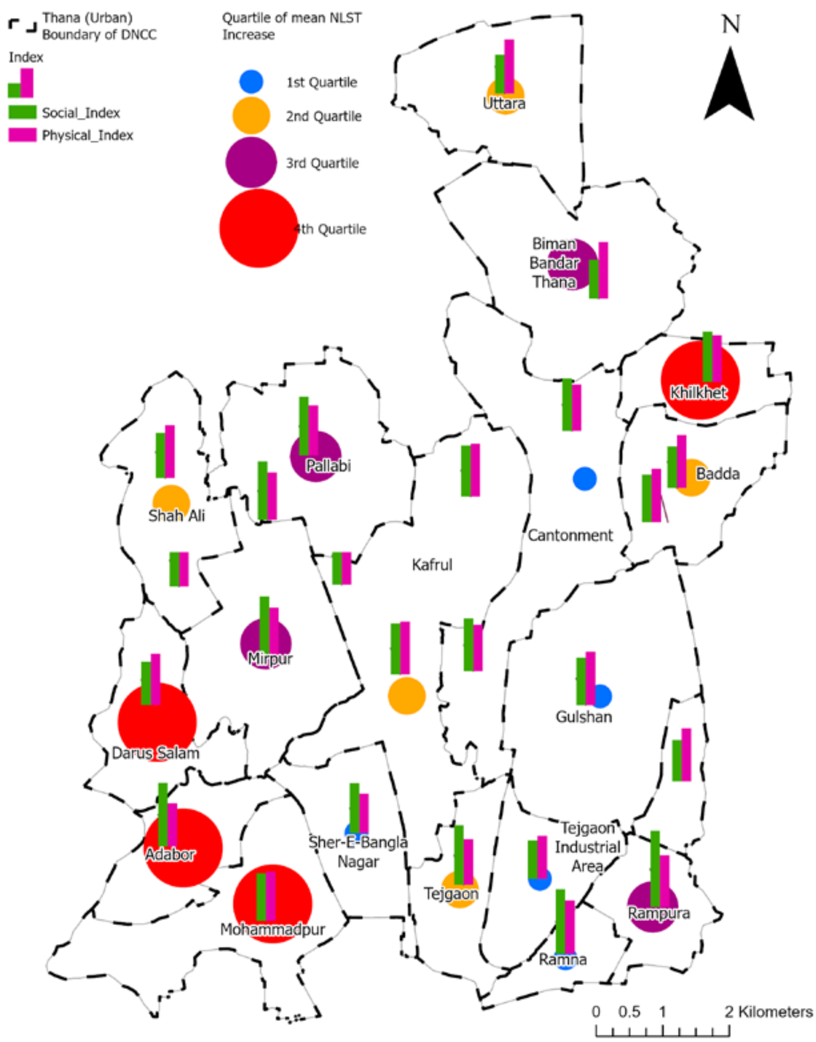

Figure 1. Comparative distribution between socio-economic & physical factor and scenario of surface temperature increase in DNCC urban area

However, there is a changing pattern of surface temperature found for the Thanas where highest heat increase occurred during 2021 to 2001. Quartile distribution of mean NLST change value shows Adabor, Darus salam, Mohammadur & Khilkhet falls within 4th quartile. In this study, these four Thana areas have been identified as Heat Center Zone (HCZ) of DNCC.

Figure 2 (a) describes the pattern of relative influence by both factors on surface heat change. The result shows that surface temperature has decreased with simultaneous decreasing trend of socio-economic factor and gradual skewness towards physical factor. The relation also describes that, the effect of physical factors is stronger than that of socio-economic in surface heat reduction. Socio-economic variables like population density, density of community facility, percentage of affordable housing etc. determines the varying rate of land consumption per unit area of a building. For example, a building with same area footprint will have different level of functionality depending on the number of populations using it as well as the type of Landuse. Depending on the type of functionality, an unit of building area will generate varying level of surface temperature.

Figure 2 (b) shows influence of positive and negative factors on heat increase of four HCZs of DNCC area. The highest zone (Adabor) of heat increase is skewed towards highest level (100) of positive factor, whereas the contribution of negative factor for the area remains lowest (1). The heat change pattern of other comparatively lower HCZs describes a gradual decrease in surface heat with increasing influence of negative factors. Therefore, the finding testifies that negative factors play an effective role in reducing the surface heat intensity over time.

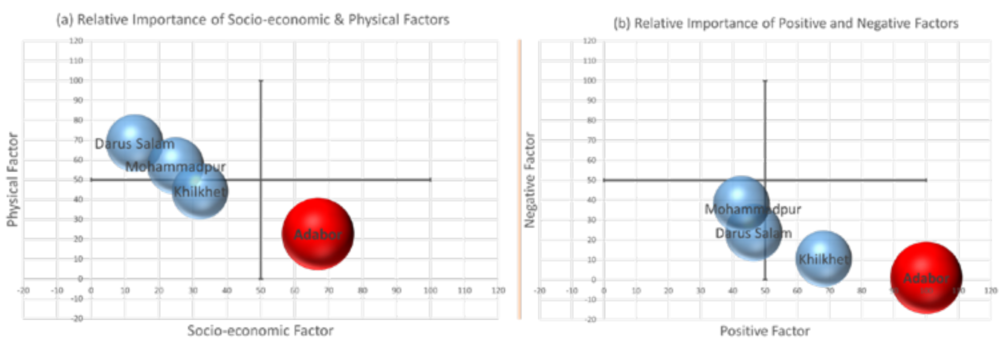

Figure 2. Pattern of influence by (a) socio-economic & physical factors and (b) positive & negative factors in increasing surface temperature

4.3 Mitigation Strategy

The study addresses several challenges the authority should consider towards adopting mitigation actions. The LULC prediction map finds 85.48% of total land will be exposed to heating factor by 2041. A major transformation will occur by 2031 and hence respective authority requires an immediate action tackle the rapid spatial propagation of surface heat risk. Considering all the aspect of analysis outcome, the study proposes three components of mitigation policy for DNCC. Figure 3 illustrates all the components of surface heat mitigation strategies for DNCC urban area.

Component 1: Some areas are more susceptible to surface heat risk as per definition of urban order transition category. Mitigation action should be preferred to the areas with susceptibility to Heat at early stage. In Figure 3, mitigation response clock describes which Thana should be considered as an area of priority for mitigation action, due to its temporal impact on heat risk caused by spatial transformation.

Component 2: There should be a balance between existing level of factors as defined by quadrantal position of each Thana. Although, areas towards higher physical index are less likely to heat risk, however, higher physical index along with comparatively less socio-economic index in a Thana does not comply with the concept of sustainable development. Because, Dhaka being a central place of activity cannot afford to invest more on physical feature for less social attribute (population and community facilities). Therefore, the mitigation strategy suggests respective Thanas to be located as closer as to the point of equilibrium. In quadrantal graph of figure 3, the intersection points at the middle between both factors indicated the point of equilibrium.

Component 3: Finally, the study specifies leverage features of heat mitigation tool such as waterbody, vegetation and SVF because of their strength and negative contribution in reducing surface heat risk. Based on the proportion of these three features, each Thana of DNCC area has been categorised by its capacity to cope with heat sensitive urban development. In Figure 3, the percentage value in each Thana represents the level of capacity as defined by prevalence of physical negative variables.

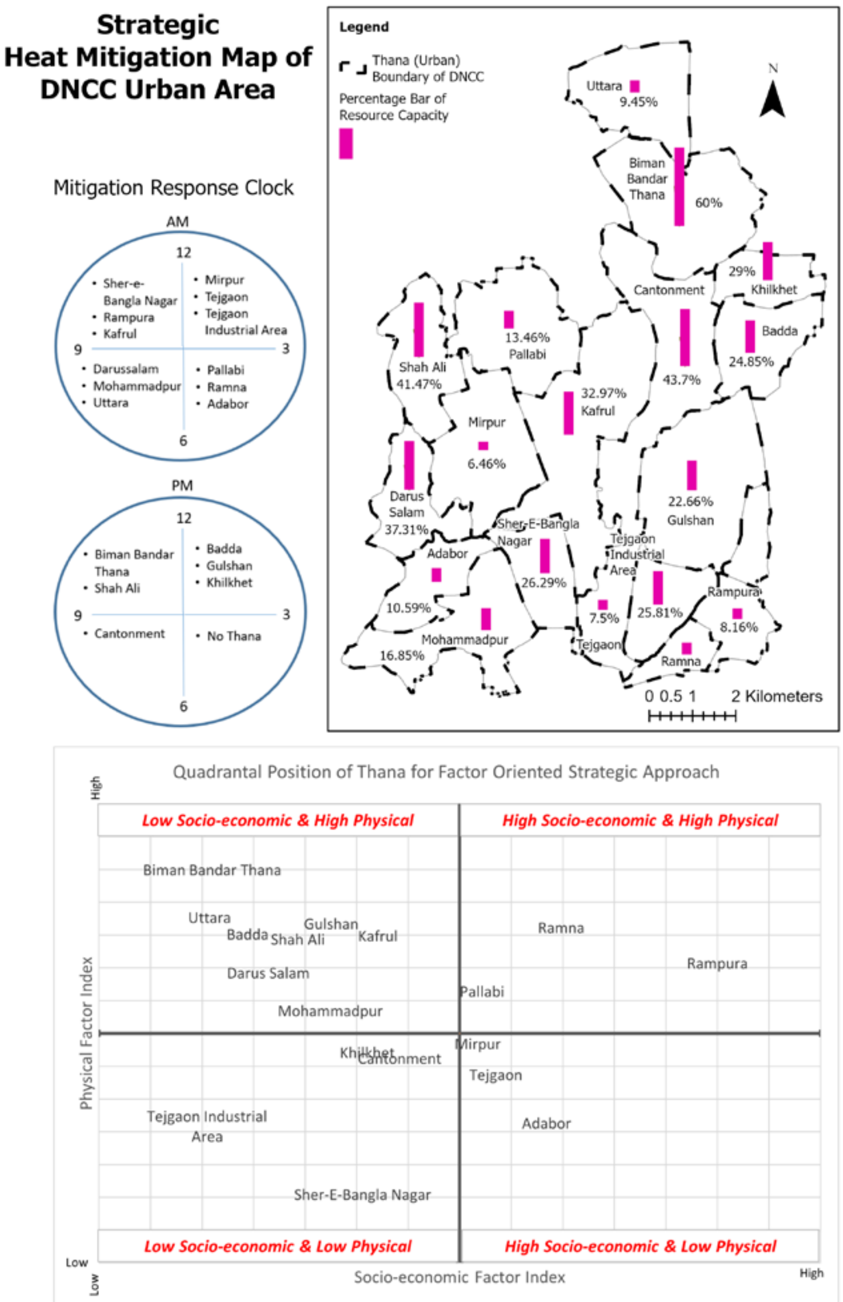

Figure 3. Composite map of mitigation strategy to reduce the risk of surface urban heat island (SUHI) effect of DNCC urban area.

5 Conclusion & Discussion

A systematic mitigation strategy to reduce the risk of surface heat island is an urgent need for local government authorities to tackle the adverse impact of climate change and at the same time continue to support urban growth. The goal of this study is to provide necessary information as required for undertaking specific mitigation actions for a particular Thana areas of Dhaka North city Corporation. Using Spectral and thermal Satellite sensors of Landsat satellite, it has become possible to extract accepted level of accurate Land Surface Temperature (LST) and Landuse Landcover (LULC) map for the year of 2001, 2011 and 2021 respectively. The result of error matrix and chi square test shows that, unsupervised and predicted LULC classification comply with acceptable range of accuracy respectively. In this study, NLST map is the source of base information which indicates areas of highest surface heat difference over the decades. The highest threshold area of heat increased is the indicator to identify pattern of LULC transition and factor contribution triggering the increasing trend of Surface Urban Heat Island (SUHI). The intersection result shows variety of LULC transition pattern overlying the area of hi-moderate surface heat increase zone, which is later considered as a susceptible type of land transform responsible for creating high heat surface in the study area. The output of this transition is further classified into three order of transition phases based on development decades of built-up class. This order indicated the area possesses an earlier development history of built-up class have strong probability of surface heat increase. the composition of LULC transition also describes in the hi-moderate surface increase heat zone built-up areas has been developed replacing existing cooling factors such as vegetation and waterbody.

On the other hand, the relative factor analysis output demonstrates if a Thana is skewed towards social index, the area can be considered to become a heat centre zone of the city. Higher Socio-economic intensity means the area has higher level of urban activity regularly performed by population from inner and outer side of the boundary. In this context, the study outlines that related socio-economic variables are more influential for increasing surface temperature than that of physical variables based on the human behaviour on that land.

However, in reducing heat intensity of surface physical factor play stronger role that socio-economic. This refers to an increase of negative physical factor will be comparatively higher influential in reducing SUHI effect rather than reducing the concentration of socio-economic variables. Therefore, in mitigating surface heat island effect, the focus should be given to physical negative factor to get a short-term benefit. On the other hand, socio-economic variables will be effective for long term mitigation plan as it has a slower but stronger impact over surface heat intensity.

Mitigation actions require existing resource capacity of both man-made and natural features, and the efficiency of action can be fostered by optimal investment. As a third world nation, Bangladesh lacks the financial capacity to invest on climate adaptation and mitigation. The mitigation strategy suggested in this study direct authority a cost-effective guideline by sharing information about probable heat susceptible zones, area of strategic focus and capacity of existing mitigation tools. The guideline will be supportive for concerned authority who are working on social and physical development of the area to continue development work considering climate sensitivity of the area.

This study focuses on the local administrative boundary within a city. The statistical data used in this research is from the census of 2011, there are no other statistical data source at this detail level recently published by any government and non-government organization. Therefore, this study assumes that variables of socio-economic factor will follow a linear growth over next decades. Apart from this due to limitation of in-situ measurement, information from secondary research papers has been used to describe the validity of LST.

The study provides mitigation plan in context of city scale. The proposed mitigation strategies paved the way for further action research at micro scale. Based on the Thana wise outcome of heat profile, there is a scope of conducting detailed investigation on evaluating dynamic relationship between variables as a source of surface heat intensity.

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MODJRIAN, NEWSHA

Prediction of Outdoor Thermal Comfort Changes and Uncovering Mitigation Strategies based on Machine Learning Algorithm

A decision support tool for climate- sensitive design: A case study of Glasgow, UK

In light of managing the outdoor environment to meet thermal comfort, this research developed a framework for predicting and simulating the thermal comfort proxies depending on the secondary and historical data. This framework will facilitate the decision-making process from a climatic perspective at the initial planning stage by forecasting the heat stress changes in urban settings. Among various linear and non-linear regression models, the ANN model achieved better performance in predicting MRT and LST, considering the identified predictors. Among all the factors, SVF and NDBI were the best factors in predicting MRT and LST, respectively. The framework was validated by predicting the impact of greening strategies (100%-50%-0%) on LST for vacant lands in Glasgow. The results from LST prediction depict the modest effects of urban greenery in decreasing heat stress at the surface level under a non-linear trend. The UTCI simulation in ENVI-met was applied in the framework to understand thermal comfort. The impact of shadowing from plants and buildings, for instance, could alter thermal comfort depending on the area's compactness and openness in Glasgow's central district. Heat mitigation measures at the level of lowering the surface temperature do not always meet human thermal comfort.

1 Introduction

According to the United Nations, cities will accommodate two-thirds of the world's population by 2050 (United Nations 2019). Densely populated areas push cities to grow either vertically or horizontally, causing greater heat generation, a broader blockage impact against urban air circulation, more extensive accumulation of solar radiation, and eventually a reduction in long-wave emission to the atmosphere due to building blockage and usage of artificial materials (Ashtiani et al. 2014; Kleerekoper et al. 2012; Mirzaei 2015). The lack of greenery, the considerable use of impervious surfaces, the urban spatial structure absorbing solar radiation and the reduction in wind velocity, along with expanding anthropogenic activities, all contribute to the evolution of heat islands (Lee et al. 2016). Several challenges linked to UHIs have been identified, including increased air pollution, heavy precipitation, excessive energy consumption, rising energy prices, and increasing greenhouse gas emissions (Synnefa et al. 2008), thermal discomfort, heat stress, the high fatality rate among the physically susceptible population (Lima Alves & Lopes 2017). Therefore, excessive heat makes the condition for human beings to experience thermal discomfort in outdoor spaces, along with increasing environmental disasters and health-related issues.

One of the major challenges in developing a practical tool to address the effects of climate change and overheating on a city and its citizens is the lack of an appropriate simulation and prediction model of thermal stress as a result of city development (Parsaee et al. 2019). Massive volumes of data have been generated in cities due to the application of modern information technology (Gadgets, IoT, Sensors, and so on) (Tekouabou et al. 2022). Machine Learning algorithms can potentially deliver significant improvements in terms of both understanding and forecasting climate consequences. What makes machine learning so powerful tool is its ability to compute massive amounts of data, process data, and exhibit nonlinear behaviour (Koc & Acar 2021).

The aim of the present study is to generate a machine learning-based model in terms of new urban development to facilitate the decision-making process at the initial planning stage from a climatic perspective. This model can forecast thermal comfort, and heat stress changes in an urban setting, and Glasgow City will be employed to validate the climate-sensitive model. Thus, it is guided by the objectives listed below.

1. Identify the contributing parameters to outdoor thermal comfort (OTC) and heat island derived from historical and secondary data at the spatial and quantitative levels.
2. Investigate the spatial distribution of outdoor thermal comfort indices and proxies in order to explore the linearity and non-linearity relationship with urban design features, air quality factors and remotely sensed derived (RSD) data.
3. Train and evaluate the performance of various prediction models for outdoor thermal comfort indices to identify robust models and significant variables.

4. Simulate scenarios on vacant lands (vacant and derelict) to evaluate the effect of predictors on outdoor thermal comfort.
5. Proposing the holistic workflow through the use of ArcGIS, MATLAB, and ENVI-met to predict changes in thermal comfort based on secondary data for policymakers.

2 Background

2.1 Global Warming and Increasing Temperature in Urban Settings

It is estimated that global temperatures will exceed 1.5°C within two decades under the current rate of global warming (IPCC 2021). There will be more heatwaves, longer warm seasons, and shorter cold seasons. On the other hand, cities are expected to accommodate roughly two-thirds of the global population within three decades (United Nations 2019), exposing more people to the risk of global warming (Alexander & Arblaster 2008). Extreme weather events, heatwaves and cold spells, which are now recognized risks linked with increased mortality and morbidity, present seasonal threats to the health and well-being of vulnerable people (Seltenrich 2015) with adverse effects on environmental quality and water supply (Venter et al. 2020; L. Zhao et al. 2018). According to Emmanuel & Baker (2012), climate change is the most severe threat that modern humans have ever struggled with. Rising temperatures caused by climate change, heat waves, and the Urban Heat Islands (UHI) effect necessitate immediate response; otherwise, future generations would suffer from the same repercussions as the current generation.

The term "Urban Heat Islands" refers to the extra heat generated in cities as a result of the density of buildings, automobiles, and impervious surfaces. UHI is associated with larger air temperature variations in urban areas than rural regions (Oke 1976; Oke 1982). Such temperature difference which is more prevalent throughout the night (Memon et al. 2009; Wilby 2003), can aggravate the excessive heat caused by heatwaves for city dwellers and world's cities (Patz et al. 2005; Watkins et al. 2007; L. Zhao et al. 2018). The morphological and climatic factors that cause UHI can be either (1) Controllable: human-related activities or (2) Uncontrollable: fixed factors with the possibility of prediction (Memon et al. 2008). Climatic parameters, meteorological variables, and geographical features are considered uncontrollable. The other variables are related to urban planning and design, decision-making, building geometry, urban morphology, and transportation. In this respect, the UHI is a direct outcome of urbanisation (Levermore et al. 2018; Parsaee et al. 2019).

2.2 Thermal Comfort in Outdoor Environment

Several academics who specialise in the domains of climate studies, urban planning, and environmental sustainability have acquired an interest in the topic of outdoor thermal comfort as a result of the major detrimental effects that climate change has had on population health (Aram et al. 2020; Jamei et al. 2016). Thermal comfort is defined by the ASHRAE as a state of mind that displays satisfaction with the thermal environment (ASHRAE 2010).

Four environmental aspects, together with two distinct characteristics, can be used to sum up the remarkable parameters that influence how comfortable people are outside, such as air temperature, radiant temperature, humidity, air velocity, human activity, and clothing. There are significant changes in thermal conditions and, therefore, in how the human body regulates its internal temperature in dense urban environments due to the high number of commuters and vehicles as well as complex urban geometry (Lau et al. 2021). Such a compact urban shape minimises air velocity and shields solar radiation (Zhang et al. 2022). The contribution of urban geometry is for analysing the openness of urban spaces. Factors like SVF (He et al. 2015; Souza et al. 2003; Yan et al. 2022); H/W (Krüger et al. 2011); building density and coverage ratios (Mehrotra et al. 2020); floor area ratios, as well as vegetation density (Alavipanah et al. 2015) and coverage ratios (Duarte et al. 2015) have been studying.

2.3 Prediction Model of Outdoor Thermal Comfort

The development and implementation of new methods and policies for monitoring the additional heat trapped in outdoor environments have been made easier by the capacity to predict the influence of heat stress factors on outdoor air temperatures (Mangal et al. 2020). Machine Learning (ML) techniques have the potential to deliver significant advancements in terms of both explanation and prediction of climate repercussions. Several methods of prediction in the climate research context have been used, including trend and regression analysis (Kolokotroni & Giridharan 2008; Liu et al. 2021); neural network (Ashtiani et al. 2014; Equere et al. 2021; Fan et al. 2021; Gobakis et al. 2011); tree-regression (Acosta et al. 2021); time-series analysis (K. Lee et al. 2020); long short-term memory-recurrent neural network (Koc & Acar 2021); support vector regressor (SVR) (Mendez-Astudillo & Mendez-Astudillo 2021).

2.4 Heat Stress Mitigation Strategies in Policy-making

In theory, lowering the urban heat is in light of reducing the net radiation. On this basis, plants and reflecting materials are extensively employed as passive techniques of heat mitigation in metropolitan areas (Taleghani 2018). Another efficient method of reducing the excess heat trapped in an urban canyon, which lessens the level of thermal comfort for people, is to create shading through vegetation, buildings or urban furniture (Emmanuel 2021; Ketterer & Matzarakis 2014). From an urban design perspective, street orientation along with building density can be useful in considering MRT and thermal comfort as they affect the wind velocity and radiation angles on the surfaces and open areas (Thorsson et al. 2017). The strategies for heat mitigation can be summarised in Table 1 on the next page.

Strategies	Scale	Source
Vegetation	Park	(Taleghani 2018)
	Street Tree	
	Green Roof	
	Green Wall	
Material with high albedo	White roof	(Taleghani 2018)
	Reflective Pavement	
Shading Effect	Vegetation	(Ketterer and Matzarakis 2014)
	Building (shadow-casting)	(Emmanuel 2021; Ketterer and Matzarakis 2014)
	Urban furniture	(Emmanuel 2021)
Urban Geometry	Urban Orientation	(Thorsson et al. 2017)
	Building density	

Table 1. Heat Stress Mitigation Strategies (Table: Emmanuel 2021; Ketterer & Matzarakis 2014; Taleghani 2018; Thorsson et al. 2017)

2.5 Climate Sensitive Decision Support Application

Since cities are more prone to heat stress when the urban environment is heavily constructed and densely populated with a scarcity of green spaces (Leal Filho et al. 2021), specific considerations in planning policy should be provided to tackle several environmental issues as consequences of urbanization. Givoni et al. (2003) pointed out the value of using the specified tool to evaluate the impact of changing the environment in a certain way through specific design aspects.

Numerous studies have been conducted to investigate the mitigation interventions to understand, simulate and minimize the negative impact of heat stress along with scoping the future of urban climate conditions with conservative scenarios; however, most of them have not been included in spatial planning guidelines owing to:

1. Lack of a generalized multi-faceted model (Parsaee et al. 2019) to predict thermal comfort based on historical and secondary data
2. Time-consuming and costly field studies of thermal comfort, specifically at an initial stage
3. Lack of a tool for planners with less knowledge of climatology to apply in the decision-making process (Keith et al. 2021; Kelly Turner et al. 2022)

3 Methodology

3.1 Study Area

Glasgow as one of the financial capitals of the United Kingdom (Glasgow City Council 2017b) recorded a population of 635,640 in 2020, with growth rates of 8.3% since 1998 (National Records of Scotland 2021). Glasgow City Development Plan (2017) envisioned the solutions to beat the climate change severity under green strategies, including promoting green infrastructure, defining a greenbelt and redevelopment of vacant lands along with energy management (Glasgow City Council 2017b). Its place-making strategy puts health and well-being at the centre of aspiration. The strategic plan for 2017-2022, supported the sustainable and low-carbon city as a long-term perspective (Glasgow City Council 2017a). The high number of vacant lands in Glasgow, which covers more than 5 per cent of the whole city, is significant to be considered as the potential for future development and steps toward sustainability. About 667 vacant lots with a surface coverage of almost 9 km^2 need policy makers' attention for bringing the climate-sensitive strategies into practice.

3.2 Research Philosophy

The pragmatic research philosophy was employed to achieve the project's principal aim of developing a holistic model for decision makers since it emphasizes addressing challenges within a real-world situation (Salkind 2010). Under the abduction approach, data is utilised to analyse, identify themes, and explain patterns in order to generate a new/modify a current theory, which is then assessed, typically by further data collection (Saunders et al. 2018). Analysis methods relying on numerical models (linear and nonlinear regression) were identified based on a quantitative research design using GIS-based analysis methods, statistical tools and microclimate simulation software.

3.3 Methodology Framework

Figure 1 depicts the framework that has been taken into consideration. There are five main steps in the entire procedure, which begin with reviewing of the literature and data gathering. To create the foundational dataset for the prediction models, data pre-processing and processing were put into account. Linear-based regressions and ANN models were employed to shed light relationship between predictors and response variables. Following that, the trained ANN model was used to estimate LST for quick scenarios throughout the planning process. Eventually, the microclimate simulation was run to evaluate the performance of ANN.

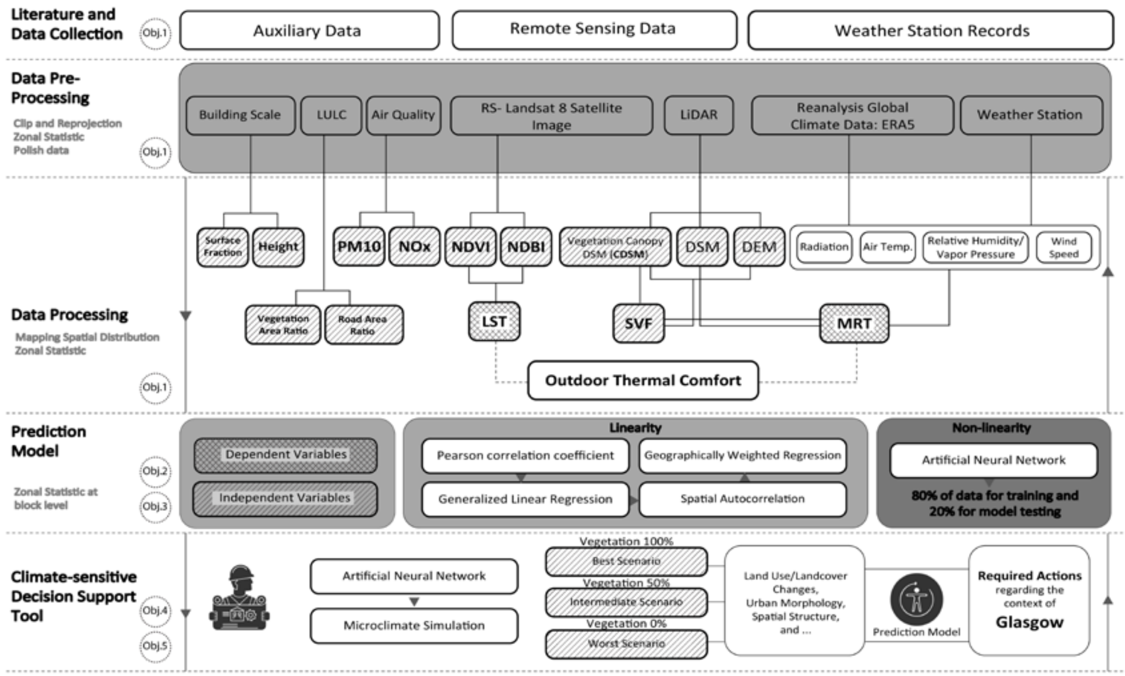


Figure 1. Framework adopted for the study (Modjrian 2022)

3.4 Dependent and Independent Variables

3.4.1 Independent Variables

Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-Up Index (NDBI), Digital Elevation Model (DEM), Digital Surface Model (DSM), Vegetation Canopy of Digital Surface Model (CDSM), Sky View Factor (SVF), Road Area Ratio (RAR), Vegetation Surface Fraction (VSF), Building Surface Fraction (BSF), Building Height (BuildHe), PM10, and NOx were considered as predictors and were collected from open-source datasets (Figure 2).

3.4.2 Response Variables

Land Surface Temperature (LST) retrieved from Landsat 8 taken on 25th June 2018 and Mean Radiant Temperature (MRT) calculated from the SOlar and LongWave Environmental Irradiance Geometry (SOLWEIG) model for 28th June 2018 have been identified as proxies of OTC (Figure 2).

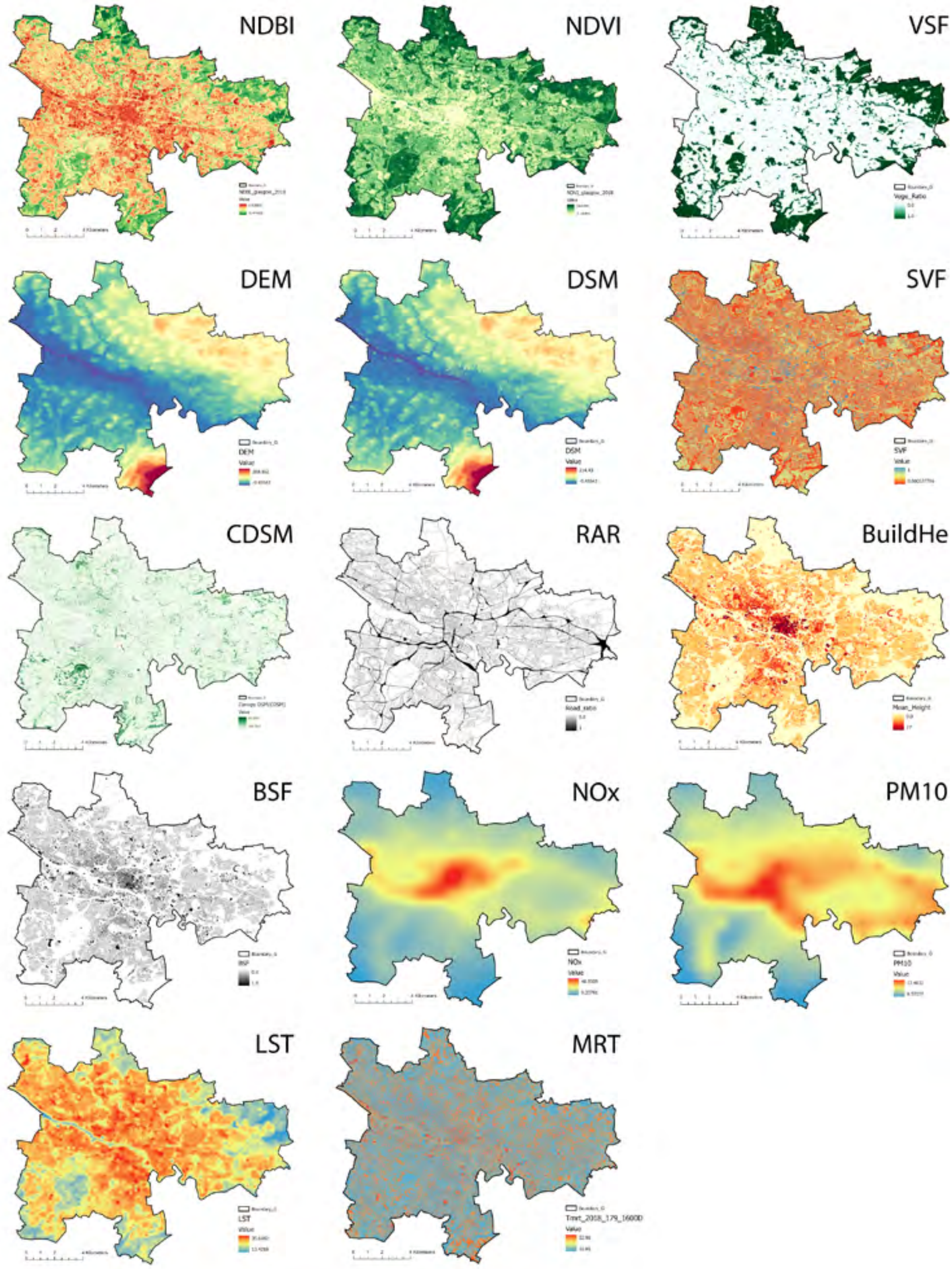


Figure 2. Independent and dependent variables adopted for this study (Modjrian 2022)

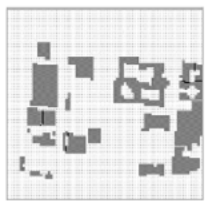
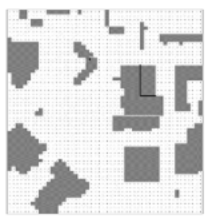
3.5 Regression-based Prediction Models

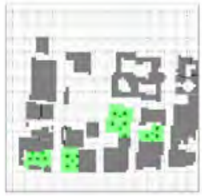
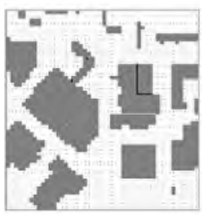
To reach the goal of the project to develop the prediction model, Pearson Correlation Coefficient, Generalized Linear Regression (GLR), Exploratory Linear Regression, Spatial Autocorrelation (SA), Geographically Weighted Regression (GWR), and ANN were considered. For ANN model, the optimum neuron number of 22 was selected due to the low error value for all three portions of the training dataset (70%-15%-15% for training-validation-testing) aside from the 20% of the whole data assigned for testing.

3.6 Microclimate Modelling

SOLWEIG and ENVI-met microclimate models were utilised to analyse the impacts of changes in urban design factors on human thermal comfort. Both models simulate the microclimate in a specific period (Table 2). The UTCI and MRT indices were calculated via BioMet (ENVI-met tool) and SOLWEIG (UMEP-Processing tool), respectively. In addition, the UTCI assessment scale in terms of thermal stress (TS) by Błażejczyk et al. (2013) was followed.

Table 2. ENVI-met models' settings (Modjrian 2022)

	Parameters		Model layout
Main model			
	Grid Size	5m x 5m x 3m	
	Date	28th June 2018	Domain_Site 1: 77x75x23
	Simulation period	30 h	
	Model starting time	27th June 2018 18:00	
	Model level	Simple forcing (Appendix II)	
	Model rotation	0	
	Wind speed	9 m/s	
	Wind direction	141.75	
	Roughness length	0.01	
	Min-Max Temp	13-31 C	
	Min-Max RH	29%-94%	Domain _Site_2: 50x52x14
	Soil type	Asphalt road Sandy Loam Loamy soil	
	Material	Building: default Pavement: asphalt	
	Vegetation	Trees Hanging Birch(middle): 15 m Acer Campestre: 12 m	
		Grass 25 cm	

Site 1	Nesting grid	3	
	Best Case	30 Birch tree 12 Acer tree	
	Intermediate Case	15 Birch tree 7 Acer tree	
	Worst Case	No Birch tree No Acer tree	
Site 2	Nesting grid	15	
	Best Case	12 Birch tree 6 Acer tree	
	Intermediate Case	6 Birch tree 3 Acer tree	
	Worst Case	No Birch tree No Acer tree	

4 Results and Discussion

4.1 How do Regression models work in the case of MRT and LST?

The GLR results demonstrate the value of R2(.64) which is not significant to be considered a reliable and robust linear model in the prediction of LST, while in the case of MRT, the low value of R2(.37) shows other factors might be needed to be considered in finding a good fit model with the significant contribution.

The GWR model used in the LST scenario performed better when several predictors were taken into account. The model with 12 predictors failed to develop due to the redundancy and correlation between the input variables. To avoid redundancy, working on a larger grid size might be helpful as the importance of different resolutions in GWR studies was examined by H. Zhao et al. (2018) and Luo & Peng (2016). GWR was not applicable for MRT because of the lower value of SA. It is worth mentioning that MRT mostly relies on radiation, and geographically close predictor values may not anticipate its variation. Overall, GWR Regression performed as a powerful prediction model based on each independent and LST. Due to the high volume of grid-cells, ignoring the redundancy and multicollinearity between the independent variable made it impossible to develop one generalised model.

Both LST and MRT were investigated using the same optimised ANN model. The models indicated that LST is more likely to be predicted than MRT using the identified predictors. Approximately 80% of the variance in LST could be predicted using an ANN model with a Mean Absolute Error (MAE) of 1.1750°C. The MRT model estimated 65% of untrained data with a MAE of 1.5144°C. The previous ANN prediction models in UHI and thermal comfort studies could be compared with the outcome of this study. Integrating the terrain factor (TF) significantly improved LST forecasts made using an ANN model for substantial terrain variation areas, with average RMSE decreasing from 1.26 to .90°C and R2 increasing from .74 to .81 (Equere et al. 2021). The outcome of the study by Shah et al. (2022) showed a high coefficient of correlation of .87 to .99 and a low RMSE of .11 to 1.72, demonstrating the ANN model's exceptional predictive accuracy for UTCI prediction.

The weak performance of the MRT model in both linear and non-linear regressions could be the lack of significant predictors to provide a robust prediction. It is expected that including fine-resolution meteorological data will result in a superior prediction model, as Shah et al. (2022) revealed the substantial capability of microclimatic factors in forecasting UTCI and PET using an ANN algorithm.

4.2 Significant Parameters in Prediction

Pearson correlation coefficient proved the contribution of each variable for each response variable of this study. Under Pearson correlation of LST, NDBI, NDVI and VSF were the most crucial factors with a correlation of .696, -.637, and -.618, respectively, which was aligned with previous studies (Guha et al. 2018; Malik et al. 2019; Goldblatt et al. 2021). MRT Pearson correlation revealed SVF as the most significant correlated component, as shown in a study by Gál & Kántor (2020). The most powerful predictors of MRT in linear regression are CDSM, NDBI, BuildHe, VSF, and PM10.

ANN, as a black box, does not provide the contribution of each factor in the regression model. The sensitivity analysis provided the most contributing factors in the model by the elimination of each factor by the difference of error metrics. In the case of LST, NDBI got the highest error difference in the elimination process. In the second place, DEM, DSM, PM10, NOx, NDVI, BSF and SVF got the same contributions. In MRT model, SVF was by far the best factor in prediction. Research by Xie et al. (2022) also portrayed the importance of SVF in ANN model prediction of MRT. Other notable factors are NDBI, NDVI, and RAR.

4.3 LST as Proxy of Thermal Comfort

The findings from LST-ANN reveal that increasing urban vegetation has a minor influence on reducing heat stress at the surface level. Vacant land conversion to fully green space can decrease the LST by .177°C, while the built-up area could rise by 1.289°C. For the same location, the UTCI modifications were seen to drop 3K by greening strategy. The shading effect of surrounding high-rise buildings reduced TS as the built-up area increased. Compared to other studies' findings, the impact of vegetation on achieving climate comfort conditions was shown to be modest, which was discovered by Stepani & Emmanuel (2022). Furthermore, shading through plants or buildings is a great way to manage heat stress at the street level, which improves human thermal comfort by blocking solar exposure (Ketterer & Matzarakis 2014). Under the simulated condition, the effect of buildings' shading was stronger than the vegetation in site A (Figure 3), which is located in denser urban settings surrounded by tall buildings. The results show that the LST mitigation strategy does not necessarily lead to TS mitigation (Martilli et al. 2020), where the correlation between LST and MRT proved this. Enormous cooling spots are produced by the shadows of high-rise structures, which may have stronger impacts than vegetation. Furthermore, it is impractical in some regions of the city to correspond to thermal comfort using the same heat mitigation strategies (Stepani & Emmanuel 2022).

The contrast has been seen in the role of vegetation and built-up in two selected sites. In site B, the greening strategy decreased LST by .057°C, while the combination of both built-up and greenery ended with decreasing the LST by .281°C. In addition, the worst scenario operated to mitigate LST by .217°C. The UTCI index reveals that vegetation had a beneficial effect on lowering TS by more than 3.39K at street canyon. However, the worst-case scenario caused UTCI to rise to 4.61K at the street level. Due to the higher rate of openness in site B (Figure 3), the buildings' shading appeared to have less impact than the vegetation u. As a case in point, a tall building in a compact urban setting might have a better shading effect at a street level compared to a tree at the peak of solar radiation. It resulted in research conducted in Jakarta (Stepani & Emmanuel 2022), where the LST favourable strategy in heat mitigation is a combination of building and vegetation together, the UTCI responds positively to the greenery intervention.

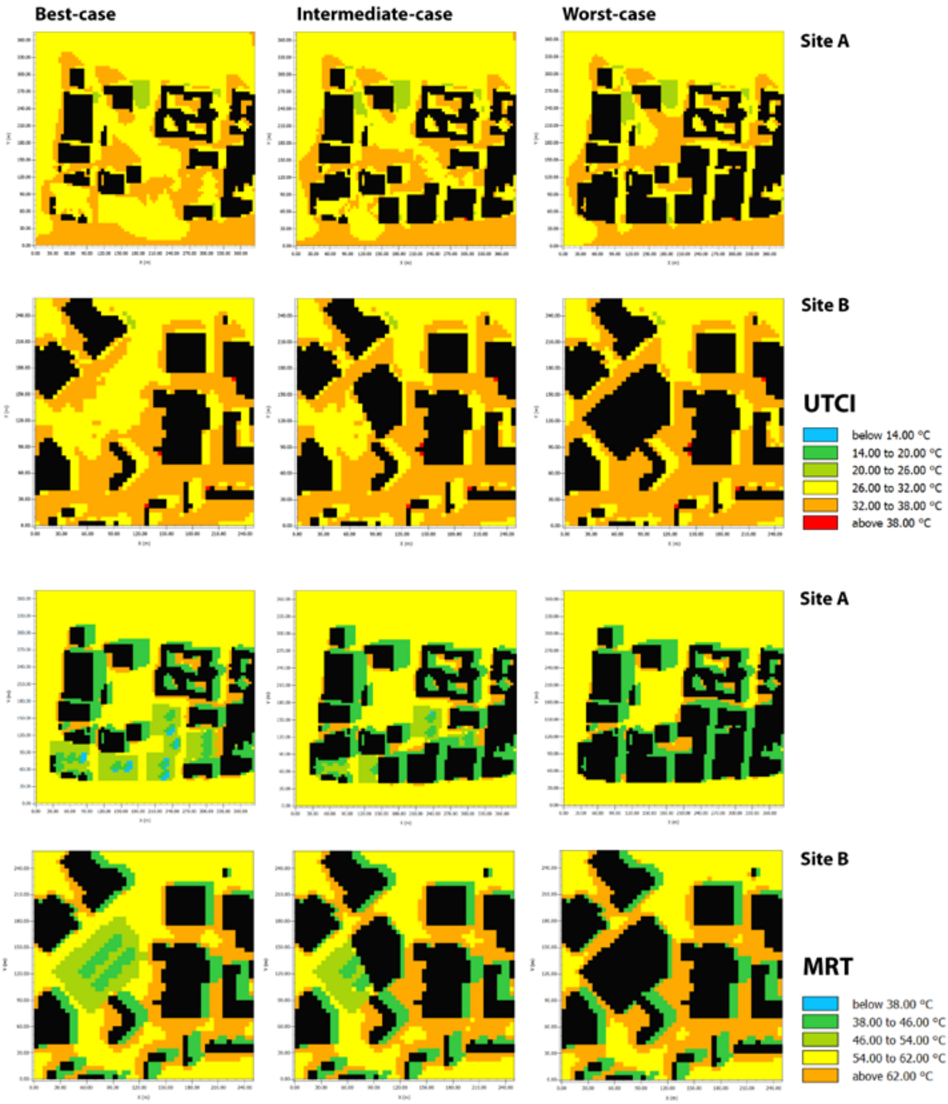


Figure 3. Simulated UTCI and MRT for three scenarios (Modjrian 2022)

In light of the study's intricate approach, there were several limitations and shortcomings in data processing and data availability including the lack of continuous, high resolution data with an appropriate resolution along with application bugs, which made the process of study longer.

5 Conclusions and Recommendation

5.1 Conclusion

Apart from reducing energy usage and reliance on fossil fuels, city development methods can help to reduce heat stress caused by climate change. The concept of generating radical situations was to comprehend the quick changes and effects of Glasgow's rising vegetation, as well as how these modifications affect heat stress and people's comfort levels. The ML prediction of LST was validated by ENVI-met, which could somewhat enhance overall thermal comfort.

ANN as a powerful model with a broader range of applications, needs high-quality data with precise accuracy to be able to create a valid and generalized prediction. Aside from how accurate is the training process, there is no guarantee that the estimation of new data would be exactly the same under the same realistic settings. However, the outcomes will be expressed as Inhibitory actions.

Furthermore, the amount of heat that people can actually feel outside is not correctly reflected by the land surface temperature that is measured using satellite data. This is because other factors, including shade, wind speed, and relative humidity, can have an impact on how much heat people are exposed to. Because of the complexity of TS, particularly at the level of human comfort, heat mitigation solutions must be researched in many contexts and locations for generalizing the mitigation approach. The comparison of the three scenarios shows that when more lands are developed through construction, the overall UTCI index will rise. In other terms, the surrounding area will experience more severe heat stress following physical development unless their shading effect appears to be strong.

The impact of shadowing from plants and buildings, for instance, could alter thermal comfort depending on the area's compactness and openness in Glasgow's central district. Heat mitigation measures at the level of lowering the surface temperature do not always meet human thermal comfort. The association between LST and MRT has made it clear that it is impossible to establish a direct connection between them.

5.2 Directions for Further Studies

This study focused on only one machine learning algorithm (ANN), the suggestion is to follow the same workflow under different ML regression models to find the best-fit model in thermal comfort prediction based on secondary and historical data. Furthermore, the same model configuration should be applied in similar cities under the same data source with a temperate climate to compare the performance of the prediction model. Although it is time-consuming and complicated to have people contribute to share their sense and experience of TS, a wide range of studies on outdoor thermal comfort have attempted to involve human contact through survey and fieldwork studies. It is suggested to include people's perceptions of heat stress in the process to establish a more comprehensive framework.

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SAMSON OLUWAFEMI OGUNFUYI

Quantifying the effect of Anthropogenic and Climate Parameters on Urban Heat Island Using Machine Learning

The intensity of UHI in today's developed areas indicates the extent of environmental modification. Replacing natural surfaces with artificial materials has been the main difference between rural and urban areas. Therefore, creating a massive temperature variation that researchers have confirmed. This study aims to analyse the distinct signatures of climate and anthropogenic factors in UHI formation and generate an urban heat risk map Using remote sensing, multicriteria decision analysis and machine learning approaches to aid urban planners in making policy decisions that mitigate the UHI effect. The obtained result confirmed the existence of UHI across space and time in Glasgow. Furthermore, the result demonstrates that machine learning algorithms can predict LST, and XGBoost had the best predictive performance with an R2 value of 0.8126 compared to ANN and DT. Also, the sensitivity analysis illustrated that horizontal urban parameters such as water distance, NDVI and road network distance had more influence on LST. DEM significantly affected LST, while socio-demographic and climate parameters fairly affected LST. The result confirms the role of vegetation and water body in UHI reduction. Likewise, this research revealed that enhanced NDVI could reduce heat risk. On the other hand, building height reduces vegetation's efficiency to decrease heat risk in urban areas.

1 Introduction

In every region of the world, human-caused climate change is already impacting several weather patterns and extreme climatic events (Masson-Delmotte 2021). Since the fifth assessment report (AR5), there has been evidence of observed strength accumulation, dramatic shifts in heatwaves, drought, and heavy precipitation linked to human activity. Concerns about climate change have been progressively developing due to cities' expanding population, size, and emissions (Tafazzoli et al. 2020). Logically, both direct and indirect human activity in cities is connected to the formation of emissions. According to estimates from the International Energy Agency (IEA), buildings' heating and cooling needs in 2007 accounted for over 30% of global energy use (IEA 2007). Despite the troubling figures, there is a consistent surge in urban migration and population growth. The International Organization for Migration (2015) estimates that while over 4 billion people currently reside in urban areas, this number will increase to 6.4 billion by 2050. This suggests that energy consumption would rise to meet the increased demand for infrastructure, and more pervious surfaces will be converted to impervious surfaces.

Impervious surfaces referred to in the literature as artificial impermeable materials like concrete or asphalt, significantly contribute to the UHI effect (Imhoff et al. 2010). Weak surface albedo, urban forms, and buildings also play a role in thermal storage and reduce longwave energy loss by radiation and anthropogenic heat from human activities. Also, this heat island is easily observable in urban areas, and the high emission of greenhouse gases and energy consumption in metropolitan areas exacerbate climate change (Oke 1987; Priyadarsini 2009). Howard (1833) recognised the impact of urban regions on climate. He identified several UHI factors currently being researched, such as the scarcity of evaporation, human heating, and airflow restriction (Mills 2008).

Changes in land use land cover and its layout are crucial factors in urban hydrological changes, environmental deterioration, the formation of urban heat islands, and climate change at various scales (Deng & Srinivasan 2016; Kikon et al. 2016). Urban land cover changes include decreased vegetative cover and local soil moisture and resurfacing land areas with impermeable materials like roads, buildings, and parking lots. These modifications to the ground's surface tend to boost solar absorption and storage while lowering evaporative cooling. To inform decisions and policies by urban planners, it is crucial to research how UHI parameters affect temperature increases in metropolitan areas, given the anticipated population growth. Thus, the research goal is to identify the unique signature of UHI parameters using machine learning and generate an urban heat risk map of Glasgow through multicriteria decision analysis. Lastly, an attempt was made to identify possible strategies to reduce heat risk.

2 Background

2.1 Urban Heat Island

The temperature in Cities has been substantially greater than its bordering rural areas over the years (Mirzaei & Haghighat 2010). This phenomenon is referred to as an urban heat island, and several authors have defined it. The Urban Heat Island (UHI) phenomenon is the difference in temperature between urban areas and neighbouring rural communities due to replacing natural land with urban material (Oke 1982; Howard 1833). The absorption properties of urban materials are different, and they are known to have a high albedo. Furthermore, they define the characterisation of the urban area into natural and artificial surface materials that influence ecological (Arnold Jr & Gibbons 1996), climate and energy (Oke & Timothy R. 2002) state. Temperature changes in the canopy layer are triggered by four factors, according to Howard (1833): (1) human source heating, (2) the architecture of urban surfaces captures radiation and hinders it from returning to space, (3) the effect of "roughness" in the city on the trajectory of summer's "gentle winds," and (4) the evaporated amount of moisture. Anthropogenic activities are the core driver of urban-rural temperature variation, and it has greatly modified the environmental and climate condition.

2.2 Estimation of UHI

To reduce the detrimental impacts of urban heat islands, it is necessary to adopt policies that combat UHI and conduct heat island research (Yun et al. 2009). Two primary research approaches have been developed to characterise UHI. (1) The canopy layer UHI is known by measuring air temperatures at roughly 2 m above surface level (Stewart 2011), and (2) the Surface UHI (SUHI) is calculated using remote sensing data (Voogt & Oke 2003). In addition, UHI and its dispersion are also assessed using an urban canopy model (Rizwan et al. 2008).

Although the data from remote sensing and the air temperature above the surface are not similar, they are correlated (Prihodko & Goward 1997; Mostovoy et al. 2006; Imhoff 2010). However, the impact of turbulence and velocity on air temperature distinguishes atmospheric and surface UHI (Mirzaei & Haghighat 2010). The thermal band from remote sensing has been used to discuss UHI globally (Shastri & Ghosh 2019), coupled with the critical temperature variation in an urban area (Imhoff 2010; Chakraborty et al. 2020). The obtained surface temperature considers the impact of surface radiative and thermodynamic properties such as surface emissivity, surface moisture, surface albedo, the near-surface atmosphere's effect, and the irradiative input at the surface to the turbulent transfer from the surface (Becker & Li 1995).

Stathopoulou et al. (2007) used the NDVI threshold technique to assess land surface emissivity using Landsat 8 data. However, due to the underlying technological complexity of these procedures, the surface temperature measured by sensors is totally dependent on the upward thermal spatial radiation pattern received by the remote sensor (Voogt & Oke 2003). Furthermore, the author investigated the intensity of UHI dispersion using the thermal band. By examining the relationship between LST and impervious surface area (ISA), vegetation fraction, and NDVI, Li et al. (2011) proved that remotely sensed images provide convincing evidence for UHI research. Similarly, in a study looking into the influence of landscape patterns on LST, landscape characteristics revealed significant relationships with LST (Azhdari et al. 2018).

2.3 Urban Parameter that influences UHI

Satellite or airborne remote sensing photographs have been used to analyse the thermal characteristic of urban surfaces by correlating numerous indices and surface properties to LST, which is one of the essential indications for UHI. Several indices have been developed to extract horizontal geometric features from Landsat images. On the other hand, some publications sometimes refer to the horizontal morphological characters as 2D UHI parameters (Balázs et al. 2009; Huang & Wang 2019).
The vast amount of built-up is also recognised as a significant factor in UHI (Asadi et al. 2020). However, this parameter had a minor impact on LST prediction in the sensitivity analysis. Nevertheless, previous studies have shown that these variable impacts air temperature more than surface temperature (Guo et al. 2016; Kantzioura et al. 2012). In general, horizontal urban parameters significantly influence LST more than the urban vertical component (Berger et al. 2017; Huang & Wang 2019; Asadi et al. 2020). Consequently, Urban geometry, such as street width, sky view factor and building height, traps heat and slows down windspeed.

2.4 Machine Learning Algorithms

Traditional statistical models rely heavily on the regression method (Guan 2012), which has been widely used for prediction (ASHRAE Fundamentals 2009). However, for non-linear model function approximation, Machine Learning (ML) are a well-acknowledged method. Although ANN is not the only machine learning algorithm available for researchers, many authors have compared the performance of multiple machine learning algorithms (Nitze et al. 2012; Priore et al. 2006; Rogan et al. 2008). For example, Pena Acosta et al. (2021) used the machine learning (ML) python toolkit SciKit-Learn (Pedregosa et al. 2011) to apply a Rain Forest (RF) and Decision Tree (DT) approach to socio-economic and urban morphology features with UHI at the street level.
Tyralis et al. (2021) compared the efficiency of 10 machine learning algorithms on streamflow forecasting. Their result showed that neural networks are the best-performing algorithm since they outperformed the linear regression method by 16.73%. However, the ability of machine learning algorithms to replicate similar superior result over one another is not guaranteed as various factors such as data or optimisation criteria modifies their performance. For example, Zhang et al. (2019) research showed that DT has higher efficiency than RF, which counters Pena Acosta et al. (2021) claim. Furthermore, since urban scale plays a crucial role in UHI parameter interactions, spatial data is essential in various machine-learning algorithms when finding relationships between non-linear variables.

3 Methodology

The following methods: descriptive, analytical, evaluation, and forecasting, were performed on spatial remote sensing data to achieve the set-out objectives.

3.1 Study Area

The study area is Glasgow which is located around 55.8642^{0}N and 4.2518^{0}W in the West Central region of Scotland and is popularly described as the largest city in Scotland, with an area of 176 km^2 (Glasgow City Council 2017). Glasgow is classified as having a moderate climate with maritime influences by the Koeppen-Geiger climate classification system. The warmest season, July and August, has a mean maximum temperature lower than 20^{0}C, while for a minimum of five months a year, the daily mean temperature is over 10^{0}C (UK MET Office 2017). Previous research on Glasgow's UHI has revealed a warming pattern for decades (Emmanuel & Krüger 2012). Also, Considering the effect of climate change that made Glasgow record its highest temperature since 1906, weeks before Cop 26, it is pertinent to study the UHI effect in Glasgow.

3.2 Data and Research Method

Regardless of the difficulties in data accessibility, Google earth engine, Copernicus and the University of Glasgow urban big data centre provided reliable data for this study. For example, the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS) are two research instruments onboard the Landsat 8 satellite (TIRS). In addition, sentinel 2 was used for image classification due to its high resolution. In contrast, LiDAR, a much higher resolution laser scanning technology, provides points cloud sets describing objects or surfaces.

Earth observation data monitor and detect environmental characteristics by measuring emitted or reflected longwave radiation within a particular wavelength. Because the remotely sensed data are available in digital numbers, several pre-processing steps are done to obtain the desired output, as shown in figure 1 on the next page.

3.3 Land Use Land Cover Classification

High-resolution Sentinel 2 (19th July 2021) data was extracted from Google Earth Engine (GEE) cloud computing. Image classification was done on GEE using six classes (Waterbody, Urban, Suburban, Vegetation, Bare Soil, and Fallow Land) to represent the distribution of pervious and impervious surfaces. To guarantee high accuracy, google earth, and already classified images of Glasgow available on Digimap were used for validation during training site selection, also known as ground control point. The ground control point was fitted into a machine learning algorithm called SmileRandomForest Classifier. One of the most used methods for classifying land cover from remote sensing data is Random Forest (Amani et al. 2019; Li et al. 2016). Finally, the accuracy assessment of classified images was examined using a confusion matrix since it provides reports on the producer, user, and overall accuracy.

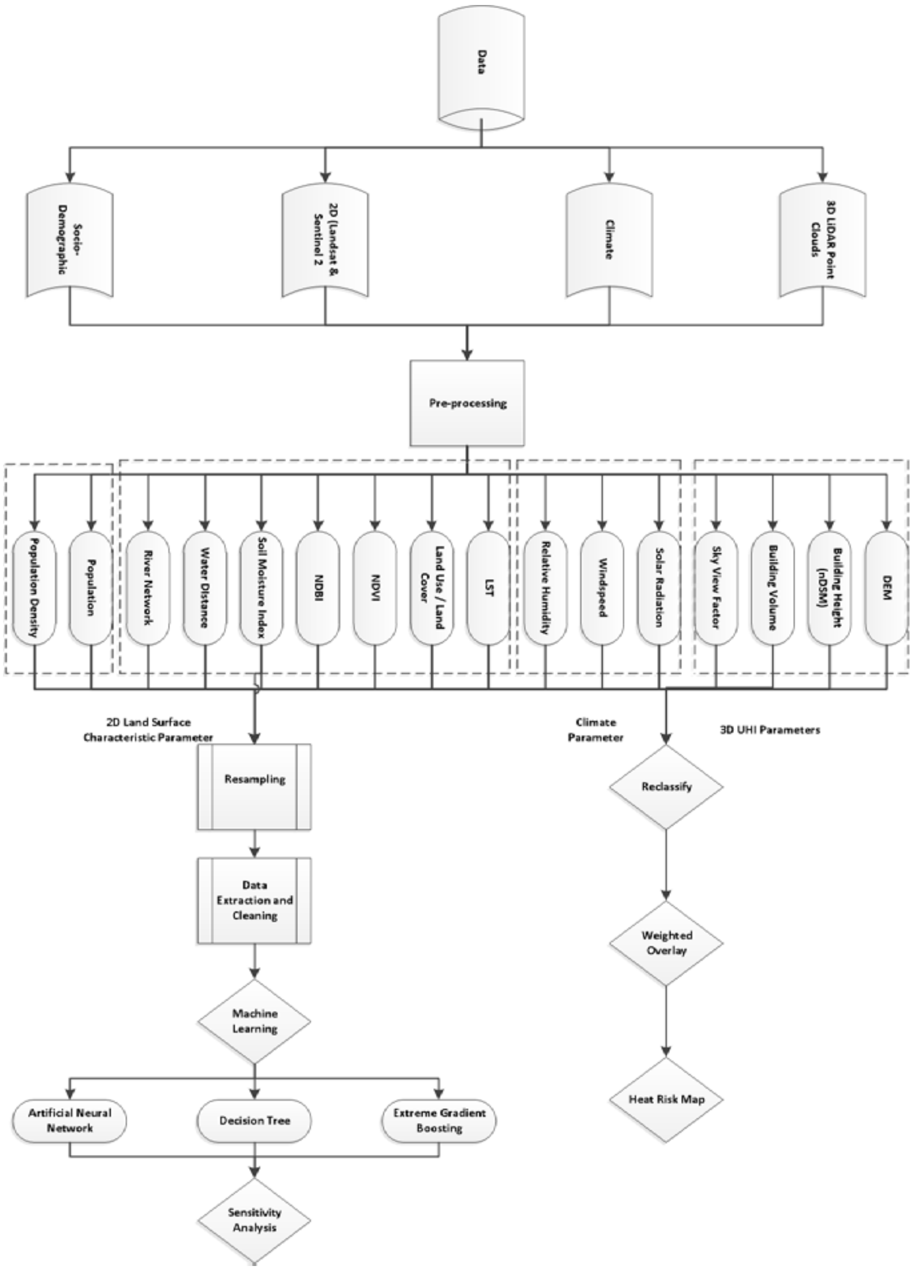


Figure 1. Data Processing Approach

3.4 Land Surface Temperature (LST) Estimation

Landsat-8 thermal band (10 and 11) of 19th July 2021 was used to calculate LST with relevant equations (Guha et al. 2018). For this study, band 10 is used because of the calibration error associated with band 11 (Wang et al. 2015).

3.5 Machine Learning Algorithm Process

The extracted data were subjected to an artificial neural network (ANN), Decision Tree (DT) and Extreme gradient boosting (XGBoost) modelling on Python, with LST being the predictand. At the same time, the other variables were the predictors. The optimisation is performed to avoid overfitting and underfitting. The input parameter was divided into two different percentages for training (80%) and testing (20%) to determine the model performance by observing the coefficient of determination (R2), mean square error (MSE), and mean absolute error (MAE). Finally, sensitivity analysis was done by retraining and removing one variable at a time to determine the importance of each predictor.

3.6 Multi-Criteria Decision Analysis for Heat Risk Mapping

Several technical and analytical processes were performed on those datasets using geographical information system software (weighted overlay). The data were re-classified into three categories, as shown in table 3.5 and adopted by Begum (2021). Furthermore, the Analytical hierarchy process (Saaty 1980) was used to assign weight to the parameter base on expert opinion, literature (Ndanusa Abdulkadir et al. 2022; Ndanusa et al. 2022), and insight from the sensitivity analysis before performing a weighted overlay to generate a heat risk map. The criterion weight (CW) was generated after computing the pairwise matrix and normalising it. The normalised matrix was calculated from the pairwise comparison matrix. The consistency ratio (CR) of the AHP was estimated to be 0.14 using the below formula. However, Saaty (1980) advised that the CR score should not be more than 0.1. But CR scores less than 0.15 is permissible because it depends mainly on matrix size (Wedley 1993), and the matrix size of this study is large (16 by 16).

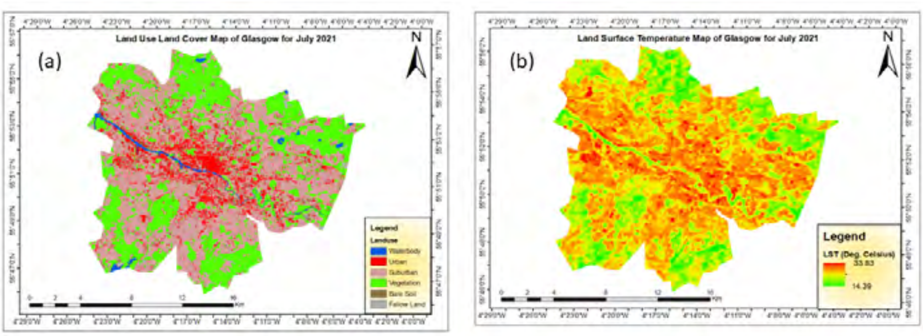
4 Results

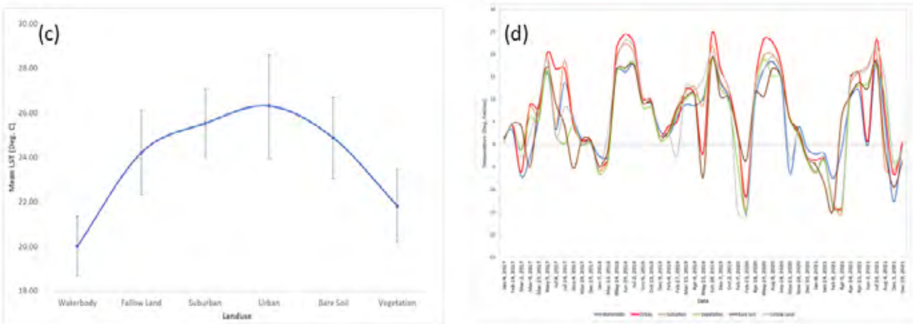
4 .1 Spatio-temporal Variation and Land Use Land Cover Distribution

This research used cloud computing Google earth Engine to perform image classification as mentioned in the methodology section. The land use land cover classification accuracy is 96%. As shown by figure 2a, land use features vary with respect to the area covered and temperature. In the city centre, there is sparse vegetation distribution except for parks used for leisure. A further attribute query was performed. Bare soil, fallow land and water had the least area covered with values of 7.01 km^2 (2.69 %), 4.11 km^2 (1.58%) and 3.51 km^2 (1.35%), respectively. The remaining three land use classes account for 94.38% of the study area, with suburban areas occupying the most significant proportion covering 133.07 Km^2 (51.13%). In addition, the Vegetated area is the second largest, with a value of 83.97 Km^2 (32.26%). While the Urban region accounts for 28.6 Km^2 (approximately 11%).

The retrieved LST map is shown in figure 2b, and its temperature ranges from 14.39^{0}C to 33.83^{0}C (26.61^{0}C) mean temperature. There is a distinct variation in LST, and this is due to the non-homogenous nature of land use. The obtained statistical description of the waterbody's LST shows that the mean, minimum and maximum temperatures are 20.01^{0}C, 16.54^{0}C and 29.49^{0}C, respectively. Since the standard deviation is 1.34^{0}C, it indicated a dispersion away from the mean. For urban surfaces, its mean LST and standard deviation value are the highest compared to other land use classes. Also, the temperature ranges from 17.75^{0}C to 33.83^{0}C. Mean temperature distribution and error bar of all landvuse categories was plotted as shown un figure 2c. As shown if figure 2d, there was a clear indication of extreme temperature occurrence and seasonal LST variation was noticed.

Figure 2. Spatio-temporal variation of LST and Land use: (a) Land use land cover classification map of Glasgow, (b) Land surface temperature map of Glasgow, (c) Mean LST and error bar plot of each land use category, (d) Time series variation of LST





4.2 Predictive Performance and Sensitivity Analysis

The performance of XGBoost when trained with the 14 parameters, stands out among the pecking order. It provided an improved version of the R2 (0.8126) value for the trained dataset by 6.41% compared to ANN and 13.58% when compared to DT. Also, there was an observed reduction in MSE and MAE values when compared with ANN and DT. The MSE and MAE values of XGBoost are 0.0032 and 0.0384, respectively. Furthermore, the coefficient of determination (R2) value of 0.8131 was obtained when the predicted LST was plotted against the actual LST, as shown in figure 3c. Similarly, the ANN predictive algorithm had a coefficient of determination (R2) value of 0.7605 for the trained dataset. The R2 suggests an excellent positive correlation between the predicted LST and actual LST. Also, mean square error (MSE) and mean absolute error (MAE) was used to examine the inaccuracy of the predicted errors. MSA and MAE had a low error margin of 0.0042 and 0.0491, respectively. Furthermore, a linear graph of predicted LST against Actual LST for the ANN model had an R2 of 0.7784, as shown in figure 3a.

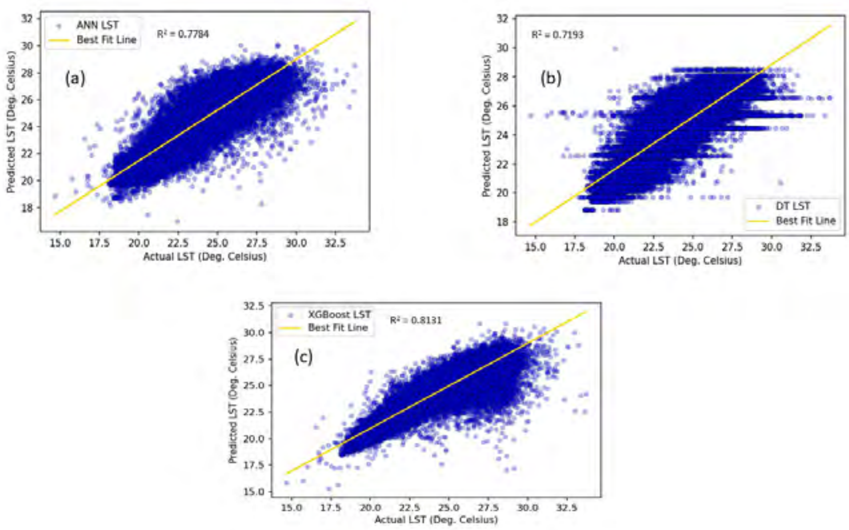


Figure 3. Predicted LST against Actual LST: (a) ANN, (b) Decision Tree, (c) XGBoost

The sensitivity analysis result (table 1) showed that water distance, DEM and NDVI had the most influence on LST with the following values: 9.96 %, 7.56% and 5.67%, respectively. Road Network distance also had a 4.48% influence on LST, making it the fourth most influential variable. Variables like relative humidity, wind speed, sky view factor and population density significantly influenced LST with values of 3.75%, 3.54%, 2.89% and 2.78%, respectively. Among the least influential variable, population and NDBI had a value of 1.44% and 1.24%, respectively. A further query into the variable was made, subdividing the variables into climate, vertical (2D), horizontal (3D) and Social-demographic parameters. As indicated in table 1 below, the horizontal parameter had more influence (11.41%), confirming the individual impact of water distance, NDVI and road network. Meanwhile, Socio-demographic and climate parameters also had a good contribution percentage of 7.06% and 6.80%, respectively. Finally, the vertical parameter had the least influence, with a value of 6.32%.

ML Algorithm	**R^2**	**MSE**	**MAE**	**ΔR^2**	**% Influence using R^2**
All	0.8126	0.0033	0.0384	-	-
All - DEM	0.7511	0.0022	0.0336	0.0614	7.5581
All - Building Height	0.8118	0.0032	0.0383	0.0007	0.0877
All - Building Volume	0.8086	0.0032	0.0382	0.0039	0.4834
All - Sky View Factor	0.7891	0.0028	0.0371	0.0235	2.8865
All - Solar Radiation	0.8053	0.0031	0.0378	0.0072	0.8888
All - Windspeed	0.7838	0.0028	0.0354	0.0287	3.5351
All - Relative Humidity	0.7821	0.0027	0.0359	0.0305	3.7539
All - Land use Landcover	0.8075	0.0032	0.0374	0.0051	0.6281
All - NDVI	0.7665	0.0025	0.0354	0.0461	5.6689
All - NDBI	0.8025	0.0031	0.0371	0.0100	1.2361
All - Water Distance	0.7317	0.0019	0.0330	0.0809	9.9559
All - Road Network	0.7762	0.0026	0.0360	0.0364	4.4808
All - Population	0.8009	0.0031	0.0374	0.0117	1.4408
All - Population Density	0.7899	0.0029	0.0364	0.0226	2.7834
Sensitivity Analysis for Grouped Parameter					
ML Algorithm	**R^2**	**MSE**	**MAE**	**ΔR^2**	**% Influence using R^2**
All	0.8126	0.0033	0.0384	-	-
All - Climate Parameter	0.7573	0.0023	0.0331	0.0553	6.7995
All - Vertical parameter	0.7611	0.0024	0.0346	0.0514	6.3276
All - Horizontal Parameter	0.7198	0.0016	0.0296	0.0927	11.4127
All - Social-Demographic	0.7552	0.0023	0.0336	0.0574	7.0622

Table 1. Sensitivity analysis showing the influence of each parameter and grouped parameters

4.3 Urban Heat Risk and Reduction Attempt

The heat risk result reveals that a high heat risk area had the least area cover in Glasgow within the study time (figure 4a). It covers 3.5% of the study area and is peculiar to areas congested with built-up and high human activities. On the other hand, Low-risk areas are synonymous with vegetated land use that are mostly away from developed zones. The low-risk area covers 4.66% of the study area and is primarily located around Glasgow's edges. Moderate heat risk is the predominant category in Glasgow, covering 91.83% of the study area. A further query between LST and the heat risk map was done using zonal statistics to determine the unique surface temperature of each heat risk zone. The result revealed that low and moderate risk zone had a mean surface temperature of 18.08^{0}C and 23.74^{0}C, respectively. In contrast, the high-risk area had the highest mean surface temperature value of 29.06^{0}C.

An area of interest (Glasgow City Centre) was selected from all existing data to perform heat-risk reduction experiment. MCDA was repeated for three different cases, as shown in figure 4. Case one involves improving the NDVI, while case two considered improved NDVI and increased building height by 3m. Finally, case three is similar to case two, but the improved NDVI was removed and replaced with the original NDVI. Among all explored heat risk cases, case three had the worst exposure due to its high percentage of high-risk zones. While case one highlighted that vegetation reduced heat risk, increasing building height affects the efficiency of vegetation in reducing heat risk, as shown in figure 4f.

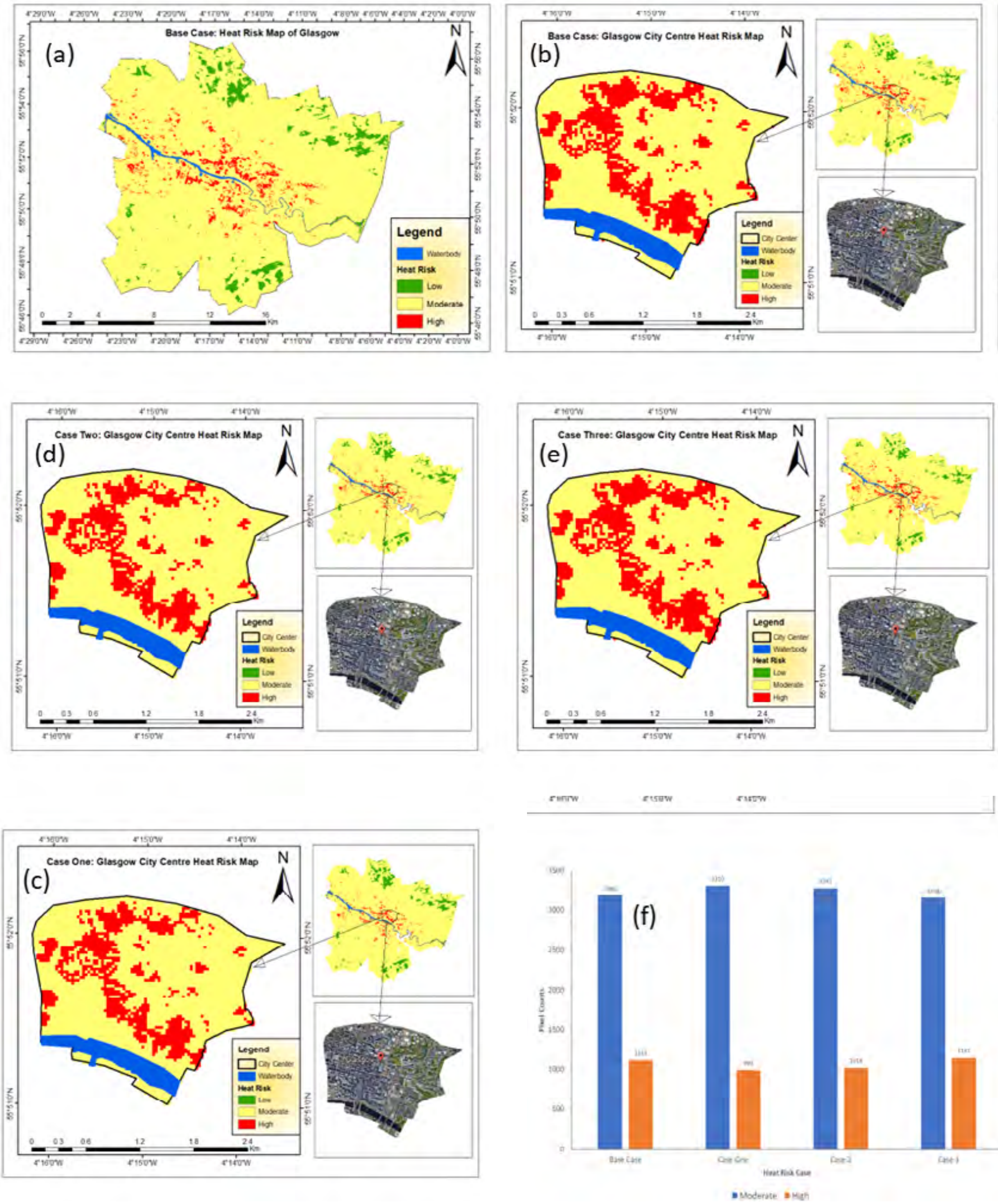


Figure 4. Heat risk map and comparison chart: (a) base case for Glasgow, (b) Base case for Glasgow City Centre (GCC), (c) Case one for GCC, (d) Case two for GCC, (e) Case three for GCC, (f) Heat risk comparison for GCC

5 Discussion

The obtained result for this research indicated the Spatio-temporal variation of LST and the critical land use features that drive LST. The cross-sectional investigation of LST confirms its variation with land use which is consistent with the assertion of other studies (Hussain et al. 2022; Tonkaz & Çetin 2007). Vegetation and waterbody have low temperatures because they drive evapotranspiration which cools the environment (Goward et al. 2002). Urban, suburban and bare soil are the three features with high temperatures which is inline with Tariq et al. (2020) resuls.

In the predictive performance of ML algorithm considered for this study, XGBoost outperformed ANN and DT. In contrast, ANN performed better than DT. Data quality is the difference between good and bad predictive model. However, the study of (Ibrahim & Rusli 2007) also showed that ANN outperformed the decision tree. Also, XGBoost model is more efficient than ANN, DT and rain forest (Xu, Chen, Xu & Shen, 2021).

The sensitivity showed that the road network, NDVI, and water body is the most influential parameter. A similar study conducted by Asadi et al. (2020) also had a related result that considered waterbody a very significant parameter for UHI. Highways and low-grade roads were found to have higher LST than the surrounding environment for distances of 180 m and 150 m (Liu et al. 2020). Similarly, socio-demographic parameters (population and population density) are the second most important parameters. Parvez & Aina (2018) confirmed population density and LST are positively corelated. The vertical parameter had the least influence, with an R2 value of 6.33. Also, when the individual vertical parameter was assessed, their performance varied, with DEM having the most influence on LST, followed by the SVF. LST reduce with an increase in elevation, but it varies across the year, both during the day and night (Phan et al. 2018). On the other hand, wind speed and humidity almost had a similar influence on LST, and they heat stress (Ashrae 2010).

The spatial distribution of high-risk zones covers 3.50% of the study area (Glasgow) and it’s dominated by building footprint. Also, the existence of waterbody reduces the presence of high-risk zones within its proximity. Saaroni & Ziv (2003) state heat stress can be decreased by even small water bodies. The presence of high-risk zone within developed areas is consistent with past research (Abrar et al. 2022; Zhang et al. 2005). The reduction attempt showed that case one improved heat-risk conditions within the city centre due to NDVI enhancement. The results justified past research that claim vegetation provides cooling effect (Chang et al. 2007). However, case two shows reduced efficiency of vegetation in reducing heat risk due to increased building height. Consequently, the case three result indicated that the city centre’s heat risk condition worsened compared to all other cases. Research has strongly linked high-rise buildings to increased energy consumption, enabling UHI (Xi et al. 2021). Additionally, tall structure cause unfair distribution of urban climate factor such as increasing temperature and decreasing windspeed (Apreda et al. 2020).

6 Conclusion

Based on the mixed research method adopted, it can be concluded that the influence of UHI parameters on LST varies across space and time. All utilised ML algorithms can produce high-accuracy prediction, but extreme XGBoost performed better. In the sensitivity analysis, horizontal parameters had the most influence on LST, followed by social-demographic and climate parameters, while vertical parameters had the least influence. Lastly, the heat-risk map of Glasgow revealed that 91.83% of the study area is categorised as a moderate-risk zone, with low and high-risk areas covering 4.66% and 3.50%, respectively. Also, Case one suggests that the heat risk can be improved by enhancing NDVI. Furthermore, increased building height by 3m reduces the efficiency of vegetation to reduce heat risk, as shown by case two. Likewise, increased building height worsened the heat risk condition of Glasgow city centre according to case three results. Due to the evidence of UHI, government, stakeholders or urban planners need to adopt action-oriented solutions to mitigate UHI. Based on this research critical finding, urban practitioners should consider incorporating a climate-sensitive urban design that considers UHI factors such as vegetation, waterbody, elevation, and road network due to their strong influence on amelioration or exacerbating UHI.

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Evaluating the Integration of Urban Heat Island Mitigation and Adaptation into Current Green Certification and Assessment Systems

Owing to the effects of climate change, the concept of sustainability, which has been around for more than three decades, is now more important than ever. One of the most vital sectors for a quick switch to sustainability is the built environment. But climate change is currently a challenge for the built environment, especially the risk of urban heat island (UHI) and urban warming. In order to make sure that existing and new communities manage current and future urban problems by creating places that are resilient, economically viable, equitable, and ecologically conscientious, sustainability assessment methods such as green rating and certification systems are put into use (Callway 2018, 2). This research is done to explore the effects of the green rating and certification system on the built environment in the setting of Glasgow. The study investigates the linkages between certifications systems and the UHI effect at various levels, including program, neighborhood, and building levels. The study analyses few of the popular rating systems currently applied in urban development practices, while diving deep into the UK certification system of BREEAM for simulation and spatial analysis in terms of UHI. The results of the present green rating and certification systems incorporate the idea of UHI to certain extent, however they do not completely compute the UHI effect. The study also recommends rigorous collection of UHI parameters be added to the current certification system to increase their potential of addressing UHI effect.

1 Introduction

The notion of sustainability, which dates back more than three decades, has grown in importance in recent years, being applied on a wide range of development sectors and at varying scales. It has become more crucial now than ever due to the impact of climate change. Global research has established that the built environment is one of the most crucial sectors for a rapid transition to sustainability. However, the built environment is currently faced by the challenge of climate change especially the risk of urban warming and the urban heat island (UHI) effect. The built environment portrays both as a cause and a victim of these impacts (He 2019, 1). Therefore, the sustainability assessment tools come into play to ensure that existing and new communities must address current and future urban difficulties by developing places that are resilient, equitable, economically viable, environmentally conscious, and 'nice' to live in (Callway 2018). One approach to do this is to adopt green rating and certification systems (GRCS) also referred to as sustainably tools. These tools are focused on the pillars of sustainability with larger emphasis on the environmental sustainability of built environment (Sullivan et al. 2015, 4). These sustainability assessment tools can be an effective decision-supporting instruments that promote sustainable development and urban policy that will shape the urban environment.

As a result, it is critical that the assessment tools consider the climate change impacts also in terms of UHI effect on the built environment. Although it is implied that these assessment tools (GRCS) measure all aspects of sustainability equally, however, in current scenario they prioritize specific aspects such as energy efficiency and carbon management, over others. Due to such limitations in the GRCS, a certified neighborhood or building even though awarded with a sustainability badge may have a favorable or unfavorable effect on the local microclimate. There is insufficient reliable evidence to support the claim that certification systems assist in reducing or adjusting to the UHI effect.

Thus, the study aims to investigate both the intended and unintended consequences of green rating and certification system (GRCS) with respect to the Urban Heat Island (UHI) effect on built environment. To accomplish this aim and fulfill the knowledge gaps the following objectives were adopted: (1) Identify criterion addressing UHI effect and microclimate moderation in current GRCS and evaluate their contribution in measuring sustainability; (2) Examine the impact of neighborhood scale certifications systems with respect to UHI effect by evaluating variations in microclimate parameters for non-certified and BREEAM certified scenarios; (3) Examine the correlation between building scale certifications systems and the UHI effect by evaluating the impact of BREEAM certified green buildings on their surrounding local microclimate.; (4) Recommend measures to enhance the criterion addressing UHI effect and microclimate moderation and augment their significance in evaluation of sustainability.

2 Background

2.1 GRCS – Sustainability Assessment Tools

To address global sustainability concerns, an increasing number of sustainability assessment tools were developed addressing few or all areas of sustainable development. Among these GRCS are sustainability metrics that rate the sustainability of a system at different scales (Srinivasan et al. 2011). GRCS were developed throughout the last few decades to aid in the evaluation of sustainable development in terms of infrastructure and buildings, as well as the assessment of sustainable urban development via community level tools (Diaz-Sarachaga et al. 2018). Government authorities, especially global investors, and property developers are becoming increasingly interested in rating and certification systems (Haapio 2012, 1). The initial certification systems were created for individual buildings that aimed to be environment conscious. However, there is a growing understanding that buildings alone cannot ensure the sustainability of the built environment (Berardi 2015; Sullivan et al. 2015). Thus, the study considers GRCS at both the levels. The literature suggests rewards from these certification systems might be massive, however, also comes with challenges. Unfortunately, some rating systems do not incorporate onsite verification of green initiatives (Allen 2014). While others have 'substitutable' and 'tradable' values. This means that most credits can be traded in order to reach a specific level of performance; in other words, non-compliance in one area can be made up for by compliance in another in order to reach the desired rating. Thus, when the certification system is utilized incorrectly, it can lead to poor building and neighborhood performance with a sustainability mask (Awadh 2017).

2.2 Urban Heat Island (UHI) Effect

Due to its effects on different facets of urban existence and ecosystem, urban overheating is a crucial topic in studies of urban climate. Undoubtedly, the urban heat island (UHI), is the main cause of urban overheating (Su et al. 2021,1). The study of UHI is not a new subject in the urban climate literature, and it has been well and widely examined globally about its genesis, causes, and mitigations (Ningrum 2018; U.S. Environmental Protection Agency 2008). Urban regions alter regional environmental factors and provide unique microclimates. UHI is a microclimatic phenomenon whereby cities routinely experience hotter surface and air temperatures than the nearby natural areas (Oke 1973; Oke et al. 2017). According to previous research, over the previous 20 years, major UK cities have occasionally been up to 5ºC warmer than the rural areas around them (Tzavali et al. 2015). Similar trends were also discovered in the northern parts of UK. While improvement will be achieved in the built environment in the future, many existing buildings and infrastructure in UK cities will be overheated by then. The impact on the urban microclimates consequently affects the thermal comfort of a space, in turn the built environment. Thus, any methodology for measuring the sustainability of the built environment must consider the UHI effect because the built environment is a significant contributor to and recipient of its effects.

2.3 Sustainability Assessment in terms of UHI – Research Gap

Rating systems range from energy performance assessments to multidimensional quality evaluations, they can be grouped into: Systems that measure cumulative energy demand; Centered on environmental facets in terms of life cycle analysis systems; Total quality assessment methods, which rate sustainability dimensions (ecological, economical, and social aspects). There are numerous multicriteria systems in use today with multiple criteria, each criterion is given a certain weight in the overall assessment. The choice of criteria and the weights assigned to them are crucial components of multicriteria systems and demonstrate which facets of built environment performance are considered crucial in sustainability evaluations. Literature also suggests that energy efficiency is consistently regarded as the most important category among the assessment systems, followed by the indoor environmental quality, waste and pollution, sustainable site, materials, and resources (Berardi 2015, 513). In case of the neighborhood-based rating systems, high significance is designated to the ecological measures, sustainable use of the land and sustainable transportations. Based on the literature, the rating systems has been provisioned to address the issues of carbon emissions and energy consumption in the fight against climate change. However, it has rarely been requested for microclimate regulation (He 2019). One single study (Shin et al. 2017) examined how LEED certification affected the microclimate cooling in comparison to conventional construction. They found that buildings with higher certification levels reduced UHI intensity by 0.48 °C, whereas those with lower certification levels had a weaker cooling effect. Another author (He 2022) observed some UHI mitigation criteria that are highlighted in current building level rating systems. However, the suggested UHI mitigation parameters are extremely limited, and the descriptions are very cryptic, as seen in the LEED as well as in the BREEAM guidelines. It is found that the current linkage between green rating systems and UHI effect is much less all-encompassing and comprehensive.

GRCS are the instruments that currently fall under the compliance category and provide qualitative best practices information. Compliance is achieved by minimum requirements of design measures, with the designer being responsible for considering a decrease in UHI. The approach makes no mention of how to calculate reductions. In these tools, the overall positive impact of deploying a UHI mitigation strategy is assumed, but this may not always be the case in practice. While detailed tools, on the other hand, are quantitative evaluation methods that seek to model the dynamic interactions between UHI and the built environment. Thus, an integration both these types of tools are required to create a comprehensive sustainability assessment tool (Hamilton et al. 2013). With limitations in the green rating and certification system, a certified building or neighborhood could have a positive or negative impact on the surrounding microclimate. Evidence explaining how certification systems help in mitigating or adapting to UHI effect are scarce to be dependable. Thus, from the literature an evident knowledge gap can be established.

3 Methodology

3.1 Research framework

The research conducted is more associated with scientific methods and positivism was adopted as the key research philosophy. From the literature review it is evident that there is no clearly defined theory in determining the interlinkages between the UHI effect and the GRCS. Thus, the study applies inductive approach, where the research moves from data to theory or contributes to establishing the theory. The research design opts for a basic mixed methodology that incorporates both qualitative and quantitative research and employs multimethod approach. This study used a case study approach and the study area chosen is the city of Glasgow. It is Scotland's largest and most populated city which is being impacted by the effects of climate change. Due to the UHI impact, Glasgow's urban center is already 4-6ºC warmer than its rural environment (Begum et al. 2021; Glasgow City Council 2020). Thus, the city of Glasgow provides a fantastic opportunity to perform UHI related study.

This research investigates the research gap at various levels – program level, neighborhood level and building level (refer figure1). ArcGIS Pro, SketchUp, Google Earth Pro, ENVI-met v.5.0.3, LEONARDO v.5.0.3, BIO-met v.5.0.3, Microsoft Excel, SPSS, and GeoDa are some of the software that were utilized for data processing, analysis, and simulation.

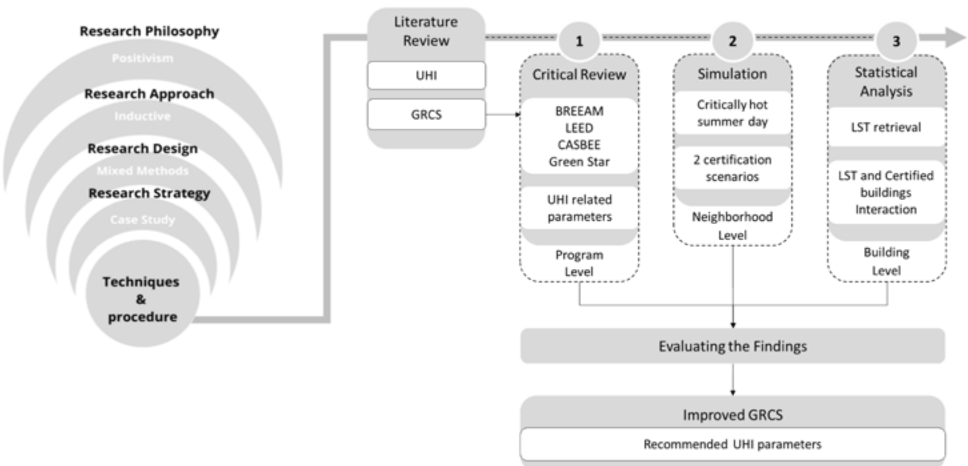


Figure 1. Research design

3.2 Critical Review of Green Rating and Certification Systems

A program level review of different GRCS at building and neighborhood scale was done in order to identify criterion addressing UHI effect and evaluate their contribution in measuring sustainability. From a plethora of different GRCS currently available in the built environment sector, four of the most commonly used and prominent GRCS are selected from geographically distinct parts of the world. The GRCS included are: BREEAM, CASBEE, Green Star and LEED. All the GRCS scheme's categories are gathered, and for each one, the proportion in the final score and the percentage of credits received from both UHI-related and UHI-unrelated criteria are determined. The UHI fraction for each category is determined independently, as well as the overall weighting of UHI-related factors.

3.3 Scenario Modelling and Simulation Analysis

This phase of the methodology is employed to evaluate variations in microclimate parameters for different certification scenarios to understand the impact of neighborhood scale GRCS with respect to the UHI effect. The study explores the GRCS at neighborhood level primarily implemented in the UK i.e., BREEAM Communities assessment tool developed by Building Research Establishment (BRE) group. Sighthill Transformational Regeneration Areas (TRA), one of the eight TRAs was selected for this phase of the study. The site is best suited for the BREEAM Communities scheme since it falls under moderate to large development project that are mixed-use. In order to create the scenarios for microclimate simulations only a section i.e., first phase of the Sighthill TRA was selected.

Two modelling scenarios with regard to BREEAM Communities certification and the base case were simulated in software ENVI-met. They include (a) Base case - Business as usual – where neighborhood and buildings are not certified; (b) Scenaio1 - both the neighborhood and the buildings are certified (refer figure 2); (c) Scenatio2 - only the neighborhood is certified, but the buildings are not certified. ENVI-met is 3D software that examines thermal relationships at the microscale in urban settings. The model is based on thermodynamic approaches and computational fluid dynamics (CFD) (Acero and Arrizabalaga 2018; Albdour and Baranyai 2019; ENVI-met 2020). ENVI-met generates a variety of outputs; this study concentrates on the factors that make it possible to evaluate the cooling efficiency and thermal comfort effects of the GRCS potential at neighborhood level. The parameters considered for the analysis are Potential Air Temperature (PAT), Mean Radiant Temperature (MRT), Physiologically Equivalent Temperature (PET). The simulations were run for two dates, on the 28th of June 2018 which is the hottest day recorded in Glasgow with the maximum temperature reaching 31.1°C and 19th of July 2022 which is the hottest day in the current year that recorded at 30°C (Weather Underground 2022).

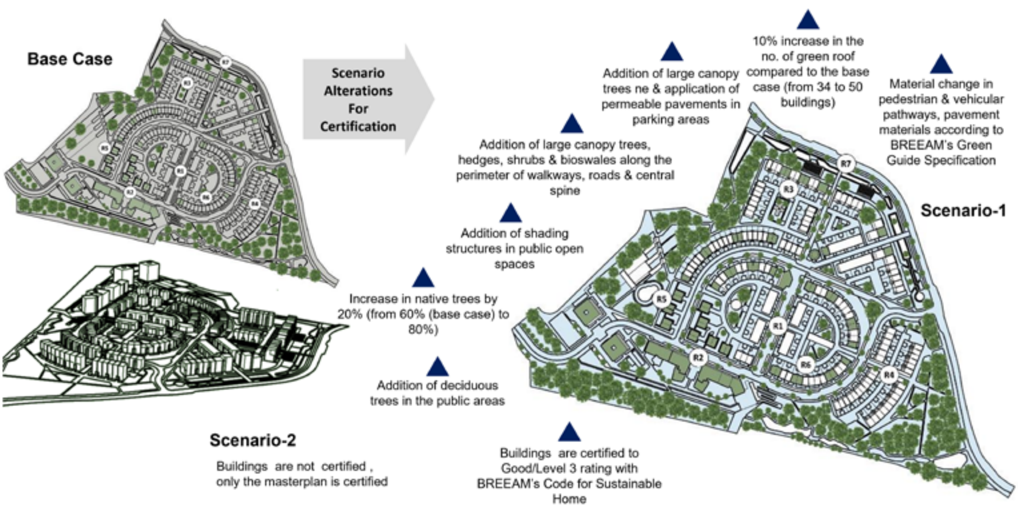


Figure 2. Certification scenario building

3.4 Statistical Spatial Analysis

This phase of the methodology is employed to investigate if there is a correlation between building scale GRCS and the UHI effect. To examine this, the study forms a hypothesis that states the BREEAM certified buildings in Glasgow impact the local microclimate especially in terms of Land Surface Temperature (LST), thus, affecting the surface urban heat island (SUHI). In order to understand if there is any correlation between the two research variables, Pearson correlation coefficient is applied to evaluate the strength of the relationship between the two determining variables and Ordinary Least Square (OLS) linear regression is used to test whether the relationship is linear.

Here the dependent variable is the LST while the independent variables is the number of BREEAM certified buildings and non-BREEAM buildings. The LST maps were retrieved from the Landsat-8 data for the summer days 25 June 2018, 28 June 2019, and 19 July 2021, which represent sizzling summer temperatures with less than 10% cloud cover. Then normalization process was applied on the LST data to bring the temperature of images taken at various dates within the same range for the analysis. A grid of 1 km by 1 km were used to divide the Glasgow city area and both the variable were compiled within these grids. Where, the mean LST and the number of buildings for each grid was calculated.

4 Results and Discussion

In order to address existing research and knowledge gaps, this study is examined at various levels and based on the integration of different methods offers verifiable evidence of impacts of GRCS in terms of UHI.

4.1 UHI Assessment Adequacy in GRCS

The critical review results suggest among the building level GRCS, CASBEE provides the most extensive account of UHI parameters. In the total score the UHI related parameters account for 12% in CASBEE, followed by LEED and BREEAM at 6% and Green Star at 5%. On contrary to the building level GRCS, at neighborhood level the BREEAM Communities present the most comprehensive account of UHI parameters. In the total score, the UHI related parameters account for 28% in BREEAM, followed by LEED at 18%, CASBEE at 13% and Green Star at 9% (refer figure 3). The entire contribution of each category has an impact on the percentage of the overall score that arrives from factors connected to UHI. Positively, the critical review's overall analysis suggests that the notion of UHI is addressed to a certain extent in all of the GRCS rather than being completely absent. Although the number of parameters addressing UHI and their proportion in the total credits is low.

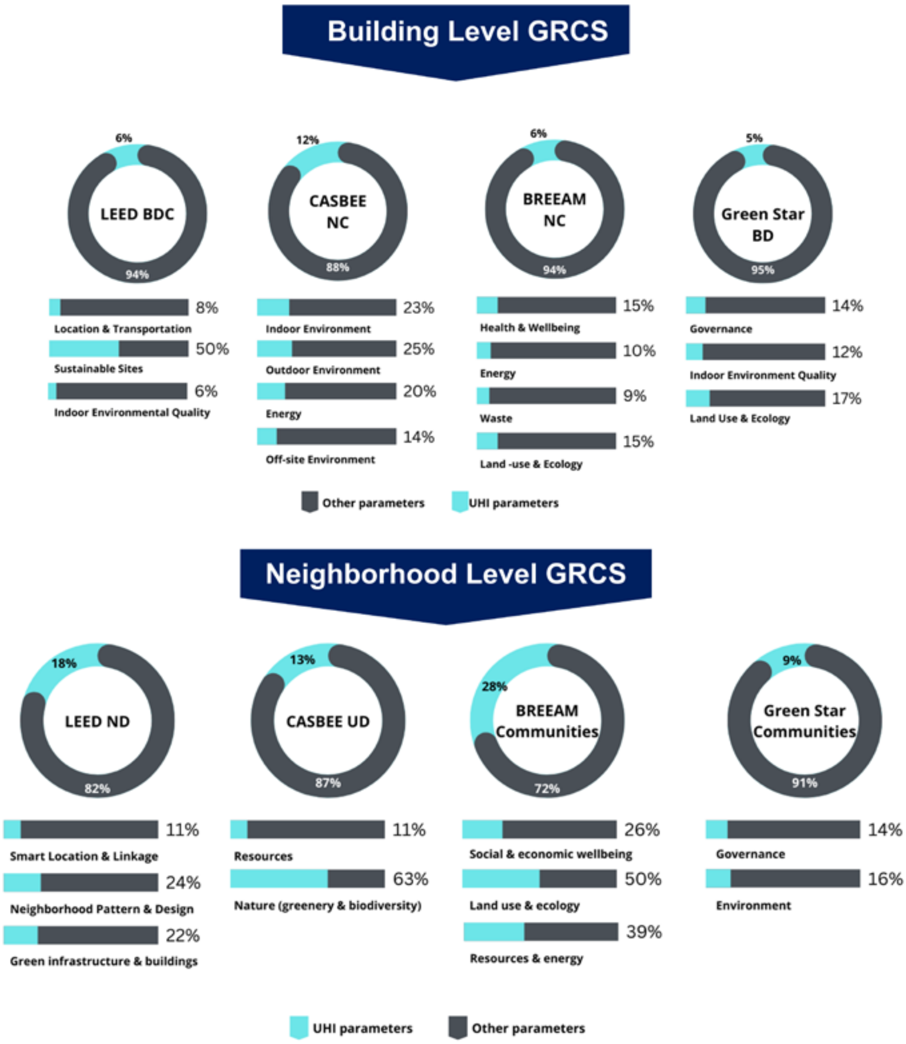


Figure 3. UHI evaluation adequacy in selected GRCS

4.2 GRCS Impact on Local Microclimate

The microclimate simulations performed with the ENVI-met software assess the influence of UHI related parameters already existing in the GRCS on the local microclimate (refer figure 4). The simulations present evidence of maximum reduction in air temperature (PAT) by 0.71 – 0.90°C in certified scenarios in relation to the base case. The certified scenarios demonstrate the beneficial effects of masterplan alterations catering to the UHI related parameters like "Green infrastructure," "Enhancement of ecological value," "Landscape," "Microclimate" and "Low Impact materials" in BREEAM Communities. The MRT is estimated to have a maximum reduction of 14.14 – 19.17 ˚C. MRT variations are more apparent, suggesting slight changes in PAT might have an impact on people's thermal comfort. Simulations show that, thermal discomfort levels inside the study area on a hot summer day, measured as PET values, can reach 41.6 - 44.5 ˚C in the afternoon. Overall, the study area is unpleasant thermally for 7 to 9 hours during the day when average PET values are higher than 29 ˚C. The PET values for the certification scenarios are estimated to have a maximum reduction of 12.2 -13.3 ˚C. The PET also presents a similar trend as MRT. On average the thermal perception was improved from hot and very hot in Base Case to warm and slightly warm in the certified scenarios.

The certification scenarios are modelled to receive the maximum number of certification credits; as a result, the findings demonstrate beneficial impact on the local microclimate relative to the base case. However, there are other factors that could influence these outcomes in the actual certification process. For instance, the alteration made in the masterplan are based on BREEAM Communities, where the UHI related parameters fall under the non-mandatory criteria. Thus, to attain the required credits the developer may or may not necessarily consider the UHI relate parameters. Thus, even though a neighborhood is BREEAM certified with good score, it does not guarantee positive impacts on local microclimate.

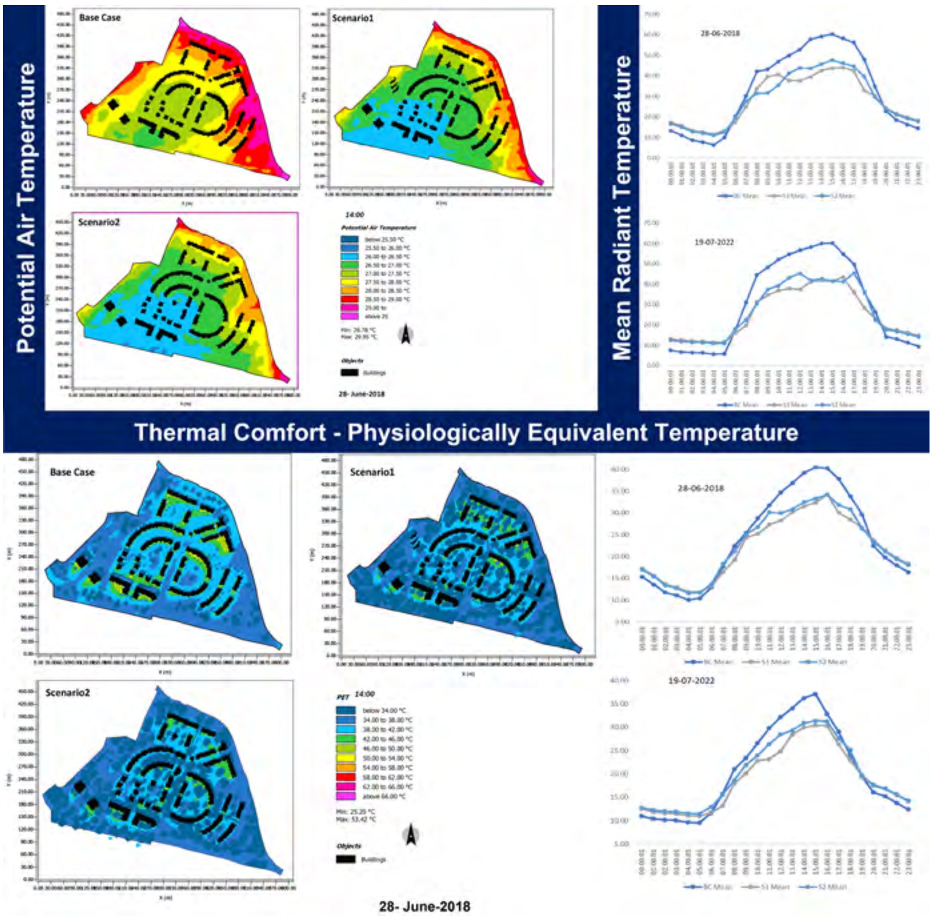
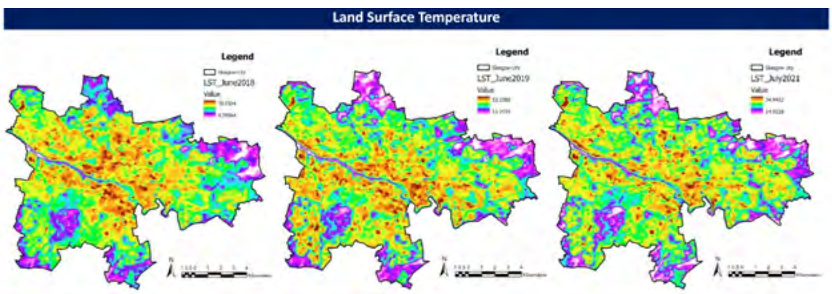


Figure 4. Neighborhood level impact on local micrclimate

4.3 Relation Between GRCS (at building level) and UHI

Pearson correlation coefficients suggest the correlation in both certified and noncertified case presents positive relationship, although the degree of relation varies. Thus, suggesting that the temperature increases with an increase in the number of both certified and non-certified buildings. The LST correlation with non-certified buildings present higher degree of correlation as the (r) lies between ± 0.50 and ± 1. In comparison, the certified buildings present lower degree of correlation as the (r) below + 0.29. To understand the causation further analysis in terms of OLS regression was conducted. It was found that only 40%-44% of variation in the LST is explained by the certified and non-certified buildings. For instance, in Model 1, the non-certified buildings' coefficient of 0.589 demonstrates that within the boundary of 1km-by-1km grid, one non-certified building may increase the surrounding LST by 0.589ºC. While the certified buildings' coefficient indicates that one certified building within the 1km boundary, irrespective of its certification level, could result in an increase of 0.199ºC in the local LST (refer figure 5). Prior literature suggests that LST data has shown spatial autocorrelation in urban settings (Dai et al. 2018; Krüger et al. 2013). Thus, the residuals of all the 3 OLS models were checked for spatial autocorrelation using the Global Moran's Index test. Which for all the models are greater than zero presenting a strong spatial dependence indicating LST clustering pattern. To neutralize the spatial dependence, spatial regression analysis in terms of spatial lag and spatial error models were employed. By considering the spatial dependence, the spatial models significantly improve the R2 where 66%-73% of variation in the LST is explained by the certified and non-certified buildings.

Overall, the analysis reveals provides evidence of a relationship between BREEAM-certified buildings have and the local microclimate. While the general expectation is that BREEAM certified buildings helps to reduce the LST due to all the sustainability measures in place, the results indicate an increase in the LST as an impact of certified buildings. However, the rate of LST increase observed in the surroundings of non-certified buildings is significantly higher than certified buildings.



At $p < 0.001$ level correlation is significant . (2-tailed)		Certified Buildings	Non-certified buildings
Pearson correlation	NLST 2018	0.234	0.601
	NLST 2019	0.251	0.605
	NLST 2021	0.230	0.638

Summary of OLS models				
		Model1	Model2	Model3
Dependent variable		NLST 2018	NLST 2019	NLST 2021
Independent variable	Certified Buildings	0.199*	0.215*	0.193*
	Non-certified buildings	0.589*	0.592*	0.627*
N		206	206	206
R-square (R^2)		0.401	0.413	0.444
Adjusted R-square		0.324	0.407	0.439
Significance		significant at $p < 0.001$ level		

*Coefficient

	OLS (R^2)	Spatial Lag (R^2)	Spatial Error (R^2)
Model 1	0.401	0.681	0.668
Model 2	0.413	0.738	0.728
Model 3	0.444	0.689	0.667

Figure 5. Building level impact on local micrclimate

5 Conclusion and Recommendations

One could argue that an accurate evaluation of the thermal efficiency of the built environment depends on a thorough understanding of the spatial and temporal variance of the urban microclimate. Thus, the assessment tools that help in shaping the built environment must incorporate well-thought-out, and combined actions with a high potential to positively impact urban climate and manage the negative effect of the UHI phenomenon (Mahdavi et al. 2016, 71). The analysis of various certification systems currently implemented in the urban environment shows that the concept of UHI is integrated to some degree in the current GRCS, however, does not accurately compute the UHI effect. No particular GRCS presents a comprehensive set of UHI related parameters that have the potential to inform and, in the best-case scenario, influence UHI mitigation initiatives. They aspects of UHI effect such as urban morphology indices, surface indices, thermal and radiative indices, building envelope indices, thermal comfort indices etc., are missing, limiting the role of certification systems in mitigating the UHI effect.

The simulation analysis at the neighbourhood level presents reduction in PAT, MRT and improvements in the thermal comfort as a result of masterplan design modification, considering the guidance provided by the BREEAM certification system. Thus, there is evidence that the existing UHI-related parameters in the certification systems can have a positive impact on the local microclimate. The study also demonstrates a relationship between certified buildings and the surrounding microclimate exists, which indicates the certified buildings have an impact of temperature increase similar to what is observed in case of non-certified buildings. However, compared to certified buildings, the rate of temperature increase seen in the surroundings of non-certified buildings is noticeably higher, suggesting that the inclusion of certified buildings reduces the adverse effect of built form on surrounding temperature.

Finally, the thesis concludes that, although the impact in terms of UHI effect may not be large, there are potential benefits of the GRCS. UHI is one of the key issues associated with climate change, hence including UHI indicators in sustainability assessment tools ensures a certain level of commitment towards reducing these risks. Moreover, this could be a challenging goal to achieve since the mitigation strategies required are extremely contextual because the heat island phenomena depend on the local climate and on the surrounding environment. Thus, it is not possible to arrive at a set of global benchmarks that defines the assessment criteria. Therefore, the research proposes incorporation of a comprehensive set of UHI linked parameters recommended in this study in addition to the already existing ones in all currently operational GRCS. A simplified range of urban environmental parameters that may have an impact on both UHI, and the variance of the urban microclimate. This will ensure the certification systems are adequately measuring and addressing UHI effect as well as greater favorable impact on urban microclimate. The recommended parameters are classified into three categories:

- Parameters that influence causation of UHI
- Thermal Comfort indices that are affected due to UHI
- Parameters that reflect UHI mitigation and adaptation measures

Unlike the BREEAM Communities it is essential that recommended parameters and the existing UHI related parameters are made mandatory evaluation criteria to obtain the certification status. With numerous development projects striving to achieve the goal of sustainability, these parameters will ensure and provide guidance for plan and design development that accounts for the changing climate scenarios. Another crucial recommendation is the mandating the onsite verification of green initiatives and have continuing reporting requirements to track commitments after the project is implemented and has received the certification. To ensure the UHI related parameters have potentially influenced the plan and design of the project for reduction in UHI intensity and improvement in the urban microclimate, several types of climate models can be employed. According to literature four main types of climate models have been used to estimate UHI intensity: 1) Mesoscale models (such as Urban Weather Generator, Weather Research Forecasting models), 2) Computational Fluid Dynamics (CFD) models, 3) Urban Thermal Environment (UTE) models (such as ENVIMET model), and 4) Local Climate Zones (LCZ) (Salvati et al. 2017, 1).

This work adds significantly to the continuing efforts of the green certification and rating systems, sustainability assessment in general, despite the study's potential limitations. Based on the analysis' findings, it is possible to conclude that the certification processes not only make the built environment energy efficient or provide marketing gains, but also may have a significant positive impact on the urban climate.

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NERXHANA, TALLUSHI

Assessment and adaption of urban cultural heritage assets as touristic destination towards the impact of UHI.

Case Study: City of Edinburgh

Urban cultural heritage sites are subject to many challenges of urbanization, amplified by the imminent risks of climate change due to extensive anthropogenic activities, development, and land-use changes. As part of the development strategies process, urban planners consider not only the differences in UHI magnitude between urban and rural but also the different levels within the city, but the evaluation becomes complex as historic towns retain unique urban forms.

Local climate zone (LCZ) is less effective in European cities cases mainly developed around a historical core. Therefore, in the case of Edinburgh, the morphological parameters were calculated in the high-resolution grid (15m) from different sources. Land use / Land cover was introduced as a parameter needed to classify the LCZ classes, but the combination with morphological parameters was not completed fully as the thresholds of different LCZ classes overlap, so the mean values were used.

Tourism, a crucial sector for income in Edinburgh, can be affected by UHI due to its direct relation to outdoor thermal comfort. The renovation of New Town, an important World Heritage tourist destination, by the City of Edinburgh, will play an essential role in the tourist's experience. This study measures the implications that new improvements can bring to thermal comfort. In case of a heat wave, the new implementations will lower the air temperature, but apart from new shaded areas, the thermal comfort (PET) can worsen compared to the actual state.

1 Introduction

Preserving cultural heritage sites has always faced many challenges in a rapidly growing and changing world, especially in urban areas (Dastgerdi & De Luca 2019). Among the actual existing pressure, researchers and authorities have now raised concerns about how climate change impacts the conservation of cultural heritage sites in the long term (Dastgerdi & Sargolini 2019). Due to the extensive anthropogenic activities, development, and land-use changes (IPCC 2014), the vulnerability of cultural heritage sites is not only defined by weather patterns (UNESCO 2015) or by the existence of the physical characteristics of heritage assets to preserve cultural values (Pendlebury et al. 2009) but can lead to other socio-economic problematics, such as loss of intangible values (Urdaniz 2018), declining in tourists numbers and loss of community identity (Markham et al. 2016; Scott et al. 2016). Cultural heritage values cannot be reversible, so once they lose their integrity or are destroyed, they cannot be recovered.

World Heritage Committee first considered climate change's impact on World Heritage properties only at the 29th Session in Durban in 2005; awareness was raised relatively late compared to other sectors. Cultural heritage sites in urban areas face various hazards like natural hazards, urban development dynamics, climate change, unsustainable exploitation for tourism purposes, etc. Even though UNESCO sites have a set of guidelines and regulations to protect and prevent the loss of these values, they are mainly focused on conserving the structures or constraints to new development dynamics, leaving out topics like: *How are cultural assets vulnerable? How could cultural heritage enhance the urban climate? Can adaption solutions within the UNESCO framework and guidelines improve the local climate conditions? How can we adapt these assets to improve comfort in touristic destinations?* However, nowadays, after more than a decade, there are still a limited number of studies and practices related to these issues. Addressing these issues develops the understanding of the benefits and wider role of the historic environment for society (Historic Environment Scotland 2019).

This study aims to experiment with sustainable and climate-sensitive solutions to adapt urban cultural heritage sites in Edinburgh by developing a Local Climate Zone classification for the city of Edinburgh focusing on cultural heritage and evaluating the specific effects of Urban Heat Island in the actual conditions in cultural assets as a touristic destination. The general outline of the dissertation starts by identifying the impacts of climate change, focusing on cultural heritage at a city level (macro-scale) and trying to find concrete solutions at a site level (micro-scale).

Apart from being the capital of Scotland, Edinburgh has a very dynamic cultural scene and has the most extensive collection in the country of historic buildings in Georgian and Victorian architectural styles and urban morphology of winding medieval streets (University of Edinburgh 2019). The city has two UNESCO World Heritage Sites, the Old and New Towns of Edinburgh and the Forth Bridge. Due to this status, Edinburgh has become an attractive destination for tourists (Ferguson 2021), becoming the fourth city in the world with the highest tourist-to-local ratio. This overwhelming with tourists is considered profitable regarding income and damagingly to cultural heritage assets.

2 Background

2.1 Urban heat island (UHI)

The Urban Heat Island (UHI) is a thermal anomaly with horizontal, vertical, and temporal dimensions (Oke 1982), with the leading causes consisting of differences in thermal structures between urban and rural environments, such as thermal characteristics of the urban fabric and geometry, urban pollution, and anthropogenic activities (Park 1986; Oke et al. 1991). The UHI phenomenon is not generated by global climate change, but it can magnify the magnitude of rising (Santamouris 2014a) or lower (Santamouris 2014b) temperatures at the local scale. The evaluation of UHI magnitude depends on the combination of four characteristics: technological (albedo, heat capacity), morphological (orientation, Height/Width ratio) and anthropogenic (traffic, industry activities) and weather/climatic parameters (Parsaee et al. 2019). These characteristics causing the effect of UHI are controllable such as technological, urban morphology, and anthropogenic, and uncontrollable such as climatic, weather parameters and geographical features (Levermore et al. 2018). However, some controllable characteristics in historic towns are limited to be modified. Historic areas are defined by their distinct morphology, urban fabric, architecture, community structure, and boundaries, which have carefully evolved through a keen understanding of local communities about their environment in which they have co-existed harmoniously, sustaining various interrelationships and built environment over generations (Jigyasu 2019).

2.2. Local climate zoning

It is not easy to provide an objective protocol for measuring the strength of an urban heat island and facilitating controlled inter- and intra-UHI comparisons. Local climate zones (LCZ) provide a research framework (Steward & Oke 2012) of the UHI compared to the rural areas, and as such, the classification of 17 zone types at the local scale; 10 built types labelled as LCZ 1~10, and 7 land cover types labelled as LCZ A~G; helps to standardise the urban temperature observations on a global scale. Each class represents a specific urban thermal environment pattern, providing a microclimate conditions estimation tool for urban planning and policymakers (Quan and Bansal 2021). The LCZ system has been widely applied in research fields related to urban climate and urban planning (Jianga et al. 2021).

The experience in mapping the LCZs division for cities is mainly conducted through remote sensing (RS) and GIS, as field surveys are not cost- and time-effective on a city scale (Kotharkar & Bagade 2018; Quan & Bansal 2021). RS approach is considered less data-intensive (Zheng et al. 2018; Jianga et al. 2021), as the division is based on supervised pixel-based classification of satellite images, contrary to the GIS approach, where primary and secondary data sources are required. The data required include urban morphology, planning and building information. Remote sensing approach is adopted in the World Urban Database and Access Portal Tools (WUDAPT) (Ching et al. 2018). GIS approach allows more diverse methods for implementing the original LCZ framework. The original LCZ scheme often has considerable problems when adapted to European cities with historical city centres, including narrow streets and irregular patterns, requiring integrating different approaches and adapting the standardisation classification to minimise the limitations. Nonetheless, this method remains valuable for comparing different parts of cities, representing heterogeneous thermal behaviour within an urban environment (Wicki & Parlow 2017). There are three assigning the LCZ classes: removal, combination, and addition, depending on the actual cases. In the case of LCZ classification, researchers have used the following:

1. Standard rule-based classifier
2. Modified standard rule-based classifier
3. Fuzzy rule-based classifier

The first one comes from the original LCZ framework and uses an "if-then" rule to assign each LCZ class while considering the range values of morphological parameters. All the parameters must fall within a particular LCZ class's range. The second method allows for a reduction of morphological parameter numbers from 10 to 3-7, but some researchers have also modified the threshold range (Zheng et al. 2018). The final one employs the membership degrees as soft labels to establish the LCZ class for each grid and uses multidimensional linear interpolation.

2.3 Outdoor thermal comfort

The urban forms strongly influence microclimates (Oke 1988) and different thermal conditions. Many studies regarding the evaluation of thermal comfort conditions in urban microclimates (Liu et al. 2015; Chen et al. 2004) revealed a strong relationship between micro-climates and the use of outdoor spaces and environments (Zacharias et al. 2001). Cultural heritage creates the conditions for tourism development, and in some cases, this industry largely contributes to the economy's income and employment opportunities (Nasrollahi et al. 2017).

Evidence shows that visiting historical sites and places can benefit health and well-being, reducing social vulnerability and increasing resilience. Tourists are likely to be affected by climate variability more than the local people (Lu et al. 2016), making climate and weather conditions the main natural factor affecting tourism (Scott et al. 2008; Matzarakis 2006; Lecha & Shackleford 1997; Shackleford & Olsson 1995). Many indices have been developed over the years to evaluate tourist climate appropriateness (Nasrollahi et al. 2017).

3 Methodology

The analysis starts with spatial analysis a city scale, but with a focus in the culture heritage assets to define the relationship between morphological parameters and potential threads. The

strategy continued in focusing in a smaller case study and mainly on quantitative data such as traverse field study, meteorological data records and computer-based simulations. In order to construct and analyse the UHI and outdoor thermal comfort issue in the context of Edinburgh's cultural assets, a multi-approach methodology was adopted (Figures 1 and 2a.), considering various approaches and data sources.

For assessing the LCZ, GIS approach was used, as it allows more diversity in assigning each class in contrast to the RS approach, which WUDAPT does not allow. The data used came from two primary sources: Edinburgh's Land use / Land cover map (LULC) was retrieved from Urban Atlas for the reference year of 2018, while the morphological parameters such as mean building height (MBH), building surface fraction (BSF), sky view factor (SVF), street aspect ratio (SAR), the impervious surface fraction (ISF) and the pervious surface fraction (PSF); were estimated by rasterizing the LIDAR data, including point cloud and DSM, DTM at a resolution of 50 cm, provided by Scottish Remote Sensing Portal (governmental portal). The building footprint and height were collected from polygons provided by Edina Digimap, Verisk Service. The different historic urban layers of the City of Edinburgh (Rowland et al. 2020) make LCZ's actual scheme not efficient in covering the heterogeneity of the city (Wicki & Parlow 2017), based on a grid of 300 m size, but instead calculation were made in a 15m grid cell size. The land cover classifications were affiliated to each LZC using the defined LCZ thresholds by Steward and Oke (2012) using the Modified Standard rule-based classifier. If the criteria are not fulfilled for all the parameters, then the assignment will be based on the following highest number of best fit.

If ([MBH] > a and [BSF] >b and [ISF] >c and [PSF] > d and [SVF] > e and [SAR] > f)
Then Classify = "LCZ x"

where: a, b, c, d, e, f - value ranges from Table 11 and x LCZ class from 1 to 7

If ([MBH] > a and [BSF] >b and [ISF] >c and [PSF] > d and [SVF] > e)
Then Classify = "LCZ y"

where: a, b, c, d, e, f - value ranges from Table 11 and y LCZ class from 8 to 10

The study case for the thermal comfort parameters measurement is New Town area, one of the most important touristic spots in Edinburgh. The microclimates under different scenarios were estimated with ENVI-met® software (version 5.0.3). The numerical model was calibrated/validated through the traverse study, with field measurement of 19 points the parameters of temperature, relative humidity, wind direction and wind speed with Tiny Tag TGP-4020 and Kestrel 3000 on 07.07.2022. The area's building footprint and height data were derived from Edina Digimap, Verisk Service and the building materials were retrieved from the "Listed Buildings" description of HES and compared with field observation. The main building material used in the New Town comes from a traditional Scottish material, the Craigleith sandstone. After the calibration, the Base Case (the actual state of the site without changes) was simulated under extreme weather conditions on 18 July 2022, with a maximum temperature was 31ºC. The hourly data was retrieved from Bannerman Way Weather Station. The Cold Case measures the impact of material change in the George Street project, while the Green Case shows the greenery impact from the same project. Facades and roofs, the materials specifications were modified to represent the improvement due to maintenance (Salata et al. 2015), while the green elements limited to hedges, shrubs along George Street and various pot trees, in order to not disturb the historic landscape. All three cases, Base Case, Green Case and Cool Case, will be evaluated using the PET index, approved by Germany's VDI standard and is used as the outdoor thermal comfort index (Nasrollahi et al. 2017). 5 points with different characteristics were selected for detailed analysis (Figure 2b).

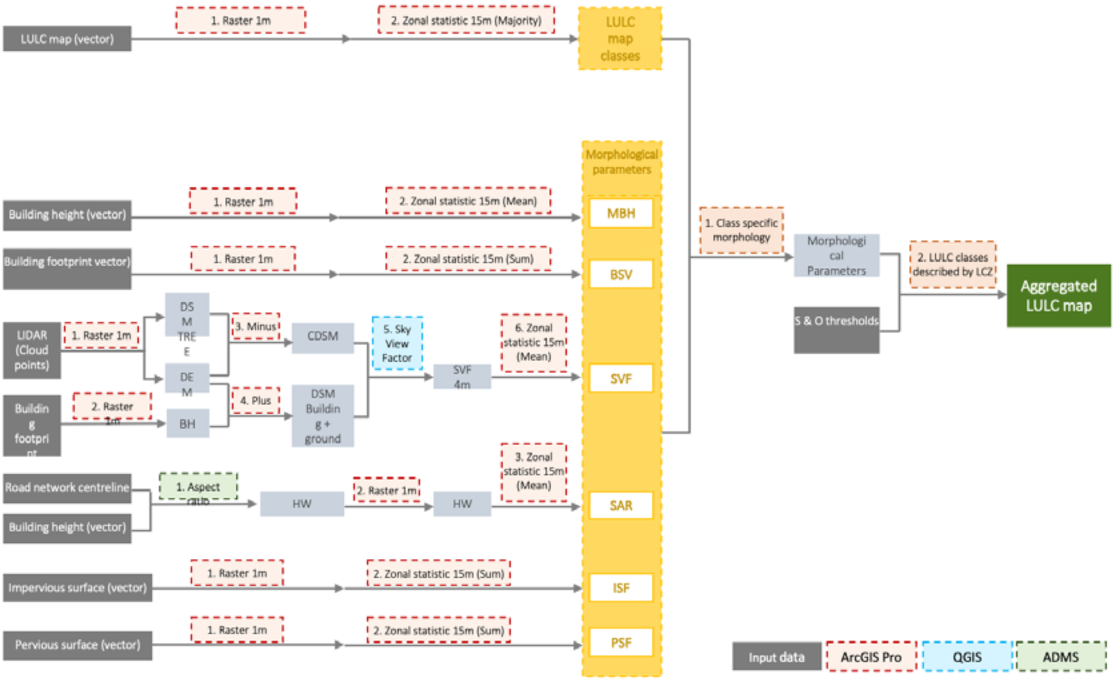

Figure 1. General framework for creating LCZ of the City of Edinburgh (Tallushi 2022)

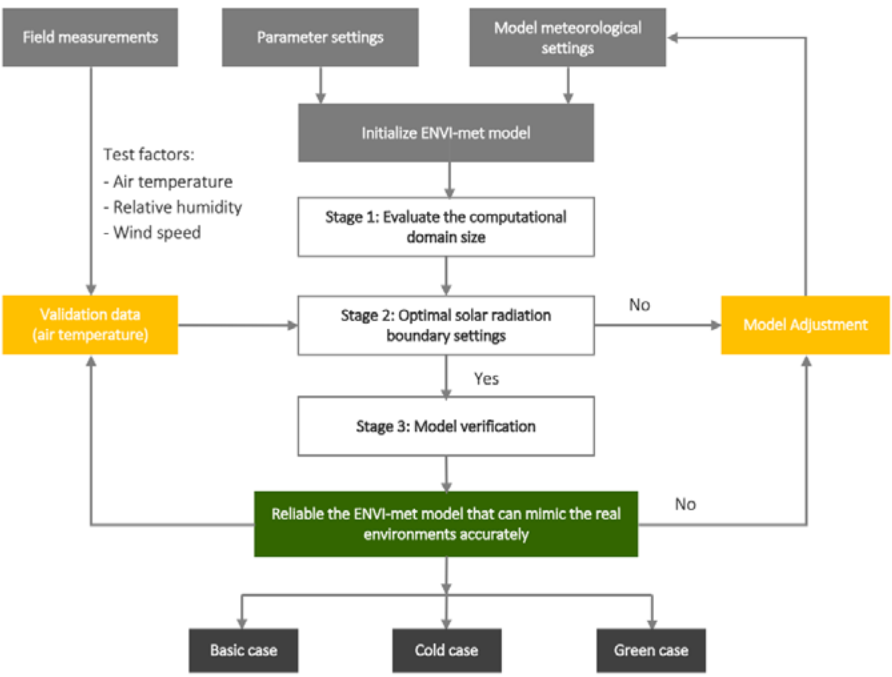

Figure 2 a) Detailed methodology for the simulation part;

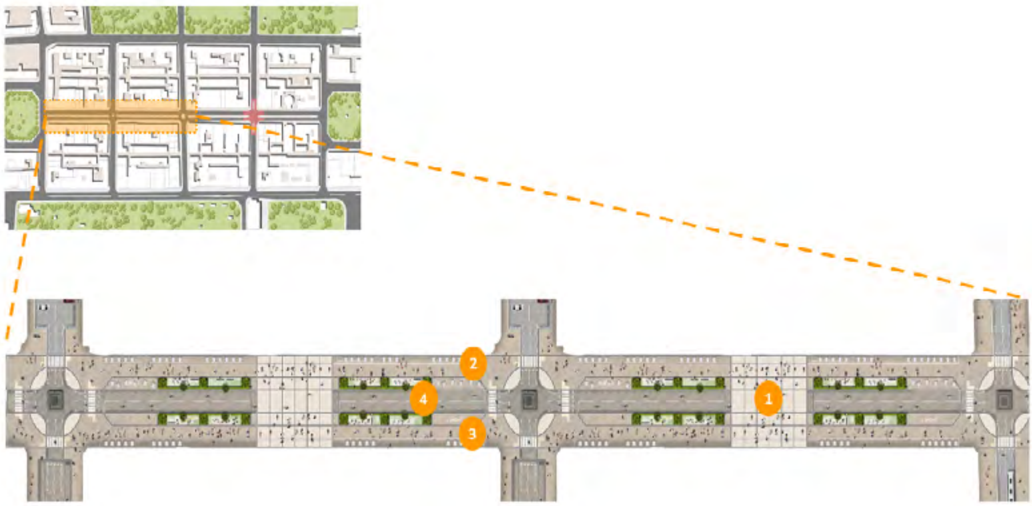

Figure 2 b) Points selected for further analysis: R1 will show tourists' thermal comfort in an area designated for activities, while R2 and R3 will show the difference in this comfort in areas with identic characteristics, but R2 is most of the time exposed to direct sunlight, while P3 is mainly in the shadow during the day. At last, R4 will show the vegetation's effect in thermal comfort in the green case scenario. (Tallushi 2022; The City of Edinburgh Council et al. 2021)

4 Results and discussion

4.1 LCZ

The discrimination process changed the total balance of the classes of the LULC classes, mainly in classes related to streets, roads and motorways, due to their linear spatial extend compared to other classes. The rural classes as expected are the one dominating. The classes covering the central historic town, including WHS, include D3 - Discontinuous medium density urban fabric, D4 - Discontinuous medium density urban fabric, D5 - Continuous urban fabric, GU – Green urban areas, R1 – Railways and associated land, R3 – Other roads and associated land, I1 – Industrial, commercial, public, military and private units and these classes cover approximately 35, 87% of the total. The mean building height (Figure 3) of the urban structures ranges between 6-18 meters, close to a binomial distribution for classes D2, D3 and D4, while in the case of class D5, the range is higher (12-24m) due to the fact this is a more compact and dense class. Regarding the other classes, the distributions do not follow any specific pattern, which is understandable due to the classes' characteristics, function and period of the build. It is essential to point out that the histograms show only the distribution of mean building height for all classes and do not include the vegetation height in the case of rural classes.

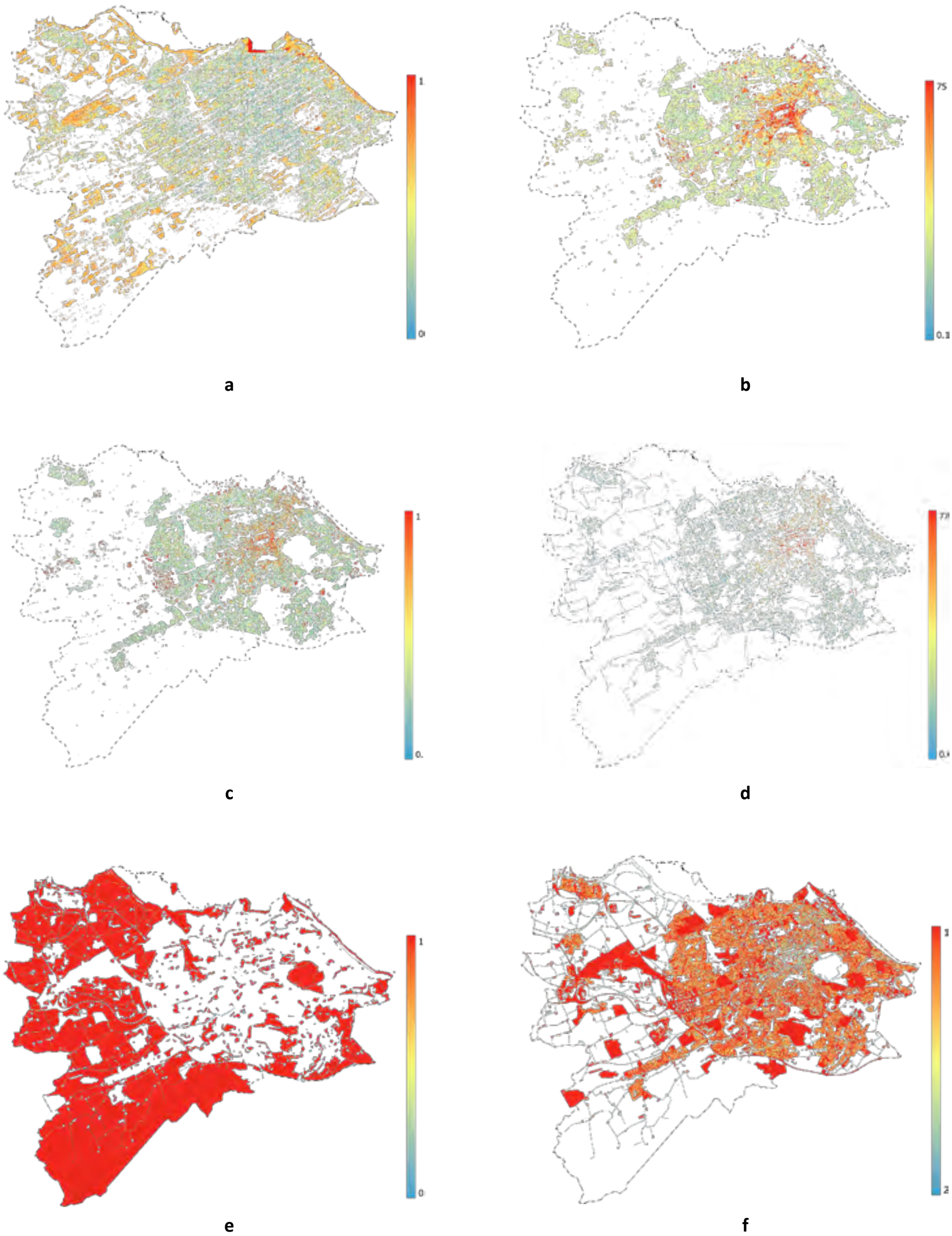

Figure 3. Morphological parameters the City of Edinburgh: a) Mean building height b) Sky view factor c) Aspect ratio d) Building surface fraction e) Pervious surface fraction f) Impervious surface fraction of the city of Edinburgh in 15 m resolution and National British projection (Tallushi 2022, software: ArcGIS Pro)

The overview of the combination with each LCZ classification was done using the range from the average of morphological parameters and the threshold values ranges by Oke and Steward (2012) from The combination between the LCZ classes and the average of morphological parameters resulted that one LULC class fitting in more than one LCZ class as the threshold values between different LCZ classes overlap. Building Surface Fraction (BSF), Impervious

Surface Fraction (ISF) and Pervious Surface Fraction (PSF) for some classes were out of the value range due to the small grid size, which can lead to reaching the minimum (0) and maximum (1) in cell size. However, only one value can reach the maximum as the ISF is calculated from BSF and PSF. The assignment of non-build classes to LCZ A-G, which was based on land cover and the description of each class (Figure 4b) based on results from a study in Oslo, Norway, using the same LULC classes (Sigler et al. 2022).

To prevent the overlapping of the thresholds, the LULC classification should represent more specific land use category. An example is the problem with I1 class, which include the Industrial, commercial, public, military and private units. These classes include also the mix use building and in sense of commercial units, there are throughout the city, especially in the Old Town and this is the area with the most ununiformed pattern. Some LULC classes as R1/ R2and R3 have been classified with unusual LCZ class. This is due to the fact that the LULC map was created in e different geographical projection system rather than British National Gird, and it is accompanied with errors while geographically transforming, compared to the high resolution of the data origin of the other parameters. However the LULC map used is only as an input factor in this case, but the use for future classification is very promising (Wilow & Parlow 2017). In creating a more detail LULC map, taking into consideration culture heritage aspect, might result need to new range values of thresholds for each LCZ class or new LCZ classes.

4.2 Thermal comfort

Overall the difference in air temperature and relative humidity has change visibly only in the Cool Case and the interventions in this scenario have reduced the TAir and increased the Rh. The effect is measurable in the areas which are exposed in direct radiation during the day, therefore we can see in the site differences up to 0.8°c mainly building faces facing south during the day, as Edinburgh is located in the North hemisphere. This reduction is positive as usually East-West oriented street constantly exhibits higher air temperature than the streets perpendicular to them (Valdez 2021). Also, as the pick hour is 4pm, the faces building faces facing west – southwest will show a difference. In the centre the difference is bigger, as in this point not only the actual area has changed, but also the surrounding, bringing more change. Mean radiant temperature (T_{mrt}) is play a vital role in human thermal comfort and during summertime is the driving parameter of the PET index. Tmrt is directly linked to the short- and longwave radiation exchange of a standard human, therefore thermic building properties tend to have an impact in T_{mrt} value ranges. In general, the change of material (Cool Case) has decreased the T_{mrt} only by 4°c at 4pm, but in cases near the shaded areas the decrease is around 24°c. However, the shaded elements positioned near the northeast facades are not affecting the T_{mrt} at this time.

LULC Class	LCZ 1	LCZ 2	LCZ 3	LCZ 4	LCZ 5	LCZ 6	LCZ 7	LCZ 8	LCZ 9	LCZ 10
D2	2	2	4	2	1	2	2	2	2	2
I1	3	4	3	0	1	0	3	1	0	1
D3	2	1	3	1	2	3	2	2	1	2
D4	2	2	4	1	1	2	3	3	1	1
D5	3	3	3	0	1	0	2	1	0	0
I2	1	3	3	2	2	1	2	1	0	2
C	1	4	3	2	2	1	2	1	0	2
S	0	3	2	1	3	2	2	1	0	2
D1	1	1	3	1	2	3	2	2	2	2
P	1	3	3	2	2	1	3	2	0	0
M	0	2	4	2	1	2	2	1	1	2
R2	0	2	3	1	2	3	2	2	1	2
R3	1	3	3	1	1	0	2	0	1	1
R1	1	2	3	2	2	1	2	0	0	2
A1	1	2	3	1	2	3	2	3	1	1

a

LULC class	LCZ class
CR1	LCZ D
CR2	LCZ D
CR3	LCZ D
F	LCZ A
H	LCZ B
W	LCZ G
GR	LCZ C
GU	LCZ B/D
B	LCZ F
WL	LCZ B/D

b

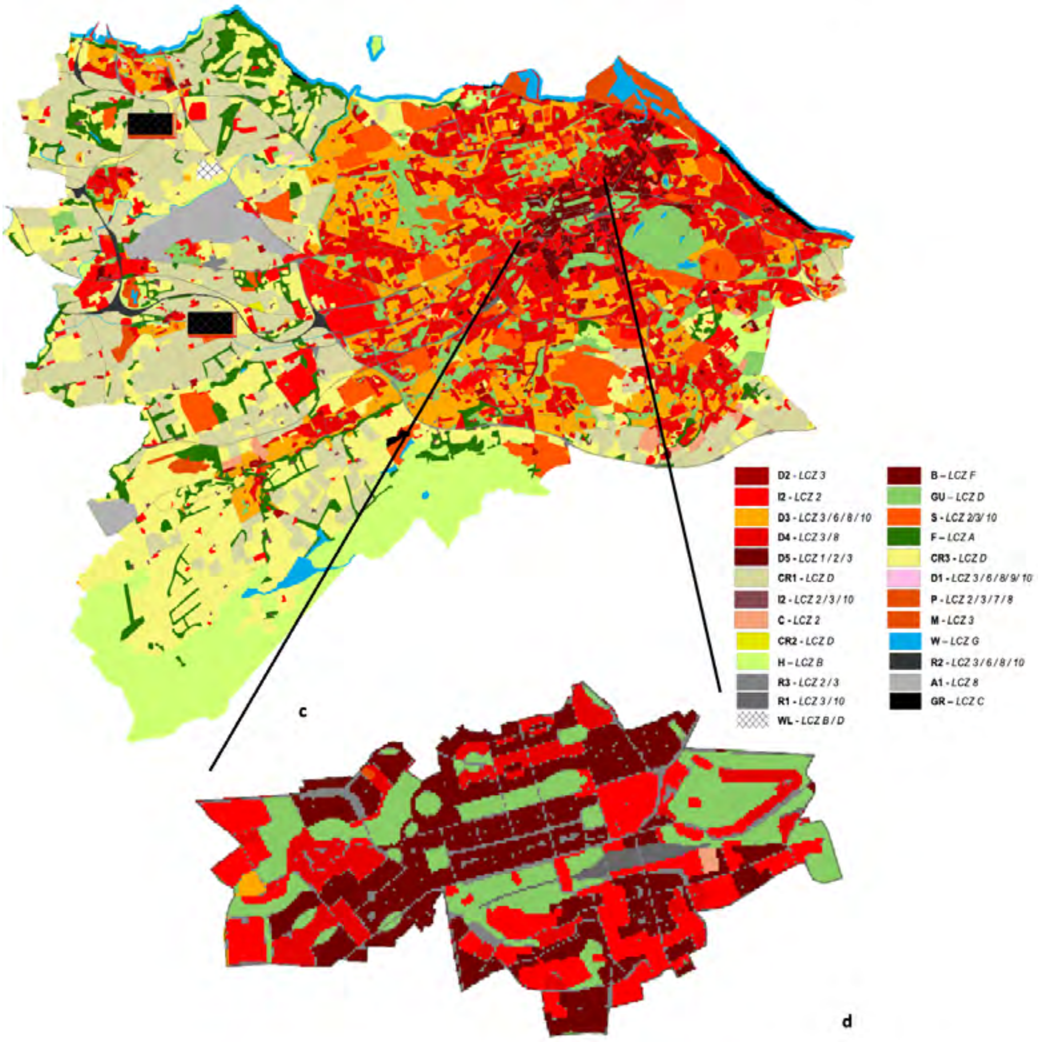

Figure 4. a) Affiliation of LULC classes according to the LCZ thresholds by Stewart and Oke (2012). All matches are summed up (maximum 6, dark red) and the individual boxes are coloured according to the number of matches; b) LCZ class A-G affiliation to the non-build LULC classes c) Final conceptual LCZ map of the City of Edinburgh in 15 m resolution; d) Close up of conceptual LCZ map in the area of the World Heritage property - New Town and Old Town (Tallushi 2022)

In Base Case only R3 is within desirable comfort range for most of the time, while in other points from 9am till 7pm tourists would be in seriously heat stress. In the Cool Case R2 reaches the desirable comfort range. In the Green Case there are not considerable changes and the R1, R2 and R4 are still locations where a tourist can experience seriously heat stress. In both cases in R1 where the space is designated for events, it is suggested that organisers avoid 10am till 6pm as it will not be comfortable for the audience. Visitors wanting to spend time in the sitting area, this time frame would not be very comfortable during hot sunny days. The changes expected due to climate change, the thermal comfort of tourists or pedestrians in general will shift even more from the desirable range. Compared to the hottest day occurred in Edinburgh, the frequency of desirable comfort range does not exceed 50% mostly (Figure 5 a/2; b/2 and c/2), and the discomfort is experienced during 10am and 6pm which is the most frequented period by visitors. The improvements proposed in the new project may improve the quality of spaces and reduce pollution by shifting from vehicle road to pedestrian one, but urban design choices can have negative impacts on thermal comfort.

5 Conclusions

5.1 Summary of findings

This study evaluates UHI in the Edinburgh case using morphological parameters in conjunction with the LULC classification and LCZ scheme method through the GIS approach. 15 m fine resolution used for the combination of the LCZ thresholds (Steward & Oke 2012) allows for capturing the heterogeneity of European cities. The morphological parameters, estimated from high–resolution data, show that the values do not fluctuate substantially, but differences between LULC classes are visible and measurable. With the data available, the entire fitting combination of LULC and LCZ classes through the morphological parameters was not achieved, because one LULC class could fit in more than one LCZ class, and further studies are required. However, the existing method can be adopted in different scales (resolution) or with different LULC classifications focusing on cultural heritage.

The historical layers of Edinburgh attract visitors from all around the world. UHI affects New Town, and the local climate conditions consequently affect the thermal comfort that tourists experience. Results show in the actual state that the thermal comfort in the hottest recorded conditions is more favourable from 8 am to 10 am and after 8 pm. Thermal conditions can affect the tourists' behaviour. For instance, the northwest building facades have a probability for heavier tourist fluxes, as thermal comfort is within the desirable range in these areas. Improving the thermic conditions is constrained due to the conservation guidelines of cultural heritage sites and limiting the implementation of the most effective climate-sensitive solutions. Urban vegetation must not be invasive and create visual barriers, despite its role in the urban microclimate. Different pavement materials create different Tmrt. Even though high albedo materials can reduce the air temperature, they can worsen the comfort conditions (PET) in hot

Figure 5. a/1) Comparison between PET and comfort range - Base Case for 5 points of interest; a/2) PET frequency in comfort range – Base Case for 5 points of interest; b/1) Comparison between PET and comfort range - Green Case for 5 points of interest; b/2) PET frequency in comfort range – Green Case for 5 points of interest; c/1) Comparison between PET and comfort range - Cool Case for 5 points of interest; c/2) PET frequency in comfort range – Cool Case for 5 points of interest (Tallushi 2022)

seasons. New shade elements have a more beneficial impact than pavement material change, preventing direct solar exposure and storing less accumulated heat.

5.2 Recommendations for future studies

The methodology employed throughout the study can be modified to accommodate various LULC classifications and resolution scales, depending on the target group (urban planning, ecology, landscape, etc.). The presented conceptual LCZ map can be used as a reference to conduct detailed studies on the cultural heritage locations, using in-situ surveys to improve the classification's accuracy. At the same time, it is a guide for urban planners and designers to enhance outdoor thermal comfort in the future.

The tourists' outdoor thermal comfort is directly related to the tourism industry, economy and employment opportunities. An extended observation time fitting the entire touristic season in Edinburgh can produce a proper calendar showing the most optimal time to visit the New Town area. The impact of climate-sensitive solutions can prolong tourist stays and more revenue for the citizens, so the effect of the proposed interventions in other critical conditions, such as cold and rainy days, is essential to investigate. Additionally, defining the local desirable comfort range through field surveys for a more accurate correlation with the thermal sensation of Edinburgh and PET can be more useful if integrated and compared with Tourism Climate Comfort Index. Estimating the TCCI allows estimations with other cities and implements similar tourism development strategies.

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Assessing Local Climate Functions of Urban Green Open Spaces

A Case Study on Public and Institutional Open Spaces in Glasgow

Due to the emergence impact of global climate change and increasing urbanization, 21st century is at a critical state in terms of UGOS adequacy and competence. The research paper aims to construct upon improving UGOS- categorized as neighbourhood scale green open space in Glasgow as a case study. It is essential to foresee the potential support with integrated biodiversity and the socio-ecological benefits of UGOS to meet the SDG goals of UGOS and climate change mitigation strategy. The gap between policy development and on-ground action weakens these facilities that a local UGOS are meant to provide. The methodology is reinforced by the thermal comfort simulation analysis, spatial and ecological configuration analysis, and interview of experts' opinions. An institutional open space and a public open space are assessed as investigation sites. Based on the findings and interviewed experts' opinions, attempted thermal comfort indices analysis (MRT, PET, UTCI) and linking them with open space quality indicators combinedly illustrates the broader influences of UGOS as a resilient device for tackling heat stress, bio-diversity loss, health risks etc. Existing scenarios, larger green cover scenarios, ongoing development scenarios, and proposed scenarios from the detailed ENVI-met climatic analysis highlights the key findings and suitability of UGOS. Based on the analysis result, the concept of this research work can initiate holistic and multidisciplinary planning steps and solutions for future UGOS development.

1 Introduction

In the long course of industrialization and modernization, cites growth leads to dysfunctional environments, a sense of scale, and feeling lost in between or ignored in experience(Gehl & Svarre 2013). Between 2015 and 2020, urban populations globally have grown by more than 397 million people (UNDESA 2019). One of the most affected elements of inconsiderate urban growth is Urban Green Open Space (UGOS) which is often portrayed as only a physical space by urban and landscape designers, architects, and planners; without acknowledging its integrated part such as environment, liveability, socio-cultural engagement and the rights of individuals and groups (Mehta 2013). Due to high housing and economic demand, and infrastructures within urban areas, neighbourhood-scale UGOS is blatantly under threat. It is not being revised unless urban hazards and climate change phenomena such as heat stress, Urban Heat Islands (UHI), urban flooding, and urban pollution occur.

Thompson's question regarding the need for urban open space in the 21st century contextualizes the situation, should it be a more flexible and productive landscape to incorporate loose-fit landscapes with innovative urban networks (Thompson 2002). There is a wealth of existing research, but the context has changed significantly in UGOS design and planning; it should be centred around climate change impact mitigation with spatial equity for the people.

Open spaces significantly impact the city's ecology and biodiversity from different scales. The tendency to develop densified areas and city centres often complicates the connection with natural components. Every open space, like a green park, promenade, plaza, or street, is the source of these same components. However, it is too expensive to leave one unit of space because of the economic benefits of the built environment, and it does not qualify for the basic need of shelter. Therefore, small to medium-scale UGOS have a significant role to play in sound-microclimate solutions in local context. There are insufficient holistic guidelines for establishing local UGOS in terms of ecological benefit with an integrated and qualitative approach from palnning level. It is essential to review the existing works of literature by urban planner activists over the climate change period days; to connect the dots from the isolated development index in terms of climate and integrated social diversity. Therefore, the research aims to identify and evaluate UGOS through case studies in Glasgow with spatial elements and microclimate analysis in growing urban areas. It further recommends UGOS quality indicators for climate change mitigation-focused UGOS planning through the following objectives.

1. Identifying dimensions and criteria of UGOS strategies with their associated environmental benefits from existing planning and policy. Including the influence of different actors in the planning, construction, and governance of UGOS.
2. Understanding UGOS spatial and ecological features on a neighbourhood scale.
3. Assessing Key Performance indicators of UGOS by integrating expert's and stakeholder's opinions and climate change adoption-led design approach.
4. Analyzing microclimate indices and thermal comfort through case studies in previous, present and post-design contexts with the integration of Key Performance Indicator for UGOS
5. Giving recommendations for future UGOS quality assessment, design and planning development.

2 Background

2.1 Strategies and Planning Act

According to UN-Habitat, 15-20% of urban land should be preserved for public open spaces, with 30-35% for the streets and roads. The need for re-evaluating mentioned auditory indicators in Glasgow Open Space Strategy (GOSS) 2020 is because it doesn't reflect the holistic driving factors of a climate-resilient park, due to the gap between policy level ambition and on-site development. In local level, it depends on the site-specific context and users' reflections on the current amenities regarding UGOS. For example, Edinburgh's Open Space Strategy plan has benefited its people as a post-survey shows 82% satisfactory results from the users of different UGOS (CWPSS UN-Habitat 2019). The goals of Copenhagen's Green Structure Plan integrated neighbourhood scale with innovative green Infrastructure in UGOS has evaluation reports of exiting POS inventory for the entire built-up and undeveloped urban area to experience nature in the city. In terms of Glasgow, previous researchers have depicted that the initial discursive and policy practices adopted by the city and urban park developer were a mere collaboration with inclusive urban park development but ultimately benefitted a more comprehensive image and attractiveness for potential buyers (Inroy 2000). However, presently the situation is being acknowledge.

2.2 Neighbourhood UGOS and Growing Urban Area

COVID pandemic has brought up different concerns from the urban scholar regarding the crisis in the urban planning framework for UGOS (Bravo 2020). WHO has recommended 9 sqm of open space per capita, which must be accessible, safe, and functional and up to 50 square meters in terms of generous standards. A neighbourhood park defines a place with diverse needs at a comfortable distance, has basic recreational amenities for all users, and is located within the centre of development (Chapman 1999). Often, a park close to home is a highly valued green area with substantial restorative value (Kaplan et al. 1998). The walking distance from a usable open space should be 400m from the user's home. However, 60% of people in Glasgow live within 500m of derelict land that can be a viable UGOS (GCC 2020). In this context, considered UGOS is addressed at a neighbourhood scale (area<3ha) and the scale is based on the limitation of pragmatic climate analysis with a broader perspective in the planning process.

2.3 Climate Change Adoption, Thermal Comfort and UGOS Contrast

The 2015 Paris Agreement aims to limit temperature rise to well below 2ºC above pre-industrial levels and pursue efforts to limit it to 1.5ºC (IPCC 2022). The mitigation steps adopted in the strategies prioritize carbon emission reduction than deal with the change via land use or land cover manipulations (Emmanuel & Loconsole 2015). According to UK Climate Projections (UKCP) model 18, projected increased heatwave frequency for Scotland in the upcoming future (O'neill & Tett 2019). In recent times, the >28 ºC band can be seen very often in the dry spell of summer (June to August), increasing to 40ºC across Europe and the UK. The most affected sector is facing a change in service demand for the impact on human health (Curtis et al. 2017) such as level 3 heat-health alerts due to heatwave. NHS, the owns most significant portion of open space in Glasgow and has adopted different climate challenge mitigation plans as the administrative body with Greater Glasgow and Clyde board and GCC for reviving the derelict land and unsuccessful open space in institutional and hospital compound.

The role of urban climate change is a significant part of human experience, and it is being recognised increasingly (Emmanuel & Krüger 2012). UGOS creates an environment with specific microclimatic qualities due to complex surface structures (Mahmoud 2011). The definition of thermal comfort is "the condition of mind that expresses satisfaction with the thermal environment", (ASHRAE 2009). A comfortable thermal environment is significant in the outdoor spaces as UGOS due to frequent exposure to the weather while spending recreational and leisure time of its users (Mahmoud 2011). To assess thermal comfort conditions, the researchers use several thermal indices to understand the effect of comfort levels on people's use of outdoor spaces Thorsson et al. 2004; Oertel et al. 2015). Some commonly used indices are Predicted Mean Vote (PMV), Physiologically Equivalent temperature (PET), and Universal Thermal Index (UTCI). For analysing these indices, meteorological input variables such as air temperature, air humidity, wind velocity, and Mean Radiant Temperature (MRT) (Jendritzky & De Dear 2009).

However, a study based in Glasgow showed that the 'optimal' PET comfort range is 9ºC to 18ºC, which is visibly below the suggested thermal comfort range from 18ºC to 23ºC (Oertel et al. 2015). Outdoor thermal models are created by using ENVI-met modelling software, which allows the determination of outdoor thermal comfort with basic and possible proposed scenario variables (Yilmaz et al. 2018). Pilot and comparison studies done by researchers in address optimization of microclimate conditions such as shading, cross-ventilation, and thermal comfort to facilitate longer stays and use of therapeutic functions as indicators and questioner surveys (Xue et al. 2017). In cities, green spaces are a regulatory role and establish positive microcirculatory effects in different seasons with positive environmental aesthetics and economics (Nouri & Costa 2017)

2.4 Wellbeing and Climate-Focused Key Performance Indicators

It is important to design well for green public open spaces, but often the ambitions are not met by reality (CABE 2004). Nonetheless, a high-quality open space can offer extensive economic, social and environmental benefits to the local communities (Khalid 2019). Different built environment components such as surface covering, evapotranspiration of vegetation, and shading by artificial objects and trees extensively affect the outdoor thermal environment (Mahmoud 2011). A well-designed UGOS reduces the heat-absorbing surface, brings solar protection, and increases cooling by shading and evapotranspiration. It mitigates air pollution microclimate issues, filtrates air pollutants, and enhances species diversity and composition and cultural and educational values (Semeraro et al. 2021).

An indicator provides a clue to a matter of larger significance or makes a trend or phenomenon perceptible that is not immediately detectable (IJC; Indicators for Evaluation Task Force, 1996). Inclusiveness, meaningfulness, safety, comfort, and pleasurability these five fundamental attributes of open space were identified by Jan Gehl (Gehl 1987) and researcher has applied the framework for creating an open space index through observable and perceptual indicators (Mehta 2013). A climate-focused Key Performance Indicator (KPI) for UGOS can seek to capture quantifiable measures and subjective dimensions of sustainability. Aiming on climate resiliency with existing qualitative research on user experience with spatial, ecological quality still lacks the true contribution of UGOS.

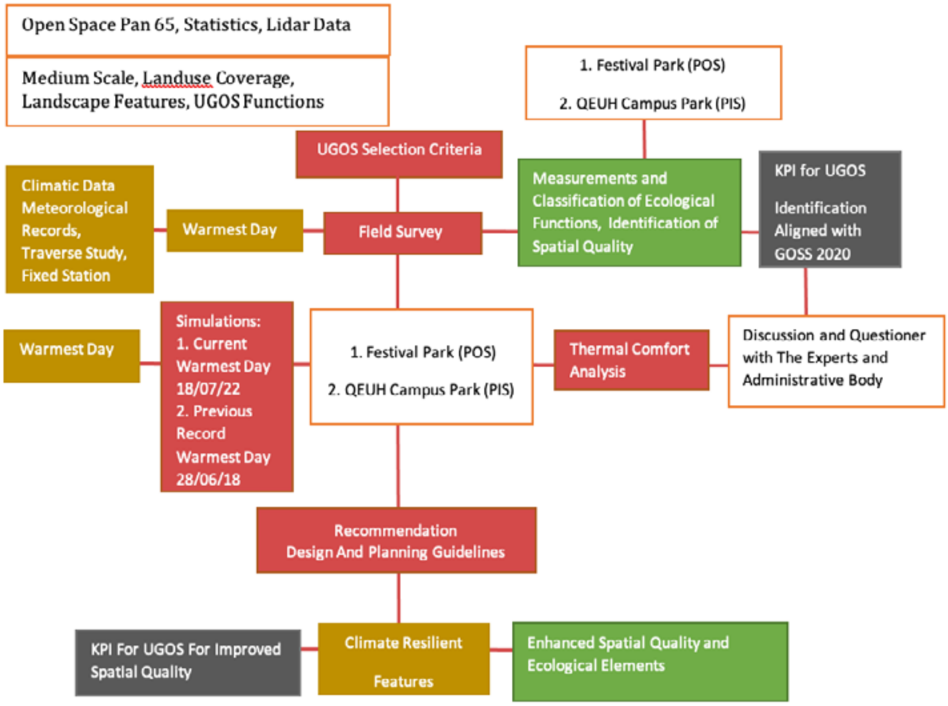
3 Methodology

3.1 Research Framework

Two UGOSs have been found to carry out the research, and both are in a similar administrative area, Govan located at the southwestern bank of Glasgow. The intention was to compare an existing typical UGOS park (Festival Park) and an ongoing institutional UGOS park (Queen Elizabeth University Hospital Campus Park) on a similar scale with nearer built environment features. They show both phases of vacant open space and a designed open space that can transform into an influential public park. Through an abductive approach, the research topic finds the scope of work in different groups and criteria that are fundamentally entwined with UGOS design decisions. The deductive approach finds out the microclimate situation of parks and key performance indicators.

Both quantitative and qualitative methods are conducted throughout the research. Experts' opinion, traverse survey on two hottest days, city profile from the weather station, represents the quantitative method. Ultimately its asses the performance out of comparison of two cases which answers the research questions. Finding sustainable KPI indicators and ecosystem services has consisted of both methods.

Table 1. Design Diagram table of Research Framework (Tasnim 2022)



3.2 Data Sources

3.2.1 Meteorological Features Study

The survey is based on the past and forthcoming scenario of heatwave days in Glasgow, and the thesis time frame was a relevant period in that context. Concern rises as the heatwave threshold temperatures scenario 'exceeding 28 °C and not decreasing below 15°C' will often be happening in the future period of the city (O'Neill et al. 2019). The fluctuating temperatures can impact a large population and many healthcare-related issues, including vulnerable groups of people, society, and the environment.

3.3.2 Spatial Structure, Surfaces and Vegetation Study

The scope of the research topic is extensive due to public open space being combined with both thermal comfort and ecological benefits for its users. Digimap's Ordnance Survey data from GCC were used to identify the current land use cover of the two case studies. UBDC provided the required data with LiDAR, and it has been used for shading and vegetation analysis and built structure modelling. The binary format or LAS was extracted from the airborne LiDAR data, and DSM for both cases studies were created.

3.3 Administrative Experts' Opinion and Identification of KPI For UGOS

Jan Gehl assessed public open space into different criteria which are divided into three groups: protection, comfort, and enjoyment with associated environmental elements (Gehl 2010). This research methodology includes interviews with associated administrative body or stakeholders to identify the KPI for UGOS. The site-specific reflections from this questionnaire method can identify the common risk and inadequacy of a transitioning institutional UGOS such as QEUH site and remain historical and park type UGOS such as Festival Park. Integrating Key Performance Indicator (KPI) is a suitable method to find a direct link with Ecosystem Services (ES), SDG goals and Glasgow Open Space Strategy (GOSS) for general observation of UGOS quality in Glasgow. However, the indicators are based on verifiable data and are effective for measuring, monitoring, and communicating, which have no pre-defined sets of universally applicability (Rutzinger et al. 2019). The KPI for UGOS has been generated by analysis exiting quality indicators by an elaborative research study (Gehl 1987; Groot 2010; Mehta 2013; Lynch 1960; Nouri et al. 2017) with the questioner results. A pragmatic approach will be followed for KPI identification based on UGOS relevant indicators with integrated climatic, ecosystem-service provision and associated interviewed administrative expert's views.

3.4 Traverse Survey in Park Type and Campus Type UGOS

The survey method determines the temperature and relative humidity in summer season and the settings of the ENVI-met model. The weather forecast observation selected three dates to capture the maximum heat on those dates. A walking route was mapped for both sites, which consisted of 20 points to cover different parts of each site using the Kestrel 3000 Environmental Meter tool. Additional five points at different times of the day, which determined the variables in terms of the park's inner and outer climatic influence. Among the five points, 3 points are inside the park, and the other 2 points are in the peripheral area of the park. Temporal correction of data was collected from the fixed station and nearby Paisley (Renfrewshire) weather - Met Office weather station to access the observation at a similar time. The data from traverse survey were corrected using the fixed station data and Linear Regression method to get the temperature difference. It was created with Tinytag and a weather shield probe on a vertical post within an observable distance.

3.5 Modelling and Simulation

ENVI-met software was used to generate a three-dimensional microclimate model and simulate the park environment in different scenarios. The existing built environment and park setting were developed in 3D and 2D modelling software was used. The building heights were taken from open-source data from GCC. Different measurements of buildings, pavement, and plantation types were replicated in the 3D modelling from field survey observation and existing data sources. The INX plug-in of ENVI-met has been used in SketchUp Modelling that worked as a link (plug-in) with the ENVI-met model. Eventually, through Leonardo 4.4.5, 2D simulated maps were visualized and extracted from ENVI-met binary result files. The limitations chapter discusses the relevancy and accuracy of the data.

3.6 Results and Integration of KPI For UGOS

Various scenarios were created to calibrate the final KPI for the high-quality performance of the QEUH site. Base case simulation and proposed landscape planning setting in the QEUH site were compared with the Festival Park setting through the KPI framework and the traverse survey data. The proposed simulation from ENVI-met modelling result validates the importance of climate-focused open space planning on a neighbourhood scale UGOS. Microclimate model simulation in both case studies and comparative analysis methods summarized the recommendation for future UGOS provisioning.

4 Analysis and Result

4.1 Overview and Comparative Analysis of Two UGOS

According to GOSS 2020 the four categories which are

1) Retained open space,
2) New open space,
3) Redefined open space, and
4) Redundant open space.

Remaining Festival Park lacks the previous green cover and associated ecological benefits from a large natural element as it was before in 2010. The remaining festival park is identified as 1st and 3rd. The QEUH green space area found as derelict land on the campus in this research due to poor soil quality and poor planning. It falls into all four categories because the park area is going under landscape development and as 3rd because existing functions will be redefined as a therapeutic garden and creative platform for the users etc. It is also the 1st due to expected maintenance for restoring the quality. Thus, combining different priorities makes spatial distribution more logical in this context. This comparative overview depicts the performance and characteristics of two case studies and the current condition of open space development.

4.2 Spatial Structure, Surfaces and Vegetation

DSM analysis predicted the vegetation cover and shading cover in Festival Park because large tree canopy coverage or shading from buildings are effective design strategies against urban heat stress (Kantor et al. 2018). There are mature trees and spreadable canopy coverage, but QEUH campus area has insufficient vegetation cover due to poor soil quality and less mature trees. Survey shows 25% to 55% of park visitors tend to go under shade during warm weather conditions (Thorsson et al. 2004). The vegetation profile assessment was done only for Festival Park. The LiDAR and DSM depicted the three-dimensional elements of vegetation cover of the site to understand the three-dimensional aspects of the park. Natural waterbody is identified as a linear retention pond in Festival Park. The wetland is integrated with natural elements such as stone, wet plants, and shrubs, and it has a shallow depth from the ground level. The SUDS Pond in the QEUH campus has been identified as a design flaw and an inactive pond.

4.3 Administrative Experts' Opinions and KPI Integration

The extracted features of the discussion and questionnaires (table 2) to valuable guidance for the KPI of UGOS. Forty performance indicators included in set A to set O have been identified from the above definition of the open space quality matrix category. Priority sign individual upwards arrow (↑) has been assigned with each indicator relevant to the case studies and aligned with GOSS 2020 auditory matrix scoring value. For example, high priority (↑↑↑↑↑) is equivalent to a score of 1 as it is in poor condition and needs immediate measures. The explanatory analysis note indicates assessment and the scope of enhancement for each indicator in the priority area of case studies. It describes all these indicators with clear applicability in the planning, design and management division of UGOS.

Table 2. Generated KPI for UGOS development and quality assessment (Tasnim 2022)

Score by GCC 2020	Priority	Priority Value
Score 1 - Poor	High priority	(↑↑↑↑↑)
Score 2 - Fair	Mid-high priority	(↑↑↑↑)
Score 3 - Good	Moderate priority	(↑↑↑)
Score 4 - Very Good	Semi-low priority	(↑↑)
Score 5 - Excellent	Low priority	(↑)

GCC Indicator & Description	Suggested KPI for UGOS	Priority level in Festival Park (POS)	Priority level in QEUH Campus (PIS)
A) size *area coverage> 0.3 ha*	A) Eligibility of a public park/green space 1) Area Coverage> 0.3 ha	>2 ha	>2 ha
B) configuration	B) Configuration and Imageability 2) Appropriate design 3) Site spatial sequence	(↑↑↑) (B2) (↑↑) (B3)	(↑↑↑↑) (B2) (↑↑↑↑) (B3)
C) surveillance	C) Surveillance 4) Wayfinding of key areas. e.g., sitting, standing etc 5) Potential pocket space e.g., sustainable use of corners allocated with the right species	(↑↑) (C4) (↑↑) (C5)	(↑↑↑↑) (C4) (↑↑↑↑) (C5)
D) accessibility	D) Accessibility 6) Equity and inclusivity 7) Experienced distance 8) Physical distance	(↑↑↑↑) (D6) (↑↑) (D7) (↑↑) (D8)	(↑↑↑↑↑) (D6) (↑↑↑↑) (D7) (↑↑↑↑) (D8)
E) aspect	Ei) Climate Aspect 9) Balanced sunlight exposure 10) Landscape shading 11) Regulated air quality 12) Sustainable material for all-season landscape furniture 13) Permeable material for ground cover	(↑↑) (Ei 9) (↑↑) (Ei 10) (↑↑) (Ei 11) (↑↑↑) (Ei 12) (↑↑↑) (Ei 13)	(↑↑↑↑↑) (Ei 9) (↑↑↑↑↑) (Ei 10) (↑↑↑↑↑) (Ei 11) (↑↑↑↑↑) (Ei 12) (↑↑↑↑↑)(Ei 13)

GCC Indicator & Description	Suggested KPI for UGOS	Priority level in Festival Park (POS)	Priority level in QEUH Campus (PIS)
Eii) natural capital (new addition)	Eii) Natural capital 14) Improved soil quality 15) Natural drainage 16) Heritage tree 17) Natural surface cover	(↑↑) (Eii 14) (↑↑) (Eii 15) (↑↑) (Eii 16) (↑↑) (Eii 17)	(↑↑↑↑↑) (Eii 14) (↑↑↑↑) (Eii 15) (↑↑↑) (Eii 16) (↑↑↑↑) (Eii 17)
F) place quality	F) Place Quality & Pleasantness 18) Touristic 19) Recreational (landscape conversation) 20) Creativity 21) Cultural presence 22) Cognitive development	(↑↑) (F 18) (↑) (F 19) (↑↑) (F 20) (↑↑) (F 21) (↑↑) (F 22)	(↑) (F 18) (↑↑↑↑) (F 19) (↑↑↑) (F 20) (↑↑↑) (F 21) (↑↑↑↑) (F 22)
G) use			
Gi) informal sport/recreation	Gi) Informal sport/recreation 23) Gently sloped grassland 24) Green exercise area e.g., therapeutic garden, yoga & meditation area	(↑↑) (Gi 23) (↑↑) (Gi 24)	(↑↑) (Gi 23) (↑↑↑↑) (Gi 24)
Gii) children's play	Gii) Playground 25) Children play area 26) Interactive space for diverse age group	(↑↑↑) (Gii 25) (↑↑↑) (Gii 26)	(↑↑↑↑) (Gii 25) (↑↑↑↑↑) (Gii 26)
Giii) relaxation	Giii) Relaxation 27) Third place and spirituality	(↑↑↑) (Giii 27)	(↑↑↑↑↑) (Gii 27)
Giv) biodiversity	Giv) Ecological Service 28) Flora and fauna diversity 29) Site-based habitat provision	(↑↑) (Giv 28) (↑↑) (Giv 29)	(↑↑↑↑↑) (Giv 28) (↑↑↑↑↑) (Giv 29)
Gv) maintenance and condition	Gv) Maintenance of quality state 30) preservation of heritage tree 31) physical elements, objects 32) seasonal volunteer survey 33) Campaign of extreme events & green space solution	(↑↑↑) (Gv 30) (↑↑↑) (Gv 30) (↑↑↑) (Gv 30) (↑↑↑) (Gv 30)	(↑↑↑↑↑) (Gv 30) (↑↑↑↑) (Gv 30) (↑↑↑↑) (Gv 30) (↑↑↑↑) (Gv 30)
Gvi) water management	Gvi) Nature-based water management 34) Natural/Semi Drainage 35) functional waterbody	(↑↑↑) (Gvi 34) (↑↑↑) (Gvi 35)	(↑↑↑↑) (Gvi 34) (↑↑↑↑) (Gvi 35)
Gvii) community growing/ allotment space	Gvii) Community growing/ allotment space 36) Urban farming 37) Art and creative platform 38) Educational tour 39) Community gathering 40) Individual adaptation	(↑↑↑) (Gvii 36 to Gvii 40)	(↑↑↑) (Gvii 36 to Gvii 40)

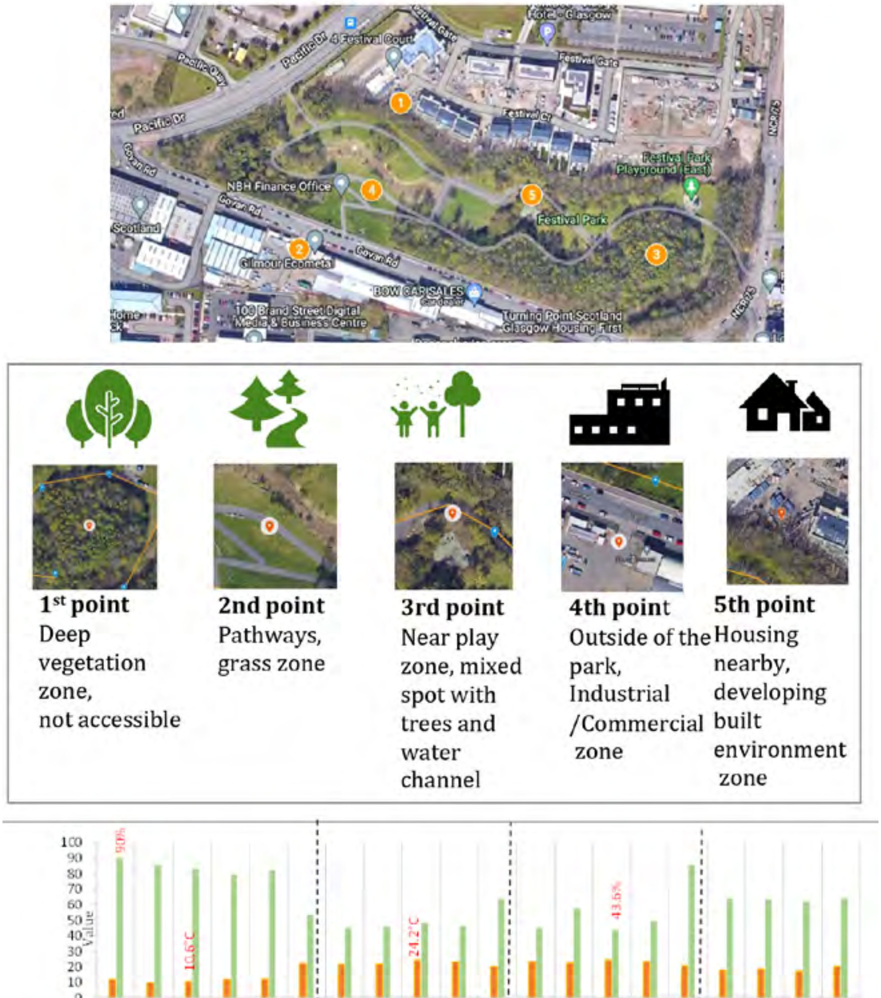
4.4 Traverse Survey and Microclimate Modelling

4.4.1 Traverse Survey 1st Part June 2022

First part of the survey consisted with two-day observation, 5th June in Festival Park and 6th June in QEUH campus in beginning of the summer season. Through Linear regression, the corrected temperature for all points at a static moment of 3:30 pm (table 3). This survey helped to determine the features of selected points in Festival Park.
A similar survey was carried out in the QEUH campus open space area on 6th June. On that day, the sky was partly cloudy. The temperature increased more than the previous day. Climate data collection on 15th June 2022 shows air temperature and

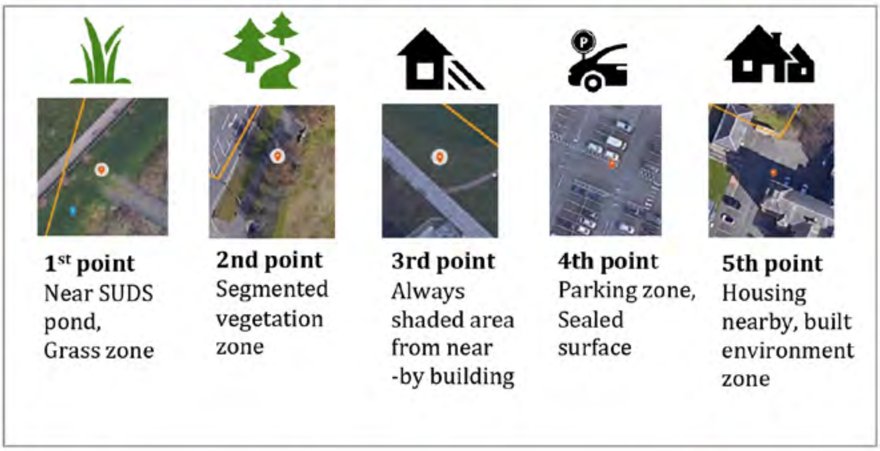
humidity fluctuation at different periods. The points were selected based on the urban profile, three are inside the green park area, and two are adjacent built environment areas. The wind flow and shaded/unshaded areas directly affected the variables of air temperature and relative humidity. In QEUH campus, the air temperature values were less than in the Festival Park due to the hour difference of measurement and weather variables. The analysis represents that the microclimate situation of the campus area is not engaged with existing elements in the open space area as there is no zoning, and it is acting as a derelict land.

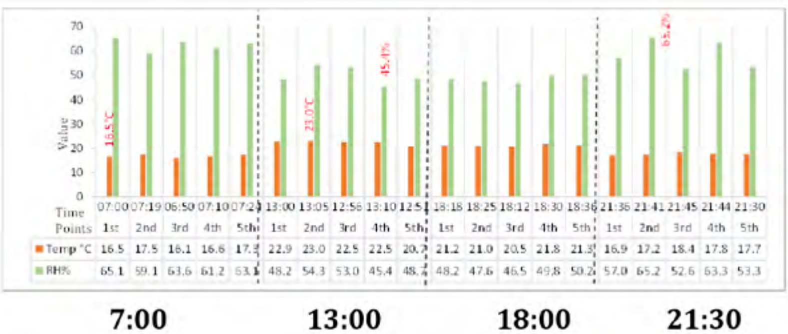
Table 3. Temperature and relative humidity data at five points in the Festival Park (left) and in the QEUH campus (right) on 15th June 2022 (Tasnim 2022)



Time	05:30	05:35	05:42	06:00	05:50	14:02	13:50	13:57	13:52	13:42	17:20	17:30	17:26	17:36	17:43	22:30	22:17	22:25	22:20	22:08
Points	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th
Temp°C	12	10	10.6	12	12.5	22.0	21.5	21.8	24.2	23.2	20.2	23.1	22.5	24.2	23.3	20.8	17.8	18.6	17.2	20.4
RH%	90	85.2	83	79.3	82.2	53.6	45.2	46.0	48.4	46.3	64	45.2	57.5	43.6	49.1	85.6	64.2	63.5	62.3	64.2


Motus Commercials (Isuzu)
Queen Elizabeth Hospital Facilities
Ronald McDonald House Glasgow
Govan Rd
Car Park S
QEUH Podiatry
Moss Rd
WestMARC
Queen Elizabeth University Hospital
1
2
3
4
5


1st point
Near SUDS pond,
Grass zone
2nd point
Segmented vegetation zone
3rd point
Always shaded area from near -by building
4th point
Parking zone,
Sealed surface
5th point
Housing nearby, built environment zone


Value
70
60
50
40
30
20
10
0
16.5°C
23.0°C
45.4%
65.2%
Time 07:00 07:19 06:50 07:10 07:2 13:00 13:05 12:56 13:10 12:5 18:18 18:25 18:12 18:30 18:36 21:36 21:41 21:45 21:44 21:30
Points 1st 2nd 3rd 4th 5th 1st 2nd 3rd 4th 5th 1st 2nd 3rd 4th 5th 1st 2nd 3rd 4th 5th
Temp °C 16.5 17.5 16.1 16.6 17. 22.9 23.0 22.5 22.5 20. 21.2 21.0 20.5 21.8 21.3 16.9 17.2 18.4 17.8 17.7
RH% 65.1 59.1 63.6 61.2 63. 48.2 54.3 53.0 45.4 48. 48.2 47.6 46.5 49.8 50.2 57.0 65.2 52.6 63.3 53.3
7:00
13:00
18:00
21:30

4.4.2 Traverse Survey 2nd Part July 2022 and Modelling

The second traverse survey was conducted on 18^{th} July 2022, when the temperature showed extreme hot weather events and overall, during red warning heat wave week in the UK. Glasgow reached 31ºC in July 2022, almost like the last highest temperature record day in 2018. Therefore, the air temperature data were collected on the same 20 points and 5 points, and it was measured for the warm day simulation analysis.

4.5 Microclimate and Thermal Comfort Simulations on Warm Days

The current year's reflected temperature and humidity transitions, 18^{th} July 2022, is the first part of the simulation analysis. The date falls into the "red warning" week. Second part simulation is done on the record warmest day 28^{th} June 2018. The selected hours are combined in two sets, one is at pick temperature hour (16:00), and after sunset (22:00). Three scenarios for each case study are shown in a comparative table. Five points of each case study show the PAT, MRT, PET and UTCI features of the simulation. The ENVI-met model validation used the Root Mean Square Error (RMSE) value analysis around 16:00 hours of that day. For both case studies, the RMSE value is around 1.3 and it was addressed as an accepted value for the base model for both case studies. For both case studies bas case represents the current condition. Festival Park case studies, 2^{nd} scenario is based on the past demarcation and green cover of the park till the year 2002. Trees and plantations were placed by following topographical data. Next, Scenario 3 highlights the possible integration of vegetation at the east and west edges adjacent to the vehicular road, permeable pathways inside the park, placements of more trees from the tree footprint of old Festival Park, and more opening towards the south side neighbourhood. For the QEUH campus the 2^{nd} scenario is the NHS Design proposal model, adopted by the proposed landscape design provided by the architects of the project. Scenario 3 highlights the integrated KPI indicators and climate-focused planning recommendations on top of the NHS proposed plan.

5 Discussion & Recommendation

5.1 Discussion of Thermal Comfort on Proposed Scenarios

The five locations demonstrated the effect of green cover and the UHI effect in both cases. Implemented design strategy has shown a slight cooling effect on the 4^{th} point in the Festival park due to a subtle increase in vegetation. However, QEUH campus analysis results show that greening the parking area from NHS's design reduces the T^{UT} value more than the T^{PET} value. It can be assumed on average summer days it is possible to bring the heat stress down towards a comfortable T^{UT} range with proper green infrastructure in focused area. A small consequential change in microclimate eventually rows the future impacts for each UGOS climate-mitigation planning and design solution.

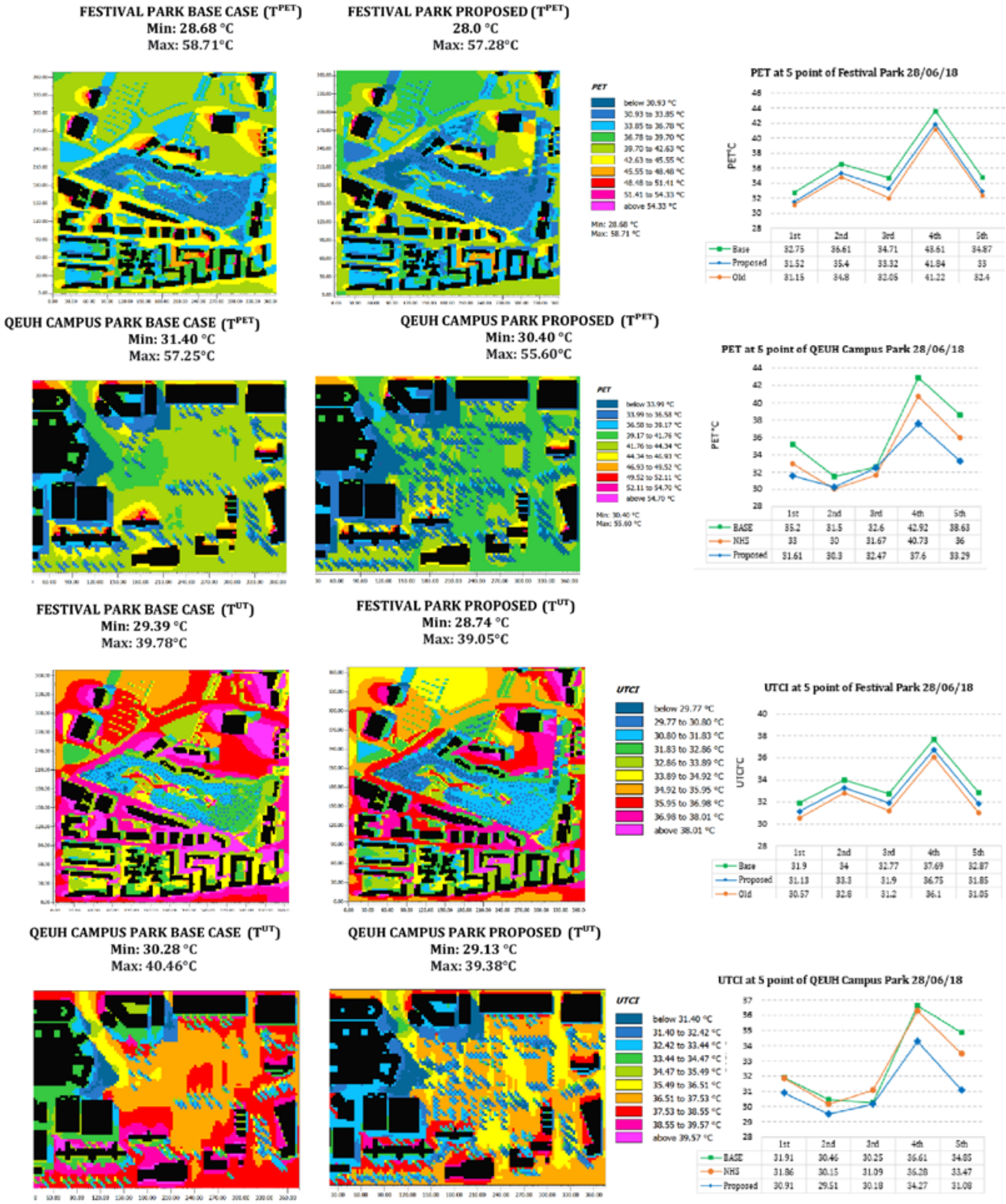


Table 4. The comparison between two scenarios of Festival Park and two scenarios of QEUH campus park in PET (T^{PET}) (above) and UTCI (T^{UT}) (below) on 28th June 2018. The time of hour is 16:00 for both (Tasnim 2022)

5.2 Climate-Focused UGOS KPI Relevancy

An improved micro-climatic environment obtained in the case studies through design proposals contributes to most of the prioritised KPI for UGOS. These findings serve objective four, a directory of KPIs for UGOS, integrating expert opinion and climate change adoption-led design approach. Most of the KPIs shown in the QEUH have been marked as highly prioritised, and the ongoing development can primarily focus on these criteria. Ultimately listed relevant indicators of UGOS benefits the wider network of city planning and mitigation measures. The QEUH campus park has more opportunities as it is going under greenspace development.

5.3 Partnership of Stakeholders and Users Group

Surveying the user's group of the UGOS will not entirely benefit until proposal decision are exchanged among the designers, planners, and users. Adopted KPI for UGOS with a climatic perspective, enhanced biodiversity and user's wellbeing comprehend not only the expert's opinion but also represent a clear vision for planning and design approach. All the expert interviewees expressed that the climate change mitigation strategy is below the expected to moderate level in ground action.

5.4 Proposal and Design Strategy Recommendation

The design strategy and recommendation primarily focus on the QEUH to aid the adaption and climate justice strategies for the most vulnerable to climate change impact. Certain aspects need bold design and planning evaluation to revive the campus park in an optimal condition and sustainable state (table 5). Despite greening the existing surface car park (NHS Design), it can be allocated into compact, sustainable, low, storey buildings which will not impact the wind flow on the campus. Interventions should be included from climate data specific points such as the warmest spots and coldest spots. Sunlight exposure and the shaded area should be balanced by the open grassland, tree canopies, or artificial shading (e.g., sun sail). Equally distributed active travel routes may encourage the users and employees to reduce vehicular activity on the roads and paths adjacent to the parking area. Therapeutic design for conviviality and art platform design strategy adopted by the NHS new proposal is a unique opportunity, and it can be enhanced by existing old building conservation. Volunteers and educational campaigns can bring awareness and enhance the examination aspects of the UGOS, such as experimenting with landscape equipment or weather measuring tools. The highlighted design strategies and recommendation expands the critical knowledge and support for optimising UGOS design and evaluation.

5.5 Conclusion

Results showed that by fine-tuning design consideration in a site-specific context, it is almost possible to manoeuvre the course of thermal comfort level for the users and neighbour habitants around an UGOS. The research represented an embedded performance system with attempted objectives. The emergent trend of warm and dry summer should be approached with UGOS to promote good health and well-being. A coherent argument is still not there regarding how to approach such events efficiently from the beginning to end, how the taken measurements can project for the common good and how they can be delivered on time. Integrating KPI for UGOS can predict the risks and benefits for functioning when needed and enable UGOS to knit the built forms of different amenities and combined them into those meaningful experiences.

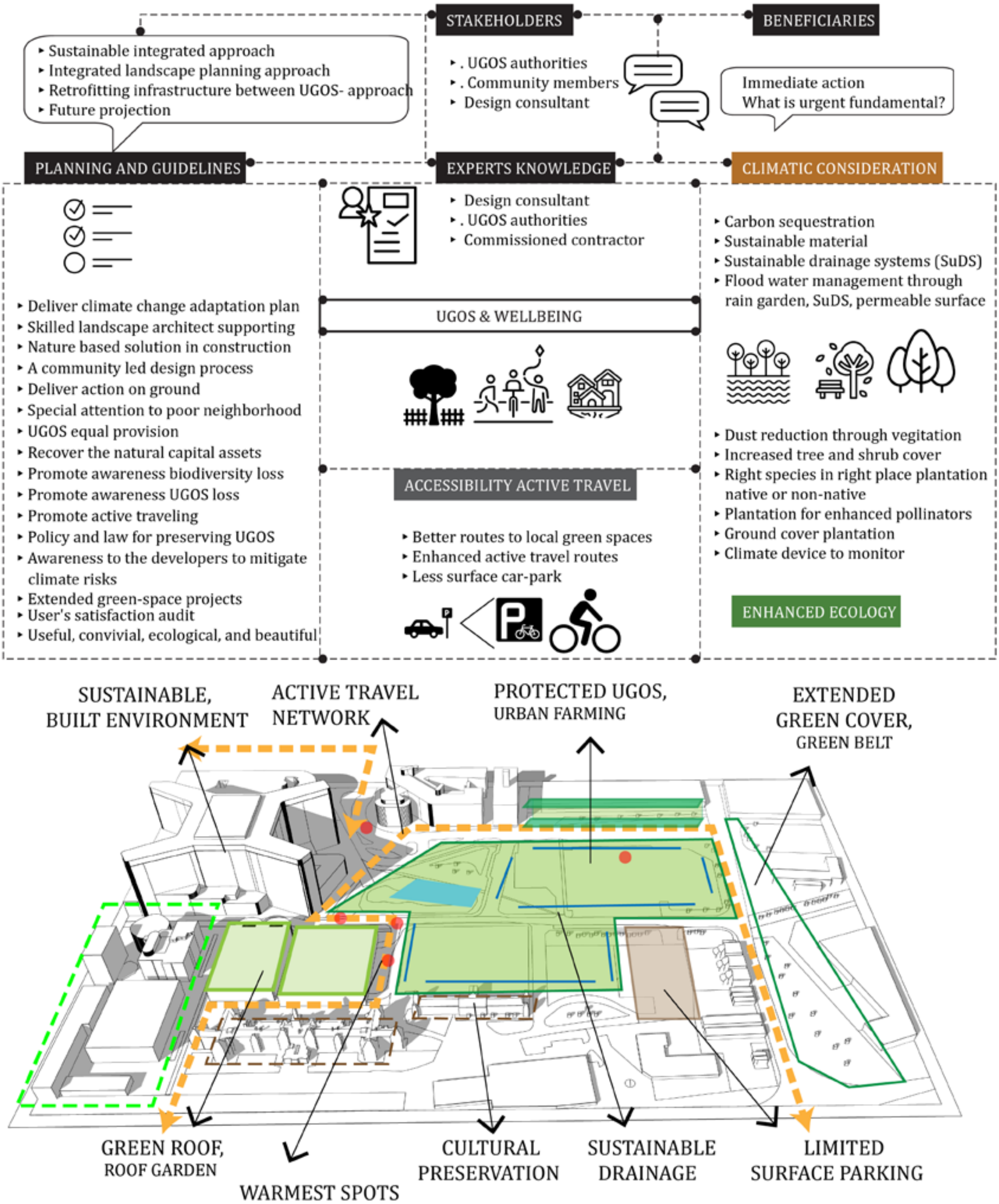


Table 5. Flowchart table of recommended UGOS planning and development aspects and design strategies and planning recommendation for the QEUH campus park (Tasnim 2022)

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Decision Support to Aid practitioners from a variety of fields

ARSHAD, MARYAM

Visual Decision Support System for Sustainable Redevelopment of Social Housing

A case study for Linstone Housing Association, Scotland

Social housing in Scotland has been reported to have high levels of disrepairs, management issues and fail to meet the minimum standard for social housing. However, these issues are difficult to address because decision-makers face immense complexities in making decisions with regards to improving social housing in Scotland due to inundation of unorganized data, new policies, and modified guidelines.

An effective multi-criteria decision support system (MCDSS) catered to this issue by encouraging smooth decision-making through use of decision support systems (DSS) to support the implementation of multi-criteria decision-making (MCDM). This MCDSS was developed for Linstone Housing Association and encapsulated the needs and requirements of tenants, housing providers and governing bodies and helped prioritize housing units in need of urgent attention. The results were represented on ArcGIS Dashboard, thereby creating a DSS which provided an effective visual display for critical information required to achieve the goals and objectives of this project. The DSS helped capture data and highlighted critical indicators and hotspots for LHA owned properties in a simple and interactive way. It also helped simplify complex data for decision-makers and stakeholders and provided body of work for stakeholders to collect meaningful data to aid their decision-making processes in the future.

1 Introduction

Social housing in Scotland has seen an excessive decrease in funding for new-build stock (Royal Institute of Chartered Surveyors 2020) and approvals for new-build plummeted to 54% among Scottish Housing Associations (Wilmore 2022). The housing in this region has also been reported to have high levels of disrepairs, with over 52% of homes having inadequate quality of essential components in 2019 (Berry 2021). Furthermore, 8,046 properties fail to meet the minimum standard for social housing (Campbell 2021). These statistics are especially alarming, since in Scotland almost 1.14 million people lived in socially rented houses in 2017 (Scottish Government 2019). Moreover, with aged population rising drastically due to increased lifespan and decrease in birth rates (Scottish Government 2022), the pressure to fix existing housing stock is at an all-time high.

In addition to this, there is a huge amount of unclassified data for these households that inundate decision makers such as architects and housing association personnel and the available data is difficult to comprehend by project managers and relevant professionals. This is especially problematic where funding needs to be arranged for the redevelopment of these buildings. Therefore, multi-criteria decision support systems (MCDSS) become necessary to help automate the decision-making processes that require the analysis of huge amounts of data in a short period of time, while keeping existing policies and standards in mind. This also provides stakeholders like architects and designers with useful information to perform informed decision making. (Yang & Ogunkah 2013.)

This project attempts to address this gap by creating a visual DSS which will be used to enable problem solving in an interactive and recursive way. Furthermore, visualization of the data will help decision makers in reaching conclusions in an efficient and conclusive manner.

The chosen area for this project is Linstone Housing Association, which is one of the many organizations responsible for ensuring safe and sustainable housing for tenants in need. The HA has over 1,500 properties across Linwood and Johnstone making it one of the largest housing associations in Renefrewshire (Linstone Housing 2022). Most of the type of property owned by LHA is comprised of either block of flats (28.5%) or small blocks of flats/dwellings converted into flats (24.79%), Information acquired from LHA also showed that almost 44% of the housing owned by the HA is in mixed tenure buildings.

The overall aim of the project was to develop a framework for a visual MCDSS to enable project managers, architects, and governing bodies to observe identified patterns, and foster collaboration and informed decision-making, thereby, effectively improving efficiency for sustainable (re)development of social housing within Scotland by conducting a baseline assessment to evaluate existing available data, policies, and frameworks in the context of the social housing sector. Next, sustainability attributes were defined and highlighted by significance through development of a comprehensive rating system. Finally, a visual representation of analysed attributes using ArcGIS dashboard was done.

2 Background

2.1 Social housing in Scotland

Social housing is typically understood to be inexpensive housing for vulnerable communities (Muczyński et al. 2019). The social housing sector in Scotland specifically focuses on delivering homes that are not only affordable but are also compliant with the latest standards, specifically in relation to quality and energy efficiency (Scottish Government 2021). However, this has become very difficult to achieve due to the increase of ownership by almost 11% (Scottish Government 2021a) of housing stock for housing associations after the suspension of right to buy in Scotland; this has resulted in immense pressure to ensure existing standards are met for a high number of properties. Furthermore, since HAs are non-profit organisations, they typically receive funding through fixed limited grants provided by the government (Robertson & Serpa 2014).

In addition, due to the increasing awareness about social, environmental, and economic issues, standards and policies are becoming increasingly complex. This includes the Energy Efficiency in Social Housing Scotland (EESSH 2) – post 2020, Social Housing Quality Standards (SHQS) 2004, and Tolerable Standards, 2006.

2.2 The complexities of decision making

This, along with the current state of social homes creates even more complexities for decision makers who are typically compelled to perform highly complex tasks in environments where data is constantly changing and information is highly cluttered (Baizyldayeva et al. 2013). In social housing, meeting set standards and policies require extensive management, retrofit and (re)development plans but can only be done through accumulating and organizing social, financial, and physical data (Muczyński et al. 2019). The Scottish Federation of Housing Associations (SFHA) even pointed out that tenants in social homes are deprived by lack of access to gas, proper heating and are disadvantaged by higher energy distribution costs (Heath 2022). This, coupled with an overwhelming requirement of fulfilling national and international obligations for greener homes adds to the complexity of decision-making for social homes as some of the problems can be difficult to grapple with. Jankowski and Richard (1994) highlighted that problems are becoming increasingly complex due to higher awareness, hence resulting in a surplus of new rules and regulations. This leads to a significant increase in the number of criteria required to do a complete analysis. In addition to this, a lot of problems that need to be addressed are either ill-structured or include qualitative figures (Vessey 1991).

While problems are becoming increasingly complicated, finding a solution is even more complex in Scotland's social housing sector because for a lot of housing associations, it is difficult to work with data. This is primarily due to lack of management, organisation and classification of data as it moves within the development chain, hence creating issues for decision makers (Howell 2022). This also makes it difficult to ascertain which houses are at risk as it makes the data unreliable. Data organization is fundamental for decision makers (DMs) to assess the ongoing issues and implement the right strategies to meet the requirements of stakeholders. Generally, even the technology used for decision making lags in the social housing sector (Howell 2022). This is especially alarming since housing associations need to increase their approvals and grants for revitalization of existing homes as well as for new-build properties.

2.3 The role of multi-criteria decision support systems (MCDSS)

An effective MCDSS can cater to the issues faced by decision makers by encouraging smooth decision-making and using decision support systems (DSS) to support the implementation of multi-criteria decision-making (MCDM). Mustajoki and Hämäläinen (2007) highlighted various ways in which digitalisation can elevate the use of MCDM methods. With advancements in technology, it is now possible to create an interactive interface to enable the best kind of decision making; and with the integration of MCDM to a model base of DSS, DMs now have even greater capacity to analyse, explore and compare different alternatives (Razmak & Aouni 2015). MCDSS can eventually help DMs visualise data in their preferred way of highlighting risks and priorities.

The process of MCDSS requires the consideration of multiple attributes to make strategies which are best carried out by Multi-Criteria Decision Making (Bell et al. 1977). The MCDM process entails making decisions that involve multiple attributes and objectives to consider (MacCrimmon 1999). It provides a ranking result based on relevant criteria, their matching values and assigned weights (Ozsahin et al. 2021). Among the MCDM methods are compensatory techniques like AHP and SAW and non-compensatory methods, such as ELECTRE III (Banihabib et al. 2017). While all the methods are highly popular and widely used, the selection of the ideal one depends on the type of problem faced, goals to be achieved, variability in the criteria and volume of alternatives that exist (Khan et al. 2020). Research also suggested combining two types of MCDM methods to obtain more accurate and relevant results such as a combination of AHP with other MCDM methods such as: AHP-TOPSIS, AHP-WP and AHP-SAW (Hadikurniawati et al. 2018).

The MCDM can then be represented as a DSS to create an interactive system that is clearly visualized and proves to be understandable by various stakeholders (Baizyldayeva et al. 2013). This can be done in the form of text or hyper texts, spreadsheets and even dashboards (Holsapple 2008).

Published research on decision support systems to date has focused very little on public/social housing. While research applications of DSS for housing and regional planning are numerous, they are specific and cannot be replicated for social housing because of the social and economic criteria. It is also difficult to implement existing tools due to their lack of dynamic approach and lack of ability to communicate results in a visual and interactive manner. This study will help by establishing a baseline on current social housing conditions using data from a housing association using MCDM tools and then further using that data to represent hotspot/priority areas in need of urgent repairs or retrofit through DSS. This will be done to ease the decision-making process for housing associations, help visualize the current scenario and even display it for the purposes of attracting investors and donors.

3 Methodology

This project followed a pragmatic approach as it strived to develop solutions that are realistic and well-informed. Furthermore, a mixed qualitative and quantitative method was also adopted that helped establish a case study for assisting decision making for LHA.

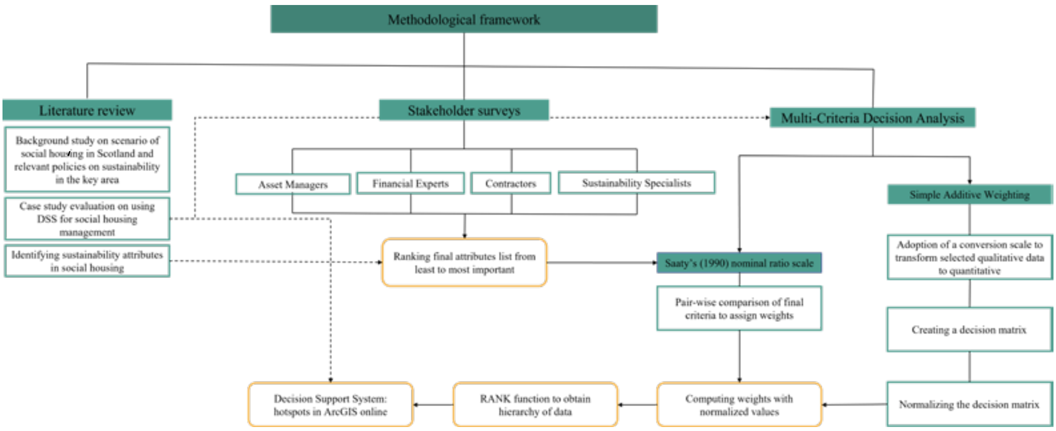

Figure 1. Methodological Framework for the project

3.1 Stakeholder Surveys and Interviews

The process of stakeholder participation was divided into two stages: shortlisting identified attributes through consultation and ranking shortlisted attributes through questionnaire surveys and interviews. 10 respondents for surveys and interviews were selected based on their level of experience in the social housing sector and all respondents belonged to LHA as they were best suited for providing insights on the priority areas that needed attention within their properties.

In the questionnaire, the respondents were asked to rank final list of attributes based on their judgement and experience from 1 through to 20. The average of responses for each ranked attribute was calculated to obtain a final ranking. Semi-structured interviews were also conducted to improve validity and provide justification for the objective responses in the questionnaire.

3.2 Multi-Criteria Decision Analysis

The MCDA consisted of using a combined decision-making method that consisted of Simple Additive Weighting (SAW) and Saaty's 1-9 scale (part of the Analytical Hierarchy Process (AHP)). Each method was applied at different stages of the MCDA. This process helped refine and organise LHA's property data and identify hotspot locations within. Due to absence of relevant data against the attributes, all ranked attributes were not assigned weights and eventually only 5 attributes were considered in the MCDA.

3.2.1 Saaty's 1-9 Scale for pair-wise comparison

Despite knowing their relative importance, it was important to ascertain the percentage weightage of each of the 5 attributes in comparison to the other. For this purpose, a pair-wise comparison matrix (n x n) for the criteria was drawn up using Saaty's 1-9 scale of pairwise comparison and each attribute was compared to the other (Saaty 1990). The consistency ratio was also determined to ascertain whether the judgment was consistent throughout the pair-wise comparison. (Cahyapratama & Sarno 2018).

3.2.2 Simple Additive Weighting (SAW)

Simple Additive Weighting (SAW) was used to find the weighted sum of performance for each alternative within each attribute. A decision matrix of (m x n) was constructed that contained 'm' housing units and 'n' criteria. A normalised decision matrix was then constructed for beneficial and non-beneficial criteria using the linear: max normalisation technique that placed values on a uniform 0-1 scale. Normalisation was a process adopted to organise a large dataset. It also ensured uniformity in how the data looked, read, and could be utilised. This was particularly important since the properties' attributes consisted of different units of measurement (i.e., there was a different unit for energy efficiency and a separate one for fuel poverty) and it was pertinent to bring all the data on one scale so it could be analysed and eventually ranked effectively.

After normalisation, each alternative was evaluated by finding the product of the score of each alternative with the weighted criteria that was established when Saaty's 1-9 scale was implemented. This finally provided the rank of each alternative housing unit, highlighting the ones in need of the most retrofit and maintenance.

3.3 Decision Support System – Development of a user-friendly interface

Dashboards specifically can provide an effective visual display for critical information required to achieve ones' goals and objectives, especially in urban areas. They are also interactive tools which can be adopted to multiple types of developments. Decision-makers use these dashboards to monitor the operation of a city by using multiple performance indicators. For this purpose, an online interface of ArcGIS Dashboards was used to present results in an interactive manner. For this project, the ArcGIS dashboard was used to represent property data in order of established ranking system. The goal of creating a dashboard was to show prioritisation of various sites to ease the decision-making process. This will also serve as a framework for creation of a fully automated DSS where rankings are established according to the user's needs and relevant results are generated instantaneously on the dashboard.

4 Results

This chapter presents the results which includes the outcomes of the survey and interview, the application of the combined MCDM methods and the development of a dashboard. It consists of five main sections: expert survey results, weighing attributes using Saaty's 1-9 scale, normalization of data using SAW, obtaining final ranks and ArcGIS dashboard. The chapter discusses comparisons with the literature and briefly touches upon various limitations identified while executing the project.

4.1 Expert Survey Results

The analysis of the survey results showed rankings for the 20 attributes (Figure 2). For seven out of 10 respondents, alleviating fuel poverty and keeping rent affordable were at the top of the list because of their importance in the social housing sector. It was also apparent during discussions that respondents leaned more towards some attributes than others due to their own bias based on their experiences and job descriptions. As predicted, the financial expert leaned more towards prioritizing "initial capital cost of retrofit" and "cost of ongoing maintenance", whereas maintenance managers preferred "fabric first upgrades". Odu (2019) also highlighted the probability of decision-makers preferring one criterion to another due to their own personal preferences, thereby adding further complexity in the decision-making process. However, personal interactive interviews – conducted after the survey – helped detect and mitigate such biases by implementing an effective discussion and feedback mechanism.

Final rankings from surveys

1	Alleviating fuel poverty
2	Keeping rent affordable
3	Cost of ongoing maintenance/replacement of new technology
4	Energy efficiency (EPC rating, EESSH2)
5	Fire Safety
6	Initial capital cost of retrofit
7	Ease of maintenance
8	Fabric first upgrades
9	User ambient comfort (thermal, acoustic, ventilation)
10	Carbon emissions (net zero agenda)
11	Tenant disruption
12	Duration of retrofit works
13	Renewable energy
14	Supply chain
15	User familiarity with building materials/systems
16	Waste management
17	Water heating
18	Security against intrusion
19	Embodied Energy
20	Job creation

Figure 2. Final Rank of attributes from surveys

4.2 Multi-Criteria Decision Analysis

The application of Saaty's 1-9 scale derived from the AHP method proved to be quite advantageous as it helped create a hierarchal structure to an otherwise unstructured problem and processed qualitative data using quantitative measures. It also considered the limit for inconsistencies during comparison of different criteria and alternatives. Pertiwi, Daniawan and Gunawan (2019) also highlighted these benefits while combining the AHP and SAW methods to design a DSS for selecting majors in school. They also highlighted certain disadvantages such as the complexity of the method and that in order to make improvements, one has to start from the initial stage. However, in this project, having less attributes to analyse decreased the complexity of the comparison matrix and allowed for more consistent results.

The final weight for each of the five criterion was obtained. As stated in the initial ranking system, the order of the criteria remained the same, however, now they have an assigned weightage, with the criterion of alleviating fuel poverty having the highest weight of 40% and renewable energy having the lowest weight of 4%. Energy efficiency, fabric first upgrades and carbon emissions were in the middle with percentage weights of 35%, 15% and 6% respectively. Ultimately, the weights provided an indication of the decision-maker's influence and the importance of a specific criterion within the MCDM process. Furthermore, a value of 0.029 was obtained for the consistency ratio, which is less than the threshold value of 0.1, indicating sufficient consistency. The data was also normalised on a scale of 0-1, which helped bring all data on one scale to be analysed against the weighted attributes.

Overall, the collaborative use of SAW and Saaty's 1-9 scale proved to be effective in highlighting hotspots for retrofit of properties owned by LHA. This combination was ultimately chosen because Saaty's 1-9 scale adds a human element to the analysis and essentially operates at a functional level, while SAW can easily analyse alternatives and improve the decision-making process significantly. This process allowed large amounts of quantitative and qualitative data to be analysed and encouraged the creation of a computerised system for decision making.

4.3 ArcGIS dashboard

An interactive display was created using ArcGIS dashboard that served as a framework for a decision support tool. The final ranks and corresponding data were uploaded, and the prioritised areas were identified by classifying the data into natural breaks. Through this, properties ranked 1-391 were classified as low priority, those ranked 392-782 were classified as medium priority, 783-1174 were classified as high priority and any rank above that (till 1565) was classified as very high priority.

Two variations of the dashboard were also developed to highlight hotspot areas, the first one being an environmental and emissions dashboard (Figure 3) and the second one being the dashboard for fabric first upgrades (Figure 4). This was done to show the possible visualisation techniques that can be adopted while developing a comprehensive and customisable DSS (which will be able to show all dashboards in one specific map, hence allowing the user to display the attributes they wish to work on or present). The GIS dashboard is overall highly customisable, which is also a property that should be kept in mind while developing an automated DSS.

Figure 3. Salient features of the Environment, fuel, and emissions dashboard

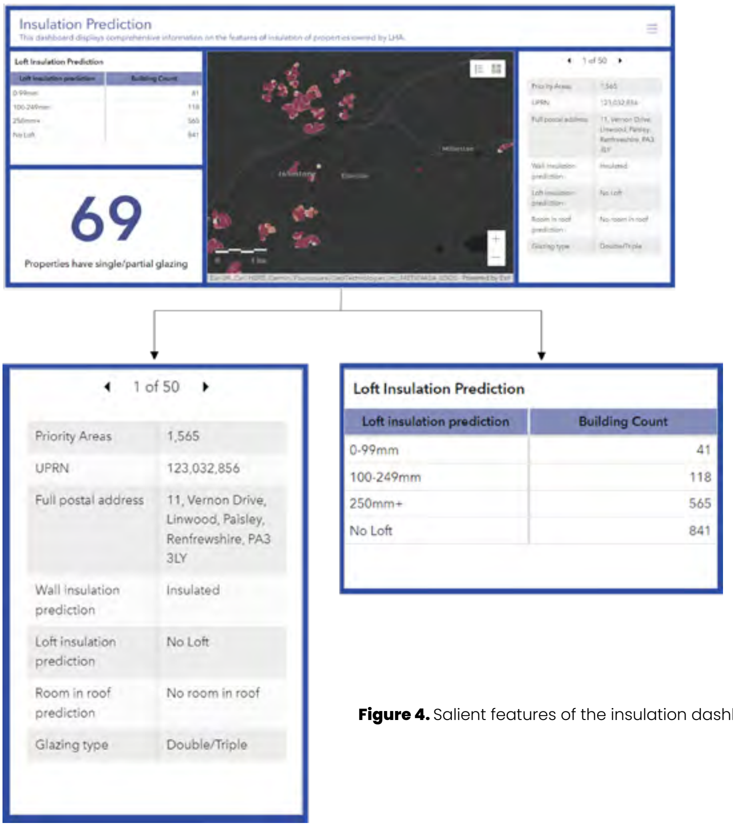

Figure 4. Salient features of the insulation dashboard framework

Upon carrying out a user engagement process, it was found that the dashboard presented accurate findings that could help LHA not only address the issues faced by their properties in an organized manner but also help them gather grants and funding to carry out those activities. It was also highlighted that more data will need to be acquired and added into the dashboard to create a holistic and comprehensive dashboard. It was also found that the dashboard was quite user-friendly and can be easily used by managerial staff without requiring extensive programming and IT knowledge. Hence it will also be easily understandable by non-expert observers or users.
Overall, developing a framework for a DSS helped capture current data and highlighted critical indicators and hotspots in the realm of social housing in a simple and interactive way. Adam and Pomerol (2008) pointed out that the key element of the dashboard is not the design of the interface, meaning that a good dashboard does not necessarily require extensive programming, but should be able to express accurate data. This is what the dashboard aimed to represent and highlight.

5 Conclusions and discussion

This project developed a case study for Linstone Housing Association and developed a framework for a dashboard that can facilitate their decision-making processes. This was done through extensive literature review, stakeholder discussions, and a combined approach of using SAW and Saaty's 1-9 scale.

A dashboard could ease the decision-making process for DMs and help them understand the patterns and quality of data. It can also help them visualize it in a more meaningful way by taking away the unnecessary issues regarding data management, such as cleaning up multiple data sets and analysing them collectively and showing them a clear picture of the current scenario. It can specifically help LHA highlight and display hotspots to potential donors.

A few limitations were also identified during this project. One of the biggest challenges was that AHP could not be applied AHP could not be applied for the survey due to the complexity that respondents would face while carrying out pair-wise comparison of 20 attributes. Therefore, a more pragmatic solution had to be adopted and a simple ranking system was established that was easy for the respondents to follow. The pair-wise comparison was later carried out for select attributes whose data was available and was then verified by a representative of LHA. Furthermore, There are very few discussions in literature over using a combined approach of SAW and Saaty's 1-9 scale. Though the method is proven to be successful in other projects, the effectiveness of the method needs to be established in a social housing context.

Furthermore, there is a need to develop a data collection strategy to fill missing information on environmental, social, and economic attributes for each property and create a centralised open-source database for constant updating. The type of data includes demographic data, information on current rent, fire safety information of each property, average capital costs of retrofit works, user ambient comfort and user familiarity with building systems and materials. Once data for the 15 attributes is collected, the ranking system can automatically assign weights to the data and the new hotspots can then be presented on the ArcGIS dashboard.

It is also recommended that the results of the study are combined with geographical and socio-economic data to provide a holistic view on the current situation of social housing in Scotland from a broader perspective. Furthermore, the current dashboard framework can be further refined by using more sophisticated visualisation methods that allow the user to add and subtract data easily, and essentially visualise based on their preferences and needs. This will also include creating a software that encapsulates the MCDM method to generate results automatically through automated data retrieval, analysis and presentation on a GIS-based system. Therefore, there is a need for integrated tools, which produce automatic graphic output (plots and graphs). The dashboard can also be made visually customisable to make it appropriate for the type of audience that is visualising or using it i.e. display of data and phrases can be changed according to whether it's a layman or an expert.

The current study can be extended to other housing associations by applying the same methodology and recommendations provided. Further research and collaborative effort will be required to create a combined DSS that could be applicable to all housing associations in Scotland. This will require dialogue and consultations with all housing associations as well as the Scottish Government to create a comprehensive ranking system where all stakeholder priorities are considered.

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LIEBER, JONATHAN

A Hedonic Pricing Model in Helsinki, Finland

Exploring the Impacts of Green Infrastructure on Apartment Listing Prices

Hedonic pricing models (HPM) are a method of regression that isolate characteristics of property to estimate the impact on valuation (Monson 2009). This method is used to evaluate how proximity to green infrastructure (GI) impact real estate markets. Although HPMs have been deployed for on-site features, very few have assessed on-site GI. This dissertation investigates the impact of on-site GI on apartment listing prices in Helsinki, Finland through an HPM. A multi-linear regression was conducted on a dataset collected from 200 property listings to measure the relationship between the structural characteristics and property listing prices.

No finding produced statistically significant evidence against the hypothesis (that GI has a positive association with apartment listing valuation). For each unit increase, the apartment listings gained or lost the following in value: square metre of living area (+€8,079), bathroom (+€101,040), floor level (+€7,928), each km away from the coastline (-€15,080), each km away from the central business district (-€14,277), landscape gardening (+€79,250).

These findings offer practical applications for the real estate industry. Strategies can be crafted to maximize apartment valuation by recognizing proximity to certain features and on-site landscape gardening.

1 Introduction

Natural elements in the landscape provide human societies with a range of benefits. These include economic, social, and environmental benefits in the form of ecosystem services. Ecosystem services encompass "*the benefits that human societies derive, directly or indirectly, from ecosystem functions*" (Costanza et al. 1998, 3–15). The benefits of ecosystem services are often organized into four categories: provisioning services (natural resources), regulating services (air/water quality improvements, etc.), cultural services (recreation, etc.), and supporting services (photosynthesis, nutrient cycling, etc.) (European Union 2019; Notte et al. 2017, 392–402; Reid et al. 2005; FAO 2022).

Regulating, supporting, and cultural ecosystem services tend to be more abstract and intangible than provisioning ecosystem services. This has caused them to act as externalities in the economy, in that their value is not captured in the market (Goulder & Kennedy 2013, 15–33). Without accounting for the value of ecosystem services, they become depleted, displaced, and removed. To address this, efforts for integrating the environment into economics through what is referred to as "environmental economics", formulated in the early 1960's (Pearce 1990).

As environmental economics advanced, the concept of natural capital developed. Natural capital refers to "the living and nonliving components of ecosystems—other than people and what they manufacture—that contribute to the generation of goods and services of value for people" (Guerry et al. 2015, 7348–7355). Ecosystem services are a product of natural capital.

A type of natural capital is green infrastructure (GI). GI is a disputed term (Benton-Short et al. 2017, 330–351) but is generally understood to be "*vegetation, soils, and bioengineered systems that provide ecological services such as microclimate regulation, air quality improvements, habitat, and stormwater management*" (Bolund & Hunhammar 1999, 293–301). GI is most often conceptualized in urban contexts. Helsinki is located on a peninsula of river valleys and granite cliffs that protrudes into the Finnish Gulf. The city has over 100 miles of coastline, which include the 315 nearby islands. The historical vegetation cover consisted of coniferous woods.

The area has undergone biophysical changes as the city developed. For example, the 25 streams that run through the city have been altered through drainage, straightening, and removal of riparian vegetation (Vierikko & Niemelä 2016, 537–547). Although the city has still managed to maintain a 46% green cover, much of the original native coniferous woods have been removed for development (Jaakkola 2012, 109–128). Population in the metro area of Helsinki has increased from 365,600 in 1950 to 1,327,762 in 2022 (World Population Review 2022). The local environmental pressures have spurred sustainable development and ecological restoration actions.

In the private sector, property development is almost entirely profit-driven. The sole purpose, like other private sector companies, is to generate a direct financial profit (Isaac 1996, 1–23). Justifying design features, including GI, in economic terms is essential for adoption. Demonstrating paybacks of GI in localized contexts builds confidence in the applications and clarifies expectations. Although much of Helsinki's development is administered by public enterprises, filling in research gaps related to the economic value of GI is expected to encourage uptake.

2 Background

A range of methods has emerged for accounting for the economic value of various types of natural capital and the ecosystem services that they provide. The main objective of these methods is to determine the total economic value (TEV) of the natural capital asset which "*represents all the ways that goods and services influence individual utility*" (Tinch 2019, 39–47). This quantification of intangible externalities in the economy is also referred to as shadow pricing (Starrett 2000). Constructs such "*The System of Environmental-Economic Accounting*" (SEEA) framework have been developed in an attempt to set standards for integrating environmental data into economic formulas (United Nations 2021).

The ecosystem services that natural capital assets provide may benefit direct private interest, indirect public interest, or both. For example, many of the regulating and cultural ecosystem services such as improved air, water, and soil quality benefit the public. Urban trees increasing property valuation however are an example of natural capital benefiting private interest.

Most environmental economics research focuses on the public interest benefits. However, natural capital assets such as GI are increasingly recognized for their contributions to private interest. The benefits include increased property valuation, extended infrastructure lifespan, cost savings, energy and water savings, property marketability, and permitting benefits.

A set of methodologies within this niche of environmental economics have been developed to estimate the economic impacts of GI applications in urban environments. These estimations serve a critical role in justifying GI through quantified metrics. Building confidence in this manner is important because, despite the well-known public benefits of GI, widespread adoption has been slow (Matthews et al. 2015, 155–163). Methods For Identifying the Economic Value of Green Infrastructure

2.1 Cost-Benefit Analysis

A cost-benefit analysis (CBA) is the "*is the estimation and weighing of the positive and negative effects of government action*" with a "*look before you leap*" mentality (Livermore et al. 2013, 3–16). This definition also extends to the actions of property developers/managers and other actors. It is one of the most basic types of analysis, as it is essentially a subtraction of the costs from the benefits. The result is a determination of the economic efficiency of the proposal.

2.2 Willingness to Pay/ Contingent Valuation

Willingness to Pay (WTP) models has been applied to estimate the market value of nature-based solutions (NBS) including GI. NBS are "*actions which are inspired by, supported by, or copied from nature*" (European Commission 2020). To estimate the WTP, a contingent valuation (CV) experiment is often conducted. CV experiments are a survey method that asks a selection of market actors how much they would pay for certain features of products or services. The results act as a proxy for the wider market (Markandya et al. 2019, 719–727).

2.3 Case Studies

Case studies are "*in-depth, multi-faceted explorations of complex issues in their real-life settings*" (Crowe et al. 2011, 1-9). Case studies offer an approach to assessing the valuation of NBS projects already completed. The studies act as retroactive CBA. The findings can help the project generalize the feasibility of forthcoming NBS applications and identify refinement practices to create future efficiencies.

2.4 Lifecycle Assessment

A lifecycle assessment (LCA) is an analysis of a product or service from its raw materials stage to the waste stage. The LCA is often used to assess the environmental burden of a product or service, but it can also be used to calculate the economic value by assessing the costs and benefits received through the lifecycle (Klöpffer 1997, 223–228). This method has been used to estimate both the TEV and identify environmental trade-offs of NBS, LID, and GI (Spatari et al. 2011, 2174–2179).

2.5 Hedonic Pricing Model

Property is sold on the market as a bundle of goods. The goods include the land, the building, the location, and the components that make up these features. HPMs uses multi-linear regression analysis to isolate physical and spatial characteristics to assess the influence on the property's valuation (Monson 2009).

There are three main types of HPMs deployed: spatial, non-spatial, and mixed type. The type of HPM utilized depends on the feature being assessed (CFI Education Inc. 2015). Spatial HPMs are used to assess the economic influence of features in spatial proximity to the property such as parks, forests, and recreational amenities. Non-spatial HPMs focuses on the economic influence of features found within the site boundaries such as building design, landscaping, and parking. Mixed-type HPMs integrate HPM types (spatial and non-spatial) to assess a series of features and their correlation to property valuation.

HPMs have been useful for identifying the economic influence of NBS as set by the market in various contexts. The use of HPMs for this purpose has grown in popularity and complexity in recent years. With the increased use of HPMs, methodologies have improved.

There is a gap in the research that examines what impact on-site GI has on property valuation (if any) in Helsinki. HPMs can inform this research gap. To date, few HPMs have been applied in Helsinki. The most prominent is by Votsis (2017) titled: "*Planning for green infrastructure*: *The spatial effects of parks, forests, and fields on Helsinki's apartment prices*". This research utilized an HPM, finding "green types yield different marginal effects and these depend on location within the city and the nature of spatial spillovers generated". A non-spatial HPM would complement this research by filling the knowledge gap of what economic dynamics are occurring within property boundaries.

Exploring the relationship that GI has with property valuation is expected to advance the understanding of how the Helsinki real estate market values natural capital. By doing so, GI can be more readily justified in the design process. It is expected that the adoption of GI would increase should applications benefit the property valuation of local real estate. Although this research focuses on the immediate economic benefit to the property owner, the economic reward of GI adoption is radiant, as the public reaps the benefit of more healthy, livable, and climate-resilient cities.

3 Methodology

3.1 Study Area

The study area is Helsinki, Finland. The city consists of eight major districts and 34 subdistricts (City of Helsinki, 2011). Property data has been selected from available listings across the city to represent a random sample.

3.1.1 Methodological approach

HPM was selected as the methodological approach for this study. HPM was selected because it utilizes actual economic data to reveal the TEV of GI. This method is commonly used for determining how GI and other externalizations in the economy influence the real estate market. The extensive use of the model increases confidence in the method. Additionally, the method can be carried out within realistic timeframes and is feasible with available resources.

The philosophy that the research adopted is a pragmatic approach through ontological terms. The study created new knowledge by drawing conclusions about how GI applications impact property listing prices in Helsinki based on the results of the HPMs using quantitative data. Deductive reasoning was applied as the research is driven by the central hypothesis that GI has a positive association with apartment listing valuation and can be quantified through an HPM.

The nature of the study involved a mixed method of qualitative and quantitative methodology. The research was conducted through cross-sectional data at a single point of time, between January 2022 and August 2022.

3.2 Hedonic Equation

This research organizes the available information and calculation through the hedonic equation listed below. The dependant variable (listing price), symbolized as Lp, is explained by adding the independent variables (constant α and structural coefficients). β symbolizes the structural value coefficients. i is the value of the coefficients.

To provide a more detailed explanation, the equation involves the addition of the listing price minus its structural values (the constant α) to the coefficients of the structural values (locational structural value coefficients (Lv), apartment structural value coefficients (Av), and GI structural value coefficients (Gv). The structural value coefficients are multiplied by the dummy variables utilized to detect the presence or absence of certain features. Non-dummy structural values with other units are not multiplied. With multi-linear regression utilized, there is an error term, which is added to the model (ε).

$$Lp\ i = \alpha + \beta 1\ Lv\ i + \beta 2\ Av\ i + \beta 3\ Gv\ i + \varepsilon$$

This simple hedonic equation was utilized to clearly illustrate the specific increase (€) per unit that the structural value coefficients have on the constant alpha value.

3.3 Structural Characteristics

A structural characteristics index was developed for the HPM. These structural characteristics are common inherent attributes that determine property listing prices (Ho Wai Son & Han Hsuen 2022). The structural characteristics are broken into three groupings: locational, structural, and GI.

3.4 Data Collection

Sales data is not public information in Finland, and therefore a data-sharing license would be required from the municipality. The time and capital resources required to secure a data-sharing license were deemed outside the scope of this project. As an alternative, listing prices were used for the HPM. Property data was collected using popular realtor websites including Etuovi, Oikotie, and Properstar. In Europe, listing prices can act as a proxy for sales transactions. Although the value is derived from the perceived value set by the seller, real estate agent, and property appraiser the listing price leads the negotiation (Fregonara & Irene 2021, 43–73).

Distances between the property and spatial variables were collected either from data in the property listings or measured using the Google Earth measurement tool. Spatial measurements are in Euclidean distance (directly between the two locations rather than through the street network).

The presence or absence of GI variables was assessed by reviewing photos from the listings, and imagery on Google Earth, Maps, and Street View. 200 apartment listings were assessed. The maximum number of listings to be assessed was selected based on feasibility for the projected timelines. Only apartments/condominiums were selected for assessment.

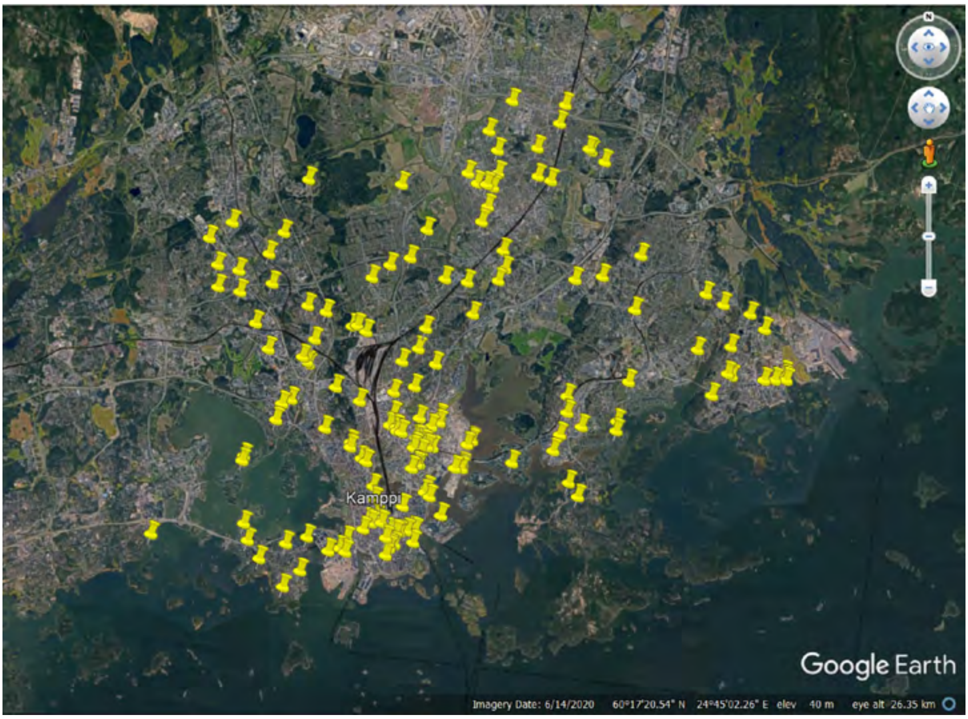

Figure 1. Map of property listings assessed (Google Earth 2022)

Figure 2. Green roof at Lauttasaarentie 52 (Google Earth 2022)

Figure 3. Measuring Ruonasalmentie 12 distance from coastline (Google Earth 2022)

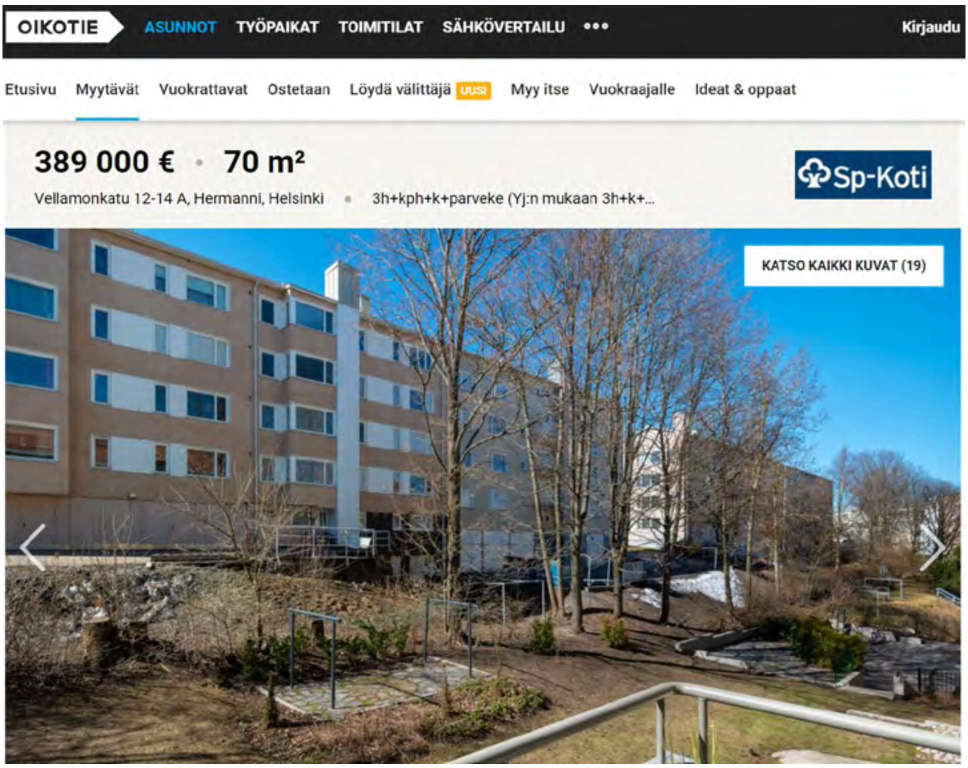

Figure 4. Assessing GI features of Vellamonkatu 12-14 on realtor website (Oikotie 2022)

3.5 Hedonic Regression Analysis

An HPM comprising of 33 variables and 200 observations was conducted. Listing price (€) acted as the dependent variable whereas the structural characteristics acted as the independent variable. The HPM was carried out in Microsoft Excel using the extension "RegressIt", a statistical forecasting tool released in 2014 by Fuqua School of Business at Duke University (RegressIt 2022).

4 Results

The complete results of the HPM are shown in Figure 5. A total of 200 observations were fitted for the HPM. Two values are listed as missing. The regression was run with a 95% confidence level.

The R square indicated that 87% of the structural characteristic's variations are explained by the price listings. Therefore, the data is a good fit for the model (Statology 2019).
The adjusted R squared indicated that 85% of the variation of the structural characteristic's values are explained by the price listings. This reinforces that the model is a good fit (Corporate Finance Institute 2022a).

The critical t of the HPM output was 1.974. In the HPM output, four of the values (number of bathrooms, landscape gardening, living area, and floor level) were larger than the critical t, in turn rejecting the null hypothesis. This implies that these values are statistically significant (Statology 2021f).

The standard error represents the average distance that the observed listing prices (€) fall from the regression line (Statology 2021a). On average, the observed values fall €126,027 from the regression line. There is a 95% confidence level that the observed sample mean is plus or minus 1.96 standard errors from the population mean.

Positive coefficients indicate that for every increase in the unit of an independent variable, the dependent variable increases. Likewise, negative coefficients indicate that for every increase in the unit of an independent variable, the dependent variable decreases (Stockburger 2022). Therefore, the signs of the coefficients in this research indicate the increase or decrease of the listing price in euros when the presence of structural variables is detected. Out of the total 34 variables, 14 had positive coefficients and 20 had negative coefficients.

Seven of the coefficients were statistically significant. This is established through P-values that are less than 0.05. This causes the null hypothesis to be rejected for these coefficients. The null hypothesis of the P-values was that the coefficient is equal to zero, implying they have no effect. Therefore, the P-values are detecting that these coefficients have a statically significant impact on the listing prices (dependant variable) (Statology 2021b).

VIF measures how many “inflated variances” are caused by multicollinearity. Multicollinearity is a term to describe scenarios where the independent variables are correlated. Only two variance inflation factor (VIF) values indicate the potential for multicollinearity (Corporate Finance Institute 2022b). Multicollinearity can disrupt models significantly because the independence of independent variables is critical for assessing their impacts on the dependent variable (The Pennsylvania State University 2018).

Confidence intervals of each coefficient provide a range of where the actual coefficient value falls. If the range occurs above 0, then it can be determined that the independent variable is having an impact on the dependent variable with a confidence of 95% (Sullivan 2022). Four of the coefficients in the HPM output had ranges that occur above 0.

The standard errors of the coefficients were also displayed in the output. This is the standard deviation of each coefficient. The standard error value indicates the model’s precision for that coefficient (Minitab 2022). The standard errors in the model are large across the output in comparison with the coefficients. This implies the model does not reflect an overall precision in the results.

The model had a mean error of 1.791. The mean error (also known as the mean square error) is “the average of the square of the errors”. A zero would indicate a perfect fit model (Rowe 2018). The low mean error in this model signifies that the model was a good fit.

The HPM output had a root mean square error (RMSE) of 114,816. The RMSE of the HPM output is considered moderate in relation to the range of the dataset (Statology 2021d).

The mean absolute error (MAE) had a value of 85,401. The MAE is similar to the RMSE in that it is the difference between the observations and predictions, but it is the mean absolute value of the difference rather than simply the difference (Statology 2021e). As with the RMSE, the MAE value in the HPM output is considered moderate in relation to the range of the dataset.

Mean absolute percentage error (MAPE) is a percentage value that signifies model accuracy and forecasting. In general, MAPEs over 50% are suggestions that forecasting would not be highly accurate with the current model (Statology 2021c). The HPM output for this model was 54.56%, indicating the model is not well suited for forecasting.

To test if the data came from any specific distribution, the HPM output ran an Anderson-Darling Test (A-D* Stat). The A-D* Stat is a “goodness of fit” test because it tests to see if the random data sample follows a theoretical normal distribution. The A-D* Stat rejects the null hypothesis that the dataset has a normal distribution when the P-value of the test was less than 0.05 (McNeese 2011; National Institute of Standards and Technology 2022; Springer 2008, 12–14).

The P-value of the A-D* Stat in the HPM output was 0.007. Therefore, the null hypotheses can be rejected. This indicates that the dataset did not have a normal distribution. Ultimately, the rejected null hypothesis implies that the A-D* Stat can not be used to infer meaning other than that the data were not distributed normally.

In summary, the results were largely unexpected because many of the coefficients did not demonstrate high enough statistical confidence to meaningfully defer implications. Four of these were spatial variables, two were structural variables, and one was a GI variable.

With only one of the 16 GI variables producing a statistically significant result, it is difficult to test the planned hypothesis that GI impacts listing prices in Helsinki. Therefore, rather than testing the planned hypothesis, the data, and results of HPM output was explored. The aim was to analyze why the results were unexpected, make inferences from the statistically significant coefficients, identify data predictors, and determine how future HPMs can be improved.

Model: Model 1
Dependent Variable: Listing_Price__Euros

	R-Squared	Adj.R-Sqr.	Std.Err.Reg.	Std.Dep.Var.	# Fitted	# Missing	Critical t	Confidence
	0.878	0.853	126,027	329,212	200	2	1.974	95.0%

Variable	Coefficient	Std.Err.	t-Statistic	P-value	Lower95%	Upper95%	VIF	Std. Coeff.
Constant	113,436	67,448	1.682	0.094	-19,730	246,601	0.000	0.000
Age	-124.548	387.288	-0.322	0.748	-889.193	640.096	2.408	-0.014
Attached_garage	24,767	24,648	1.005	0.316	-23,897	73,430	1.434	0.033
Balcony	-20,139	25,000	-0.806	0.422	-69,499	29,221	1.533	-0.027
Balcony_greenery	16,037	38,245	0.419	0.676	-59,472	91,546	1.356	0.013
Bathrooms	101,040	32,956	3.066	0.003	35,974	166,106	2.502	0.132
Bedrooms	-20,170	20,555	-0.981	0.328	-60,753	20,413	3.223	-0.048
Bioswale	6,621	83,977	0.079	0.937	-159,179	172,421	1.312	0.002451
Detached_garage	-33,461	60,919	-0.549	0.584	-153,737	86,814	1.139	-0.016
Distance_to_the_central	-14,277	5,136	-2.780	0.006	-24,417	-4,137	5.041	-0.169
Distance_to_the_coastli	-15,080	7,298	-2.066	0.040	-29,489	-671.475	2.329	-0.086
Distance_to_the_neares	73,733	47,383	1.556	0.122	-19,818	167,284	1.526	0.052
Distance_to_the_neares	116,292	62,182	1.870	0.063	-6,479	239,062	1.443	0.061
Distance_to_the_neares	-12,042	14,240	-0.846	0.399	-40,156	16,072	1.372	-0.027
Distance_to_the_neares	29,767	22,083	1.348	0.180	-13,833	73,367	1.537	0.045
Distance_to_the_neares	25,030	115,359	0.217	0.828	-202,730	252,791	1.305	0.006727
Distant_to_the_nearest_	-22,132	33,099	-0.669	0.505	-87,483	43,218	1.649	-0.023
Green_roof	-2,803	43,574	-0.064	0.949	-88,834	83,228	1.348	-0.002027
Landscaping_garden	79,250	23,670	3.348	0.001	32,516	125,984	1.357	0.106
Lawn	-36,382	23,146	-1.572	0.118	-82,080	9,317	1.632	-0.054
Living_Area__m2	8,079	573.294	14.092	0.000	6,947	9,211	3.983	0.763
Living_wall	-105,823	77,079	-1.373	0.172	-258,004	46,358	1.466	-0.045
Meadow	155,167	137,635	1.127	0.261	-116,573	426,907	1.187	0.033
Parking__non_garage	-3,474	22,900	-0.152	0.880	-48,687	41,738	1.471	-0.004994
Postal_Code	-268.996	59.180	-4.545	0.000	-385.839	-152.153	2.956	-0.212
Rain_garden__Bioreten	22,786	105,679	0.216	0.830	-185,863	231,435	1.392	0.006904
Rooms__excluding_kitcl	-21,801	18,760	-1.162	0.247	-58,840	15,238	4.905	-0.070
The_floor_on_which_the	7,928	3,981	1.991	0.048	68.075	15,787	1.259	0.061
Vegetable_Garden	-38,397	51,959	-0.739	0.461	-140,982	64,188	1.148	-0.021
Vegetation__5_or_less_	-16,493	30,038	-0.549	0.584	-75,798	42,811	2.290	-0.023
Vegetation__6_or_more	-38,601	30,812	-1.253	0.212	-99,434	22,232	2.988	-0.059
Vegetation__shrub	-15,056	30,888	-0.487	0.627	-76,040	45,927	1.958	-0.019
View_of_Natural_Eleme	-1,822	24,583	-0.074	0.941	-50,359	46,714	1.613	-0.002555
Waterbody	-135,878	101,882	-1.334	0.184	-337,029	65,273	1.294	-0.041

	Mean Error	RMSE	MAE	Minimum	Maximum	MAPE	A-D* stat
Fitted (n=200)	1.791E-10	114,816	85,401	-370,620	426,138	54.6%	1.11 (P=0.007)

Figure 5. Output of Regression

5 Conclusions and discussion

The model produced mainly unexpected results. Many of the coefficients were counterintuitive values, not statistically significant, or do not meet confidence thresholds in the variety of statistical tests run in the HPM. This implies that the results and model should be reviewed critically.

Out of the 34 coefficients in the model, only 14 had positive values. Many of the negative coefficients deviate from expectations and comparisons in the literature. There are several potential causes for unexpected results in multi-linear regression including the "range of independent variables is too small, excluding important variables from the model, multicollinearity and computation error" (Mullet 2018, 121–126).
The most probable factor for the unexpected results is the limited sample size. If the sample added 140 property listing assessments as a minimum or had some of the independent variables removed, the model would likely produce more expected results. Time constraints were the limiting factor for more extensive data collection in this research.

Out of caution, meaning was not derived from any of the coefficients unless there was statistical significance. The coefficients that were not statistically significant are still explored against comparative literature. The aim is to investigate the unexpected results and contextualize the variables within Helsinki's context.

This research hypothesized that GI would have a positive impact on property listing valuation in Helsinki. Although many of the GI structural variables did not produce statistically significant results, its worth noting what was not produced. No statistically significant result conflicted with the hypothesis or with the literature that supports positive associations of property valuation with GI.

Due to Helsinki's unique economic system, any HPMs applied in Helsinki are context specific. The findings are indications of a mix of private demand and government estimations. The value of independent variables deduced are relevant locally but may not apply in other contexts.

Although the model was overfit (requiring a larger sample), several significant findings were discovered. The estimations indicate that:

- For every unit increase in postal code, apartment listings lost €268.99 in value.
- For every one km increase in distance from CBD, apartment listings lost €14,277 in value.
- For every one km increase in distance from the coastline, the apartment listing lost €15,080 in value. This equates to a €15.08 loss of value per metre away from the coastline.
- For every square metre of living area, apartment listings gained €8,079 in value.

- For every additional bathroom, the apartment listing gained €101,040 in value (€2,526 for every sq. ft of bathroom).
- For every floor level increase of the apartment, the apartment listing increased by €7,928 in value.
- Landscape gardening increased apartment listing prices by €79,250.
- No coefficient produced statistically significant evidence against the hypothesis (that GI has a positive association with apartment listing valuation).

These findings offer practical applications for the real estate industry. Strategies can be crafted to maximize apartment valuation by recognizing proximity to certain features and on-site landscape gardening. The findings support the notion that spatial and on-site GI increase property valuation. Planning officials can consider the findings a gauge of market demand in the city.

It is recommended that this HPM is improved upon and extended by including
1) sales data and
2) a larger sample size.

Enriching the dataset in this manner would reveal more significant findings about the market value of GI features in Helsinki. Further HPMs could be undertaken to assess the market value of other on-site sustainability configurations related to green building features and water management.

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Assessing the Environmental Performance of Waste to Energy Gasification

A Life Cycle Assessment

This study employs Life Circle Assessment (LCA) approach to assess the environmental performance of gasification using two main input parameters: (i) Feedstock inputs (Municipal Solid Waste and Refuse Derived Fuel) and (ii) energy or electricity inputs (national grid mix and internal source). The impact indicators used for the assessment are Emission to air, emission to freshwater, valuable substance, resources and deposited goods. CML 2001 impact category was also employed to assess the impact of the inputs parameters.

The results showed that the use of Refuse Derived Fuel (RDF) as the main feedstock has less environmental impact as compared to unsorted or untreated Municipal Solid Waste. MSW has a higher potential of contributing to air emissions, resource depletion and emissions to freshwater as compared to RDF. Again, MSW (untreated) has a higher impact on global warming, acidification, and eutrophication than RDF. Regarding the energy inputs, energy from the national grid mix has more environmental consequences than depending on the system's internal energy.

The study, therefore, recommends the use of RDF for waste to energy gasification plants. Also, it recommends the self dependency of gasification plants in terms of energy input to enhance their full environmental potential.

1 Introduction

Waste generation rate is a function of population growth and economic development (Tabasová et al. 2012; Singh et al. 2014; Heidari et al. 2019; Ramos and Rouboa 2020). According to Moya et al. 2017, about 1.3 billion tonnes of MSW are generated in urban areas annually and this is expected to rise to 2.2 billion tonnes by 2025 (Hoornweg and Bhada-Tata 2012).

As already indicated, sustainable waste management has become a challenge to governments and city authorities because of the higher environmental cost associated to its management. As reported by (Europa.eu 2022). Landfill waste management produces methane gas which is estimated to contribute about 86 times more to global warming than CO2 for 20 years. Varying environmental impact has been identified depending on the methods and approach of the study. However, one common environmental consequence of WtE technology (gasification) is the emission of Methane and CO2 as indicated by (Foster et al. 2021; Ng'andwe et al. 2015). Depending on the fraction of the feedstock, the syngas contains a relative amount of H2, H2O, and CO2. N2, H2, and some hydro-carbon substances like propane and ethane (Sarma et al. 2022; Ng'andwe et al. 2015).

Despite the identified environmental challenges of the gasification technology, it is still the preferable WtE technology because of its comparatively high potential for energy recovery and environmental performance, especially in comparison to incineration and landfill (Chu et al. 2022). This technology has been used over the last three decades and has the potential of reducing waste mass by more than 70% and volume by over 90% (Thakare and Nandi 2016; Moya et al. 2017). Again, gasification technology has a high potential for efficiently converting different types of waste into multiple products, such as syngas and char (Chu et al. 2022; Dong et al. 2018; Moya et al. 2017; Thakare and Nandi 2016). The combusting control mechanism of gasification process contributes to a significant reduction in the emission of carbon monoxide, Nitrogen oxide, dioxins and unburned compounds (Vaish et al. 2017).

The study aims to assess the environmental performance of gasification technology through the Life Cycle Assessment (LCA) approach. The environmental assessment is based on 5 selected eco indicators and CML 2001 impact category which consists of 11 environmental impact indicators presented by table 1. The above mentioned two sets of indicators were used to evaluate the four different input scenarios, namely (i) Base case scenario 1, (ii) Base case scenario 2 (ii) Refuse Derived Fuel (RDF) 1 (ii) Refuse Derived Fuel (RDF) 2 Scenario.

The objectives of this study are as follows

- Critically appraised relevant LCA studies through a systematic literature review
- Assess the compliance level of the LCA methods in the studies with the associated ISO standards.

- Conduct a Life Cycle Assessment on four different input scenarios of gasification
- Provide a comparative qualitative and quantitative inventory analysis based on the sampled data
- Evaluate and Compare the environmental impact of the four different inputs scenario based on the 5 eco-indicators
- Evaluate and Compare the environmental impact of the four different inputs scenario based on CML 2001 impact Category

1.1 Background

The management and treatment of waste have become a challenge for governments and city authorities because of the higher cost of managing the waste and its adverse environmental impact. In 2006, emissions from waste management accounted for 3–4% of greenhouse gas (GHG) emissions globally (Chen et al. 2020). As reported by (Europa.eu 2022), Landfill waste management produces methane gas which is estimated to contribute about 86 times more to global warming than CO2 for 20 years. According to (Theroux 2014), incineration creates a concentrated CO2 stream that contributes to potential future carbon sequestration. Considering the yearly production of 90TWh of heat and 39TWh of electricity in Europe, Energy recovery from waste can prevent the emission of up to 50 million tonnes of CO2 from being released into the atmosphere if the same amount of energy was obtained from the burning of fossil fuel instead. (Cucchiella et al. 2017).

In recent years, Waste to energy technologies has been considered the most acceptable approach to sustainably manage MSW because of their advantages over conventional waste management methods. WtE has the potential to offset some or all the economic costs in the long run and reduce/prevent the emission of hazardous substances such as carbon mono oxide, hydrogen, and Methane, which could be detrimental to the environment and human health (Vehlow 2015). The potential of waste WtE technologies goes way beyond fulfilling the first goal of waste management, as stated above. Modern WTE plants can contribute significantly to the conservation and minimization of material use whiles protecting the environment.

However, the question that arises from the application of WtE Technology has to do with how safe these safe technologies to the environment. To better understand the extent to which these technologies impact the environment, researchers have used various evaluation tools and techniques such as Life Cycle Assessment (LCA) and Analytical Hierarchical Process (AHP), etc. (Cucchiella et al. 2017). Also, different environmental indicators such as CML 2006, Traci, Eco event, etc. have been used by several studies to better understand the impact of these technologies on the environment. Several studies have identified WtE technology as an opportunity for long-term renewable energy production and climate change mitigation (Cheng et al. 2022; Ioannidou et al. 2022). Moreover, the technology is widely considered to be a way to jointly tackle the rising energy demand, waste management, and anthropogenic GHGs pollution. (Cheng and Hu 2010),

2 Methodology

Data on feedstock (MSW/RDF) was obtained through a review of (Montejo et al. 2011) which provided data on 10 Mechanical and Biological Treatment (MBT) plant located across the Castilla y Leon region of southern Spain. Castilla y Leon is the largest region in Spain with a total land size of 94,224km^2 and a population of 2.5 million. Data from this source was used to modelled four inputs scenarios.

Other supplementary input data such as oxygen, hydrogen peroxide, water, sulphuric acid, etc, were also obtained from (Ramos et al. 2018). The study used two main set of environmental impact indicators to evaluate the impact of the four scenarios. The first set is the 5 eco indicators; Resources, Valuable substances, Deposited goods, Emissions to air and Emissions to fresh water. And the second set is the CML 2001 environmental impact assessment Category, updated in 2016.

2.1 LCA Framework

This study employed LCA methodology in compliance with the International Organisation of Standardisation (ISO) 14040 and 14.044 standards which presented by figure 1 below.

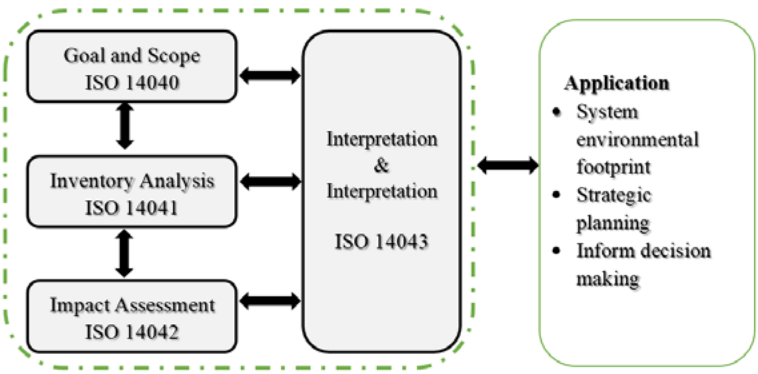

Figure 1. LCA Steps

2.1.1 Goal and scope definition

The general goal and scope of this research is to assess the environmental performance efficiency of a gasification waste-to-energy technology by modelling four different inputs scenarios. The system boundary is set to gate to gate. In other words, it starts at the point where the feedstock (MSW/RDF) is fed to the plant and ends at the point where the feedstock is converted to useful energy (heat or electricity). However, the environmental impact of other processes such as waste generation, collection, transportation, pre-treatment, and transmission were not included in the study. A functional unit of 1tonne was used in the scenario modelling. The analysis was carried out by Gabi Pro software (Version 9.2)

2.1.1.1 Description of scenarios

A. Base Case 1 Scenario.
The base case 1 scenario is a very typical case of operating a gasification plant. The main input parameters of the scenario are Untreated Municipal Solid waste as the main feedstock and energy from the national grid mix as the source of power the plant.

B. Base Case 2 Scenario.
This scenario is modelled with the assumption that renewable energy is used as the primary energy input to convert 1tonne of MSW into energy. This is helpful in the quantification of the potential environmental impact of MSW and renewable energy inputs scenario.

C. RDF 1 Scenario.
This scenario is modelled on the assumption that the feedstock for the plant is RDF and the plant depends on the national grid mix for energy to operate. The output of this scenario will enable the study to determine the potential environmental impact of converting 1ton of RDF into energy.

D. RDF 2 Scenario.
This scenario is based on the assumption that the main feedstock for the plant is 1 ton of RDF. Again, it also assumes that the plant is self reliance in terms of energy input. i.e. the plant runs on the energy it produces and does not depend on the national grid mix.

Other assumptions.
The study also made a general assumption that all other inputs quantities such as oxygen, nitrogen, water, etc. were held constant in all four scenarios.

2.1.2 Life Cycle Inventory (LCI)
At LCI stage, all relevant data on the material flow, energy inputs and outputs for every subsystem within the system boundary was collected. The main inventory are presented in figure 2 below. These inventories are adjusted and apportioned to the functional unit (1tonne of MSW and RDF).

2.1.3 Life Cycle Impact Assessment (LCIA)
The study used two main set of environmental impact indicators to evaluate the impact of the four scenarios. The first set is the 5 eco-indicators of the natural environment: Resources, Valuable substances, Deposited goods, Emissions to air and Emissions to fresh water. And the second set is the CML 2001environmental impact assessment Category presented by table 1 on the next page.

Table 1. CML 2001 Impact Category (ISO 14040)

S/N	Impact Category	Abbreviation	Unit
1	Abiotic Depletion Potential	ADPe	Kgsb eq.
2	Abiotic Depletion (Fossil Fuel)	ADPf	MJ
3	Acidification Potential	AP	KgSO2 eq.
4	Eutrophication Potential	EP	kgPO4 eq.
5	Photochemical Ozone Creation Potential	POCP	kgC2H4 eq.
6	Global Warming Potential	GWP	KgCO2 eq.
7	Ozone Layer Depletion Potential	ODP	KgR-11eq.
8	Marine Aquatic Ecotoxicity Potential	MAETP	Kg1,4-DP eq.
9	Freshwater Aquatic Ecotoxicity	FAETP	Kg1,4-DP eq
10	Human Toxicity Potential	HTP	Kg1,4-DP eq

2.1.4 Results and interpretation

This stage entails the assessment of the major contributions to the various impact categories. The interpretation is limited to the first stage (Goal and Scope) of the study. It also includes of the results.

3 Results

3.1 Comparing MSW and RDF

3.1.1 Material composition of Municipal Solid Waste and Refuse Derived Fuel

Figure 2 below indicates that the dominant material fraction for both feedstocks was organic matter, paper and cardboard and plastic which form more than half of the total stock for both the sampled MSW and RDF. Also, both ferrous and non-ferrous metals were reduced by 47% in the RDF as compared to the Municipal Solid Waste. The percentage of textile material in the MSW is higher (46) as compared to that of MSW (48.5).

Although the MBT plant had a dedicated container for recycling batteries, the sample data contained an insignificant amount of batteries with its percentage content in both the MSW (0.01) and the RDF (0.02) found to be negligible and did not reflect in the results of this study. From figure 2 below, even though the glass composition for both feedstocks varies significantly, thus its proportion is higher in MSW (32.8) as compared to RDF (4.8) representing an 85% reduction.

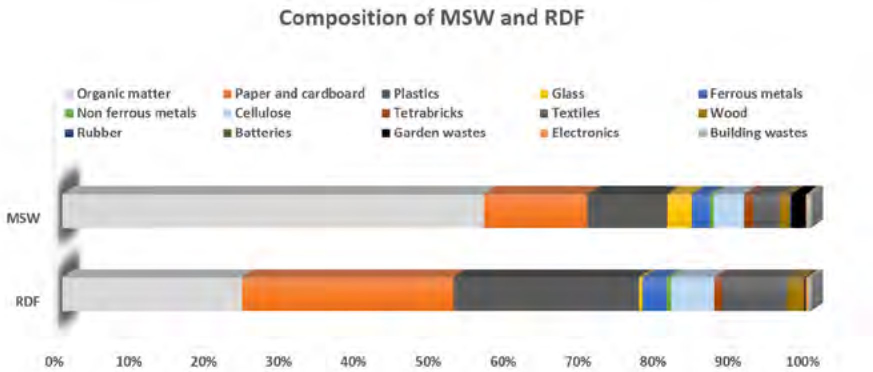

Figure 2. Composition of MSW and RDF

3.1.2 Moisture Content

Again, comparing the moisture content of both feedstock reveals both significant and insignificant variations. For example, the percentage difference of moisture content between plastic, paper and cardboard, textile and organic matter varies significantly i.e. 32, 70, 38 and 28 respectively whiles that of glass, metal and building waste were 6, 5, and 8 respectively. The overall moisture percentage of both streams has been computed as 46.46% for MSW and 22.07% for RDF.

The total environmental burden of the four inputs scenarios on the natural environment varies across the selected 5 indicators as shown in figure 3 below. Among the four cases, RDF 2 recorded the least impact. Contrary to RDF 2, Base Case 1 scenario which depends heavily on the natural environment for its inputs recorded the highest environmental impact. Again, Even though base case 2 uses MSW as its main feedstock, its environmental burden was significantly lower than RDF 1 which used RDF as its feedstock.

The overall findings of the aggregated results imply that the best inputs scenario for gasification of waste is RDF 2. Again, a comparative analysis of base case 2 and RDF 1 also shows the overall performance of converting 1ton of municipal solid waste with internal energy (BC 2) has a lesser impact than converting 1ton of RDF into energy using the electricity from the national grid mix. This optimal performance is represented by RDF 2 scenario

3.2.1. Scenario impact on the natural environment

Figure 3 below presents the environmental performance of the individual scenarios with regards to the five selected Eco indicators namely; Resource, Valuable substances, Emission to Air, Deposited Goods and Emission to Fresh Water. From the said figure, the most affected natural environment indicator is resources which constitute more than half in all the scenarios. Even though according to the aggregated impact results of the study, Base Case 1 had the highest environmental burden, its impact on resources was less than that of RDF1. Similarly, Base case 1 and RDF 1 had a significant impact on fresh water. Gasification in general has a less environmental burden on air. Despite the fact that the Base Case 1 scenario is the only scenario that contributes to air pollution, its contribution is highly insignificant as compared to others such as Resources and Deposited Goods.

Contrary to Base Case 1 which recorded no negative impact on the natural environment, RDF 2 recorded a very high performance in terms of emission to air. The figure 3 shows that all the scenarios did not have any significant burden on the deposited goods. RDF 2 recorded a negative impact making it the best performing scenario for this indicator.

Generally, the environmental impact of gasification on the natural environment varies across the different input scenarios. The results showed that RDF scenario when compared to MSW has far better performance in terms of air emissions.

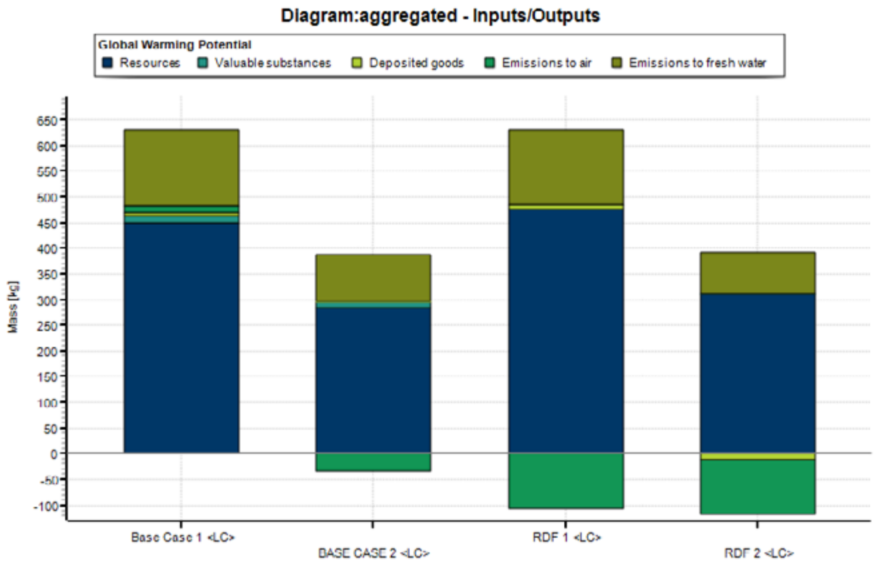

Figure 3. Scenario impact on the natural environment

3.2.2 CML 2001 Impact Categories

The environmental impact of the studied scenarios was again assessed using the CML 2001 impact to better understand the impact from a broader perspective. This CML method employs 11 impact indicators listed in table 1 above.

Figure 4 below represents how much each scenario contributes to the total impact category. It should be noted that even though the figure shows the percentage contribution of each scenario to the various impact categories, the specific contribution to some of the categories such as ODP, POCP and TETP inf. is insignificant in value terms. Again, the results show a general pattern across all the 11 impact categories. For example, the base case scenario has the most environmental burden as it contributes significantly to all the 11 impact categories whiles the RDF 2 shows the least impact
As shown in the figure below, the scenario with the least environmental impact is RDF

2 as it showed an insignificant amount in all the impact categories, especially in the case of ABD FAETP and ODP. Another key finding of the study was the evidence that factors that determine environmental performance varies with each scenario. For example, the use of internal electricity in Base case 2 and RDF 2 showed different results with the former having more environmental burden than the latter.

One major result was the impact on eutrophication. As shown in figures 4 below, all except the base case Scenario showed negative results. The negative results imply that certain substances that could contribute to eutrophication were either diverted or converted into useful resources or energy.

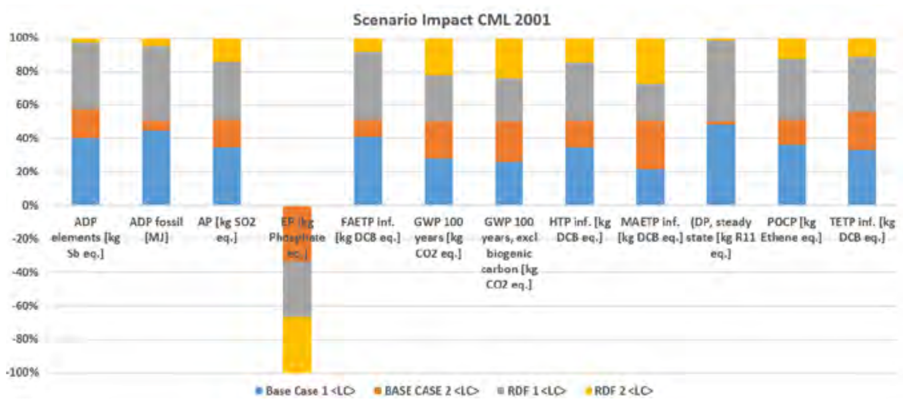

Figure 4. Scenario Impact base on CML impact categories

4 Conclusion and discussion

Gasification according to available literature is noted to be one of the most sustainable approaches to disposal and energy generation this is partly due to the higher temperature used as well as other benefits in terms of energy recovery emission control mechanisms. To fully achieve its potential, it is crucial to ensure that right and most sustainable inputs parameters are used otherwise, it expected potential will be compromised

Generally, this study is aimed at assessing the environmental performance of converting waste into energy (electricity) through the gasification process. This was achieved by assessing and comparing the environmental performance of converting 1tone of feedstock (RDF/MSW) to energy. In all the analysis was carried out based on four different input parameters (MSW, RDF, electricity from the national grid mix and self-dependence system). Using the Life Cycle Assessment (LCA) tool (GaBi). The environmental impact analysis was conducted to determine the best performing and the worst performing scenarios in terms of environmental impact. The assessment was focused on two main eco indicators namely natural environment indicators; emission to air, emission to freshwater, deposited goods and resources and CML impact categories which are listed in table 1 above.

After careful examination of the sampled data and four distinct inputs parameters/ scenarios, the conclusion and recommendation has been made based on the key finding and discussion of the results.

Conclusion base on the result. The study concludes that.

Feedstock
Holding all variables constant, different feedstock has different environmental burdens depending on the selected impact indicator this variation is due to the different proportion of material composition and other properties such as moisture content and calorific value of the feedstocks. By comparing both feedstocks, the use of typical municipal solid waste has a higher environmental impact than using Refuse Derived Fuel as the main feedstock for gasification. Unlike MSW, RDF has a lesser proportion of organic matter, a higher proportion of wood and a higher calorific value and combustible material.

Energy Input
Regarding the energy inputs, dependence on the national grid mix has more environmental consequences than scenarios where the process depends on its internal energy for operation. The energy from the national grid mix consists of different energy sources including the burning of fossil and coal and other non-renewables which has an environmental burden on the natural environment

Best performing Scenario (RDF 2)
The most sustainable input combination is the use of Refuse Derived Fuel as the main feedstock and internal energy as the main source of energy (RDF 2 scenario). Even though RDF as a feedstock has a better performance than Municipal Solid Waste (MSW), its potential is fully realized when it consumed the energy it produces and does not depend on the national grid mix. This Scenario performed well against all the 2 major indicators (5 Natural environment indicators and the 11 CML 2016 indicators) used in this study.

Worst Performance Scenarios (Base case 1)
The most unsustainable input combination is the use of Municipal Solid Waste as the main feedstock and electricity from the national grid mix. The study showed that both input parameters distinctively, has a relatively higher environmental impact and so their combination resulted in a higher impact against all the 2 main indicators (5 Natural environment indicators and the 11 CML 2016 indicator) used in this study

Even though RDF 2 is the best performing scenario, it is not entirely true across all the indicators. For example, RDF 2 had more impact on natural resources than base case 2. Similarly, base case 1 has the worst performing case, and had less impact on resources that RDF1.

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RATNAYAKE, CHANODI WICKREME

Analysis on Street Tree Planting Strategies as an Approach to Reduce Particulate Matter in Glasgow City Centre

In support of urban planning and LEZ

Particulate matter (PM) is the most frequent and toxic pollutant identified in urban street canyons for its adverse health effects. Street trees are an alternative, nature-based solution (NBS) which reduce PM by both deposition and dispersion effects. However, positioning the right tree in the right place is vital for optimum outcomes. This study critically investigates the role of street trees to reduce PM to support urban planning and policy constrains.

The investigations were conducted in a street canyon section of Glasgow City Centre. Using three-dimensional microclimate model ENVI-met, thirteen real-life examples were investigated to understand the impact of different in-canyon placement strategies of trees with effect of variables such as tree shape, porosity, size, species, and wind direction.

The results identified the effectiveness of trees to improve the air quality in Glasgow, limited to the physical geometry and wind flow within the street. It was found that a single row of leeward trees with significant canopy gaps based on the street canyon shape removes more particles compared to trees with a static distance. Findings of this research can be used to "bridge" the outcomes of Avenues Programme and LEZ strategies to "co-improve" Glasgow's air quality for a better future.

1 Introduction

Air pollution is one of the biggest environmental threats and health concerns of our time, with vehicular emissions being the major contributor in urban areas. Particulate Matter (PM) is the most frequent and toxic pollutants identified in urban streets (Pugh et al. 2012). As a proxy indicator it is often categorized based on their aerosol size, i.e., as particles with a diameter larger than 10μm (PM10) typically emitted from resuspension of road dust and wear on brake-linings, and as particles with a diameter larger than 2.5μm (PM2.5) emitted from vehicle tailpipes. Long term exposure to PM can cause respiratory infections, pulmonary and cardiovascular diseases, lung cancer, premature deaths, and severe outcomes from Covid-19 (WHO 2021b).

Many cities around the world have imposed policies to reduce atmospheric pollutant concentration. However, most of these actions are local measures based on traffic management systems, carbon-based vehicle tax systems, and low emission zones (LEZs) which typically prevents the use of high-emitting vehicles (McNabola et al. 2013). In recent years, vegetation has gained attention as a nature-based solution (NBS) to improve urban air quality through dispersion, deposition, and aerodynamics (Grote et al. 2016; Ysebaert et al. 2021). Bringing unique require to challenges, urban vegetation offers long-term solutions at a low cost along with other ecosystem benefits (Gallagher et al. 2015). However, effectiveness of such strategies is highly influenced by the development scale, microeconomy, geography and meteorology of the city (Nowak 2002; Liang & Gong 2020).

Therefore, in urban planning, positioning the right vegetation in the right place is vital for air quality enhancement and to avoid negative interfere with local air quality policies and actions plans. Although there is numerous research on street vegetation and air pollution, there is lack of knowledge on the effectiveness and suitability of vegetation to improve the air quality in terms of their characteristics, in-canyon placement, and spacing arrangements. Further, due to the paradoxes on the result it is unclear how increasing vegetation cover can potentially improve or deteriorate the air quality. Moreover, urban policies such as LEZ and NBS such as vegetation which are aimed to improve the air quality are often utilized separately, although they can be considered together for an enhanced effect. Hence, its combined outcomes are yet to be evaluated, and such understanding can be crucial for future city planning to improve public health, social well-being, and sustainable development of a city.

This study aims to critically investigate the role of street tree designs to improve the local air quality in support of urban planning and policy constrains, through assessing air pollution and mitigation measures, identifying vegetation configurations and placement strategies to formulate real-life scenario to improve air quality and quantifying the pollutant reduction potential of each scenario through ENVI-met software simulation. With interventions such as the LEZ and 'Avenues' concept in Glasgow, the simulation findings compresence the individual and combined effects of trees and street geometry on the neighbourhood air quality to devise street tree planting recommendations for avenues project and particle performances for the LEZ to "co-improve" Glasgow's air quality.

2 Background

Urban air pollution gained attention in Europe with 75% of its population living in cities (Sicard et al. 2021). Under European Green Deal's Zero Pollution Action Plan, European Commission has set goals to reduce premature deaths caused by air pollution at least by 55% in 2030 compared to 2005 (European Environment Agency 2022). Although air quality in European cities has improved over the past decade, around 90% of its population still gets exposed to pollutant levels exceeding safety limits (European Environment Agency 2022).

2.1 Emission Control Measures in Urban Governance

As outlined by McNabola et al. (2013), there are three approaches to control pollutants in cities; (i) policy tools to reduce emission quantity, (ii) vehicular technology to control emission intensity, and (iii) transport models to reduce congestion. As an approach to meet air pollution guidelines most European cities implement Low Emission Zones (LEZs), which typically prevents the entry of high-emitting vehicles into the zone (Ellison et al. 2013). Currently, more than 250 European cities implement LEZs to reduce PM10 and NO2 (Pestel & Wozny 2021).

Over the years, LEZs have been studied from different perspectives, such as its effectiveness, health, and wellbeing of pedestrians, environmental impacts, etc. Accordingly, studies in Germany (Jiang et al 2017), Netherlands (Boogaard et al. 2012) and Lisbon (Santos et al. 2019) highlights the effectiveness of LEZs to reduce pollutants and pedestrian exposure in targeted areas (Mudway et al. 2019). However, depending on the LEZ framework, diversity of pre-LEZ situations (bypass capacity, fleet composition, alternative transportation), and different behavioural changes induced by LEZs its outcome can vary (Lurkin et al. 2021). However, most studies highlight the need for more intense measures to improve the efficiency of LEZ (Gu et al. 2022).

2.2 Air Quality Enhancement Through Urban Vegetation

In urban environments, vegetation is studied and promoted as a viable, alternative solution to improve human health and local air quality. Over the years, many models have been developed for different scientific purposes to predict pollutant reduction capacity of urban vegetation. These models show that vegetation can alter the air quality through natural dispersion patterns and deposition effects influenced by meteorological condition, urban geometry, emission levels, particle sizes and characteristics of vegetation.

In a street canyon, air pollutants get dispersed away from traffic sources into the ambient air by the wind flow (Janhäll 2015). Hence, high porosity (low density) vegetation can be effective in local pollutant filtration as it allows more air to pass through it, whereas lower porosity (high density) vegetation can serve as a physical barrier and increases pollutant concentration due to low air penetration (Abhijith et al. 2017). Certain studies interpret such obstacles to dispersion as a cause for particle accumulation and human exposure (Beckett et al. 1998; Salim et al. 2011; Buccolieri et al. 2018; Tomson et al. 2021), whereas other studies show that, high density vegetation reduces human exposure by serving as a physical barrier between pollution sources and receptors (Gallagher et al. 2015; Jeanjean et al. 2016; Weerakkody et al. 2018; Abhijith & Kumar 2020).

On the other hand, airborne particles and gas molecules from the atmosphere can get deposited or absorbed onto vegetation (Janhäll 2015). Highly influenced by the aerodynamic effect, most pollutants deposit on leaf surfaces (Samson et al. 2017). Hence, leaf properties such as leaf shape, surface geometry, texture, seasonal changes, vegetation emissions, air pollution tolerance index, etc. directly determine the deposition capacity of the plant. Similarly, high porosity plants are known to have a higher deposition capacity due to its larger surface area per unit volume (Ysebaert et al. 2021). Leaf Area Density (LAD) which interprets the total one-sided leaf area per unit canopy volume (m^2m^3) describes the vegetation porosity on pollutant concentrations (Barwise and Kumar 2020).

However, due to long-term absorption of phytotoxic heavy metals, airborne particles and gaseous pollutants during the photosynthesis process can collapse certain vegetation species (Beckett et al. 1998). Conversely, many plants emit pollen causing allergies and hay-fever, and harmful gases such as volatile organic compounds, nitrogen oxides, etc. contributing to atmospheric pollutants (Samson et al. 2017). Hence, when selecting vegetation for air quality enhancement, it is vital to consider species that can adopt its stomatal structure to resist absorption and minimize emission of pollutants (Abhijith et al. 2017).

2.3 Air Quality Performance in Urban Street Canyons

An urban street canyon is the linear space within two parallel rows of buildings (Oke 1988). It is the basic unit of a modern city and interprets the concept of aspect ratio (AR): building height to street width ratio (Ysebaert et al. 2021). The particle composition on the leeward and windward sides of the street can highly vary based on the wind directions (perpendicular, oblique, and parallel flow), in-canyon wind flow, presence of obstacles, traffic accumulation, and aspect ratio (Buccolieri et al. 2011; Pugh et al. 2012; Voordeckers et al. 2021). Hence, due to its physical layout, pedestrians are most vulnerable to pollutants in street canyons.

In basic street canyon geometries, parallel winds are known to remove street level pollutants most effectively (Wania et al. 2012; Jeanjean et al. 2016), while oblique winds are found to be the least effective as it increases pollutants on both sides of the street (Gromke and Ruck 2012; Buccolieri et al. 2018). However, certain studies have identified contradicting outcomes for each wind directions (Berkowicz et al. 1997; Salmond et al. 2013; Huang et al. 2019). On the other hand, numerous studies show that during perpendicular wind episodes, pollutants largely accumulate on the leeward side, with slight or no reduction on the windward side (Pugh et al. 2012; Xue and Li 2017). However, it is not entirely clear how wind direction supports pollutant dispersion in street canyons.

However, all these studies conclude that the presence of vegetation greatly influences pollutant concentrations in street canyons and proposes different vegetation properties ideal for street canyons to improve the air quality. (Wania et al. 2012; Salmond et al. 2013; Vos et al. 2013; Janhäll 2015; Xue and Li 2017; Buccolieri et al. 2018).

3 Methodology

3.1 Study Area

Glasgow is the most polluted city in Scotland for PM and has been declared as an air quality management area for occasionally exceeding Scotland's safe limits for air pollution (IQAir 2022). Accordingly, to conduct the investigations, the research site was narrowed down to two street in Glasgow City Centre shown in Figure 1. on the next page. To determine the impact of various vegetation parameters on air quality, a north-south oriented Hope Street was selected as the 'test site' for being Glasgow's most polluted street for PM. To analyse the impact of existing vegetation on air quality and to validate research findings for practical implications, an east-west oriented Sauchiehall Street was selected as the 'control site' for being the only street in the city centre with trees.

3.2 Research Data Collection

Site analysis for Hope Street were focused on i) traffic flow and pedestrian activities; ii) emission readings from Hope Street's Kerbside Measuring Station and iii) AR calculations, while Sauchiehall Street analysis was focused on existing street vegetation characteristics (Swann 2020).

Further, air quality measurements were conducted on both streets simultaneously on four typical summer days to obtain PM emission data at a height of 2m, using two Smart Citizen 2.1 Kits, a set of modular hardware components that operate through network connection (Smart Citizen Docs 2022). The kits were used in offline mode, powered by batteries, and the data was recorded on micro-SD cards. During data analysis measured datasets were corrected considering the heat emission of the device (Camprodon et al. 2019; Mahajan et al. 2020) and were analysed against Kerbside datasets using correlation coefficient (R^2) and Root Mean Square Error (RMSE). However, due to an error encountered in the measured data, Kerbside Station records were employed as 'reference data' to carry forward the study.

3.3 Modelling and Simulations

To study the impact of vegetation on urban air quality the research employed ENVI-met 5.0.3, a microclimatic modelling software (Taleghani et al. 2020). ENVI-met has been used in similar studies to calculate the green infrastructure effect on air pollution (Vos et al. 2013; Paas & Schneide 2016; Viecco et al. 2021). In this study, pollutants were calculated by creating a user defined linear source in the Database Manager. The source was set to emit pollutants, at a height of 0.3m for all simulations, with background concentration interpreted based on minimum traffic hours.

Figure 1. Google Map and Images of Hope Street and Sauchiehall Street (Ratnayake 2022)

3.3.1 Hope Street Model Domain

Interpretation of the Validation Model

An ENVI-met model replicating a 400m X 420m area of Hope Street was created for the study. To calibrate the ENVI-met model, several models were simulated as Validation Models (VM) with different settings, until simulated datasets with an optimal agreement to reference temperature, RH, and PM datasets was obtained. Subsequently, the VM with the lowest bias, lowest RMSE, and highest R2 was selected as the Base Model (BM).

Scenario and Case Study Interpretation

The research framework for scenario formulation was developed based on, i) common vegetation parameters in urban planning, ii) requirements of Glasgow's 2021 Public Realm Design + Maintenance Guide, and iii) Sauchiehall Street vegetation analysis. Accordingly, the identified parameters were studied under two sections for Hope Street as shown in Figure 2.

The first section under the 'sensitivity study' investigated the impact of in-canyon placement and spacing effect of trees. Accordingly, six scenarios were introduced to the BM. The second section under the 'case studies' investigated the impact of common vegetation characteristics (size, shape, porosity, species, types) and wind directions. Accordingly, seven cases were introduced to the same BM. Each model contained four tree species in natural columnar shape identified at Sauchiehall Street with desired shapes and heights.

3.3.2. Sauchiehall Street Model Domain

To identify the impact of existing street vegetation, an ENVI-met model replicating a section of 250m x 290m was created initially as the 'Control Model' (CM) for Sauchiehall Street. Afterwards, a 'Sample Model' (SM) was created to verify reliability of Hope Street findings for implementation by simply replacing the existing trees in the CM with the ideal tree settings identified for Hope Street. For these simulations, measured temperature and RH and $PM^{2.5}$ data from the SCK was used due to the unavailability of a reference stations in Sauchiehall Street.

06 Scenarios	**Scenario 01** In-canyon Placement: Leeward Tree Height: *8m - 10m* Vegetation Spacing: *1.2m* No. of Trees: *56* Stand Density: *6.2%*	**Scenario 04** In-canyon Placement: Windward Tree Height: *8m - 10m* Vegetation Spacing: *1.2m* No. of Trees: *62* Stand Density: *6.9%*
	Scenario 02 In-canyon Placement: Leeward Tree Height: *8m - 10m* Vegetation Spacing: *6m* No. of Trees: *34* Stand Density: *3.8%*	**Scenario 05** In-canyon Placement: Windward Tree Height: *8m - 10m* Vegetation Spacing: *6m* No. of Trees: *33* Stand Density: *3.7%*
	Scenario 03 In-canyon Placement: Leeward Tree Height: *8m - 10m* Vegetation Spacing: *10m* No. of Trees: *28* Stand Density: *3.1%*	**Scenario 06** In-canyon Placement: Windward Tree Height: *8m - 10m* Vegetation Spacing: *10m* No. of Trees: *27* Stand Density: *3.0%*
07 Cases	**Case 01** Increased the height and width of the same trees to analyse the impact of size variations on air quality.	**Case 04** A different combination of tree species suitable for streets were selected based on pollution removal capacities to investigate the possibilities of using better trees.
	Case 02 The existing cylindrical crown shapes of the trees were altered to understand the particle behaviour change with spherical crowns	**Case 05** A row of hedges were added for the existing vegetation placement to understand the impact of increasing green cover through vegetation types
	Case 03 The existing ENVI-met settings contain low porosity trees at its sound stage. To evaluate the behaviour of particle dispersion and deposition the tree porosities were reduced	**Case 06 and 07** Case 06 investigates the impact of oblique wind direction (225º), while Case 07 investigates parallel winds (180º), as the selected scenario replicates perpendicular winds (270º).

Figure 2. Overview of the six scenarios and seven cases for Hope Street (Ratnayake 2022)

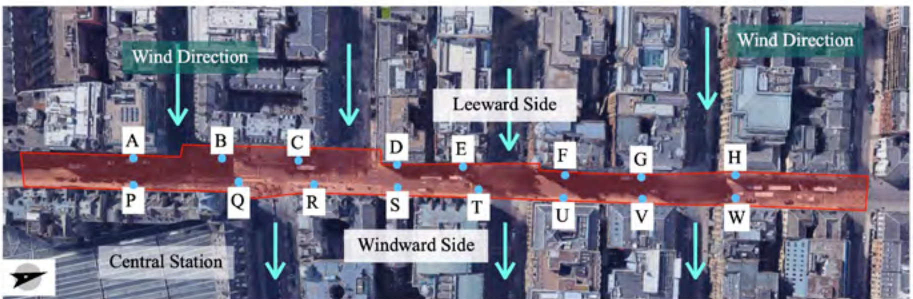
4 Results

4.1 Air Quality Measurement Analysis

During temperature and RH analysis, a notable derivation was observed in the measured datasets compared to reference data, due to the heating effect of the device. However, during PM analysis, identical values were observed for both PM10 and PM2.5 in the measured datasets although a notable variation was recorded in the reference PM_{10} and $PM_{2.5}$ for all four days. This imposed uncertainties on measured datasets. Similarly, studies indicate that SCKs can perform poorly during PM data collections due to the influence of RH (Smart Citizen Docs 2022). Therefore, the study employed reference data to carry out the research.

4.2 Hope Street Analysis

Hope Street simulations were conducted for 19th July 2022 with a recorded wind speed of 3.5 m/s in a perpendicular direction. To conduct a street wide assessment, pollutant concentrations were averaged over eight receptors along the leeward and windward pavements each in the street canyon as shown in Figure 3., at a height of 1.8m for all simulation models.



Receptors	A/P	B/Q	C/R	D/S	E/T	F/U	G/V	H/W
Aspect Ratio	1.72	1.01	1.01	1.02	1.68	1.51	1.71	0.92

Figure 3. Section of Hope Street used for the study, indication receptor points, wind directions and aspect ratios obtained at receptor points (Ratnayake 2022)

4.2.1 Sensitivity Analysis

Figure 4 illustrates the general overview of the relative difference of the day's averaged PM_{10} and $PM_{2.5}$ concentrations for leeward and windward sides for the six scenarios. Negative difference represents a reduction in PM, while the positive difference represents an air quality deterioration.

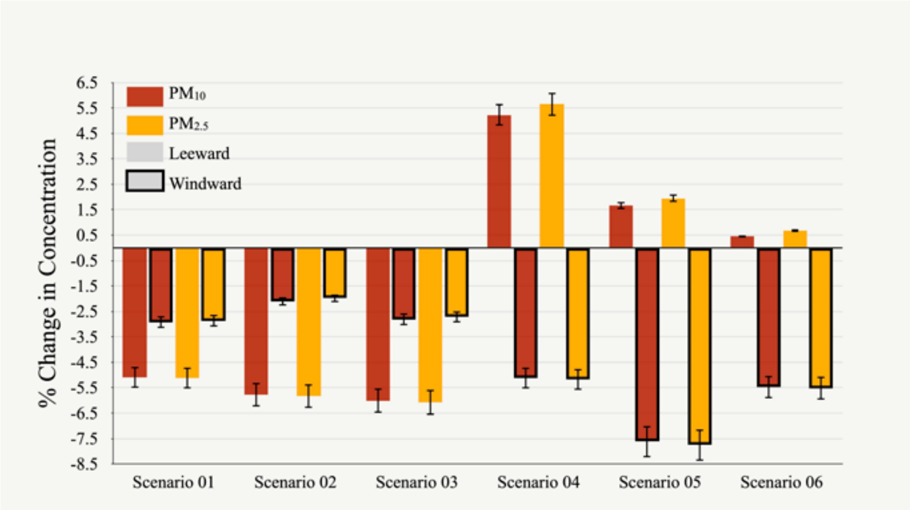


Figure 4. Percentage change in averaged PM_{10} and $PM_{2.5}$ on the leeward and windward side of the street compared to the BM for all 06 scenarios

The behaviour in PM10 and PM2.5 is similar in all scenarios. Highest particle reductions are typically found in vegetated pavements, as trees reduce PM closely around where they are planted (Jeanjean et al. 2016). Accordingly, leeward trees in Scenario 01, 02 and 03 removes particles on both sides of the street, likely due to undisturbed wind turbulence and higher air exchange. In these scenarios the deposition mass is higher compared to the BM likely due to aerodynamic effect influenced by wind turbulences.

Conversely, the windward trees in Scenario 04, 05 and 06 hinders the in-canyon wind flow and vortexes within the canyon and accumulates particles on the leeward side leading to a deterioration in the air quality. Overall, Scenario 05 reduces most particles in the given pavement. However, as Scenario 03 seems to reduce the most particles within the street it was considered as the suitable option for tree placing and spacing in Glasgow.

4.2.2 Case Study Analysis 5

The case study simulations were conducted for Scenario 03 by altering different plant properties and wind directions to investigate its effectiveness to improve the local air quality. Accordingly, all cases contain a row of leeward trees arranged at a distnace of 10m. Figure 5 represents the relative difference of day's average leeward and wind-ward PM for the seven cases.

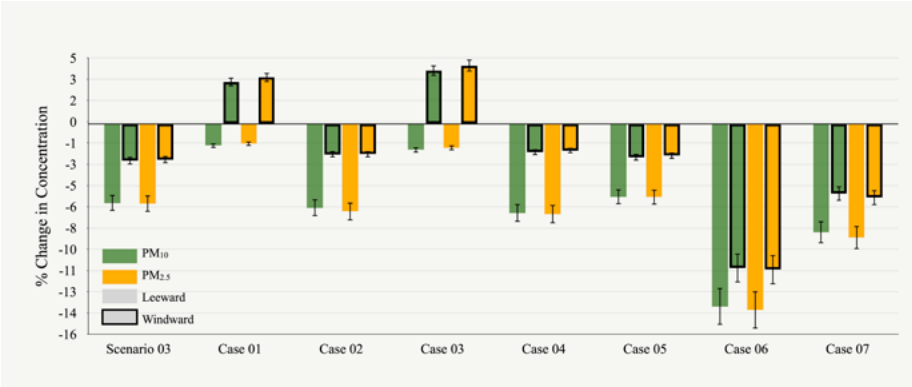


Figure 5. Percentage change in averaged PM10 and PM2.5 for Scenario 03 and the seven cases on leeward and windward side of the street compared to BM.

Case 01 with larger tree size and Case 03 with low porosity tree indicated similar results. As expected from previous studies (Gromke & Ruck 2007; Wania et al. 2011), larger tree and low porosity tree block the wind flow due to higher resistance to aerodynamics and foster particle accumulation in street canyons although the deposition effect has increased by 26% in Case 01 and 4% in Case 03 compared to Scenario 03. Overall, the tree configuration in Scenario 03 indicated a better air quality performance. On the other hand, Case 02 had similar results to Scenario 03 indicating that the canopy shape does not have a profound influence on the aerodynamic flow and particle dispersion.

Likewise, Case 04 with different tree species and Case 05 with combination of vegetation types indicated similar air quality enhancement patterns as Scenario 03. This showed opportunities to effectively implement different tree species and types of vegetation to improve the air quality in Glasgow. However, the overall performance of Case 05 is slightly lower than Scenario 03 and Case 04, likely due to reduced wind flows and velocities caused by increased vegetation cover. Hence, utilizing trees alone can efficiently improve the air quality.

Case 06 with oblique wind flow (225o) and Case 07 (180o) with parallel wind flow also indicated an improvement in the air quality as Scenario 03 which had a perpendicular wind flow (270o). In Glasgow, with south-west winds being the dominant wind direction, Case 06 indicated a better performance for air quality enhancement. Overall, all wind directions seem to perform well with the tree placement and spacing configuration on Scenario 03.

4.3 Sauchiehall Street Analysis

This section analyses the results from the Sauchiehall Street's simulation models which includes the Control Model (CM) with existing street conditions and the Sample Model (SM) with the adaptation of s-03. To carry out an assessment as the Hope Street, a perpendicular wind was assigned for the Sauchiehall Street models from south direction at a speed of 3.5m/s.

According to the result from the CM the simulated temperature, RH and PM2.5 datasets indicated a reasonable agreement with the measured data. As it ensured the validity of the model the SM simulations were conducted by simply replacing the existing windward trees with trees on the leeward side with canopy intervals of 10m in Sauchiehall Street.

Results showed that the introduction of trees on the leeward side of the Street has reduced the overall PM2.5 concentration in Sauchiehall Street compared to its existing vegetation layout, implying that under the right tree planting configurations, presence of trees has a significant impact on urban air quality enhancement and human exposure.

5 Conclusions and Discussion

5.1 Implications for Street Design and Policy Making

As the research methodology employed parameters and guidelines from Glasgow city development strategy, its findings provide a wider insight on street tree planting mechanisms for avenues and implications for the LEZs to improve the air quality and human health in Glasgow City Centre.

The wind regime is one of the critical factors for urban air quality enhancement using street trees. In Glasgow, the dominant wind flow ranges from south and west directions. Based on the research findings, it is ideal to place trees more towards the leeward side of the street canyon to enhance its air quality in the North-South oriented Hope Street. Ideally designing cycling tracks and pedestrian walkways on the same side as the trees can also provide safer and healthier commuting experiences for pedestrians and cyclists. As the city centre layout follows a grid pattern this provides an insight on how trees can be placed in East-West oriented streets as well.

Most importantly, tree canopy gaps should be assigned with respect to its canyon geometry. That is because, planting trees near street intersections or building setbacks in shallow canyons can obstruct corner eddies. Similarly, in deep canyons, closely placed trees can obstruct in-canyon wind flow. These can discourage natural dispersion and accumulation particles at street level. It is also worth mentioning that, densely placed row of trees should be always avoided as it can trap particles and deteriorate the air quality. Further, it is advised to implement these guidelines by considering the potential changes to the urban morphology in the future to make the strategies time-dependent (for short, medium, and long-term).

In terms of tree species, currently, Acer platanoides ‘Deborah’, Acer campestre ‘William Caldwell’, Carpinus betulus ‘Fastigiata’ and Ginko biloba can be identified in Sauchiehall Street. According to the research findings, combination of species such as Tilia, Sorbus and Pinus that can also be used to enhance the air quality. However, it is ideal to maintain the trees at 8m-10m heights with a crown diameter between 3m-5m due the street canyon geometries in the city centre.

In addition, policy makers can consider trees linked with existing polices and advancing technologies to mitigate air pollution based on the current air quality requirements under the AQMA in Glasgow. Considering the studies conducted by Glasgow City Council and the findings of this research, in combination a 92% of NOx, and 33.5 of µg/m3 in NO2 can be reduced in the city centre. In PM, Glasgow's LEZ expects an emission reduction in vehicle tailpipes, neglecting emissions from tyre-wear, resuspension, and break-lines which can still happen in vehicles with Euro Standards and electric engines. Accordingly, implementing trees can reduce an additional 10% of PM10 and PM2.5 from the existing streets and help the emissions to be within the Scottish safe limits for air pollution.

5.2 Limitations

The nature of this study is complex and multidimensional, with endless aspects that deserve careful research. Even in simple configurations, air quality assessments are complex, and the conclusion of this research was influenced by several limitations based around roadside PM concentration, data collection, research scope, software model configurations and constrain on time and equipment.

5.3 Conclusions

Air quality trends demonstrate the need of mandatory policies and strategies to tackle air pollution for more profound outcomes as cities and traffic congestion continue to grow (Liu et al. 2022). When evaluating the placing and spacing of trees in a street canyon, it is important to account the street canyon shape, as it plays a crucial role on the local air quality.

In conclusion, overall results of this study show trees as an effective solution to improve the air quality in Glasgow City Centre, however, limited to its physical geometry and meteorology. Further, findings of this research which focuses on optimum street tree planting strategies attributes to the Avenues Programme and the LEZ to "co-improve" Glasgow's air quality, as it is currently unknown by the city planners. Hence, policy makers can utilize trees as a tool in street canyons to regulate policies based on the research findings to "bridge" air quality mitigation strategies as well. However, it needs to be carefully assessed along with other benefits to eliminate the challenges in air quality enhancement.

Further, research findings can also be extended to similar Scottish urban centres as they contain similar urban structures and meteorological conditions. In addition, as Glasgow is also one of the most vulnerable cities to climate change (IPCC 2021) and as climate change and air pollution are interlinked in a broader scale, nature-based solutions addressing air pollution can ultimately provide direct and indirect benefits for climate vulnerabilities and aid Glasgow to become a climate resilient sustainable compact city by 2036 (GPR 2020).

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Resistance to -systemic sustainable- change in decision makers of cities and industries

Causes and possible ways to overcome it, in a Latin-American developing environment

This study aims to expose and explain the relationship between Sustainable Management and Resistance to change, providing tools and skills to identify and manage it in decision making, appreciating its relevance in the structural climate inaction, especially in the context of Colombia. The conceptual proposal is based on Harich's statement (2010) about the fact that the resistance to change of the system itself is the root of the great global environmental challenges. A Literature Review was carried out to learn about the background and relationships between Sustainability Management, Change Agency, Resistance to Change, and vested or private interests. Through interviews and survey, experts, decision makers, consultants and others who work influencing the implementation of sustainability high impact solutions and policies, participated in order to confirm and complement the findings of the literature. The most important barriers to making sustainable decisions can be framed in fear, hidden or secondary interests, oversized preponderance to the economic aspect, inflexible legal frameworks, and established thought models and paradigms.

The conclusions advise how the main tools: knowledge and strategy, pedagogy and communication, participation and transparency, can contribute to transforming the institutional and legal framework, and therefore, the market and the economic model.

1 Introduction

Sustainable Management is not and has not been the dominant management model. The unsustainability of cities and industries, of the production of most goods, the transport, and energy model, is the main cause of the climate crisis and an evident and overwhelming reality, about which science began to warn at least six decades ago.

The Stockholm Conference (1972) and the later resulting Brundtland Report (1987), agreements such as Kyoto (1997) and Paris (2015), and a number of summits all years about Urban Sustainability and related topics have seemed to be the stage for decision makers of governments and industries of the world to react, and act in regards of sustainability as an inherent characteristic of development; after all, the survival and quality of life of the human (and the other) species depend on it. But the reality is that, amidst declarations in events on a larger and smaller scale, there is no big magnitude action for change, or the paradigm shift towards regenerative development that is needed.

The concepts of sustainable and smart cities are still very incipient, more evidently in developing countries, where agendas don't advance and where most high-impact solutions are not being implemented or taken into account, despite their social, environmental and even economic viability and benefits. Why is it so?

Bauer (1992) stated, there would be certain trajectories of change that are resisted, and Harich (2010) affirms, the root problem of the great global environmental challenges that needs to be solved first is not "the ways of living sustainably", but the resistance to the change of the system itself. This is a statement of the greatest relevance for the paradigm of Sustainability Management in organizational, governmental, technical, and ethical terms.

In that sense, resistance to low carbon transition (Geels 2014) or to what could be called Sustainable Systemic Change, needs to be identified, unraveled and addressed, in order to lead the change that is needed and achieve a successful and sustainable management of cities and resources.

Who are the actors of this resistance, what are their drivers and how can those be managed, are some of the interests of this study, as well as showing the existing relationship between corruption -as a widely studied barrier to sustainable development, especially in developing countries (WWF 2022; Ganda 2020; Imasiku 2020) - and this resistance to change, where power relations and the interests of the actors involved define whether there is a sustainable and efficient model at the urban and industrial level or not, beyond the technological availability and technical development reached.

Although it may be difficult to discuss these issues and barriers -in an academic context-, due to their social nature, it is a challenge that must be assumed in order to approach the possibility of an energy transition, low carbon economies, mitigation and adaptation to climate change, among others, in short, Sustainable Urban Management. That is why this study aims to identify and address resistance to sustainable change as a real challenge, and to propose tools or skills to overcome it.

2 Background

2.1 An Unsustainable Management Paradigm

Talking about sustainable management is –in short- talking about the balance between natural resources and human needs. The fact that human activities have degraded two thirds of the world's ecosystems (UN 2008) creating the fastest extinction rate in 65.5 million years due to poor resource management (WWF 2022) tells well about the current managerial, economic (oikos-nomos from the management of the house) paradigm.

The figures from the IPCC, have been the most compelling call to transform the current unsustainable linear and brown model. 192 countries plus the EU, agreed to make great efforts to reduce emissions by 2030 in the Paris agreement (2015). Nevertheless, citizen movements, experts and NGOs denounce climate inaction and lack of ambition, and the ECLAC (2015) confirms that the processes required to limit the warming rate to no more than 2ºC are not in place. The last report of the IPCC (2022) states that the harmful carbon emissions from 2010-2019 have never been higher in human history; and the earth overshooting day is sooner every year.

This expose the incoherence between the commitments and actions, and the incomprehension of the need of immediate and significant changes in the existing development patterns, the energy mix, regulations, economic incentives, etc. in order to meet the emission targets (ECLAC) passing by eco-efficiency, towards regenerative development (Pedersen 2009) in a systemic, structural –and radical- **change**.

The people who work to make this change possible are Sustainability Managers.

There is little literature about **Sustainability Management** (SM) and institutionalizing it is still under-researched (Lozano & García 2020). SM is recognized as a new approach to organizational management combined with environmental policy (Cohen 2011; in Law Explores 2016), in an effort to correct modern management, moving it away from the abstract world of financial manipulation, to the concrete world of physical resources and constraints, recognizing the human dependence on nature and the economic prosperity on the health of the environment (Law Explores, 2016).

While the OECD (2015) remarks that lack of information remains a key obstacle to –sustainable- decision making, Tantram (2022) states that "when sustainability managers offer the key information or provide a solution, they are often hampered by resistance, apathy and misunderstanding; as sustainability is not owned by the organisations, and it needs authority to thrive in them".

It could be said that SM is a process of **decision making** about the allocation of natural and artificial resources (Barrow 2006), increasing the long-term "thrive-ability" of human and nonhuman phenomena (Starik & Kanashiro 2013). This perspective is totally insightful for understanding SM as something inherent to decision making, and vice versa.

There is a growing momentum behind these practices, especially in well-managed corporations and sophisticated municipal governments (Law Explores 2016).

2.2 Sustainable Managers as agents of change

In order to make possible the shift of paradigm, change theories and strategies need to be applied and to have ambassadors.

According to the ACPA's literature review, and Starik & Kanashiro (2013) sustainability managers and change agents share values like resilience, ethics, capability of creating systems and relationships between actors, and both short and long term vision, altogether with optimism despite the fact of being also realistic and objective, cognizant of the context.

In the SM ecosystem there are not only managers but inventors or innovators, scientists, and entrepreneurs that could be called "Sustainers", who create and offer viable solutions to accelerate the curve of the adoption of a new, regenerative paradigm. The fact that these solutions are not being applied at scale is structural inaction, and the "elephant in the room".

2.3 The concept of Resistance to Change

Kurt Lewin proposed RtC in 1940 from an organizational perspective; nowadays psychology states that resistance or support to change are associated with values, habits, and mental models within the individual (Harich 2010).

Bauer (1992) showed that the most frequent associations with RtC were fear and anxiety, followed by bureaucracy, and conservatism. Both for organizations and societies, change could be promoted by the establishment as a source of instability, and authors like Guest (1984; in Darmawan 2020) define resistance as an "attribution from a position of power and agenda setting", which is why this study approaches mostly the Political kind of resistance (that can be also Technical and Cultural [Karaxha 2019]). Bauer (1992) states that change is always happening, and what is resisted is certain trajectories of change. The crucial question is: what kind of change is resisted?"

2.4 Resistance to change and sustainability

> *"Actors use power and politics to resist fundamental transitions to new low-carbon systems"*

Geels (2015) points out how important it is to seriously study "incumbent" regime dynamics, rather than focusing only on green niche-innovations; and to conceptualize the regime actors as actively resisting fundamental change, rather than seeing them as an inert or passive part. Both Harich and Geels, state that large corporations overwhelmingly influence legislation. Here, the **moral and ethical** *dimension of work is prominent* (Karaxha 2019).

The WEF and UN point out that corruption endangers all the 17 Sustainable Development Goals and highlight the need to recognize the full complexity of it – its causes and effects – to fully address the underlying structures and dynamics.

2.5 Corruption and Resistance to Systemic Sustainable Change in Developing Countries

The prevalence of clashes between long-term sustainable investment and immediate gains or profits with governments is a source of concern and worry. Corruption is one of the greatest barriers to sustainable development (Imasiku 2020) and to improving the state of the natural environment (Ganda, 2020).

The OECD (1997) states that corruption has high impacts in less industrialised countries and the World Bank points out that for most growing economies that have large reserves of natural resources, corruption is widely known as the major cause of natural environmental destruction. Also the ECLAC and UNEP (2022) sign that Sustainability is compounded by vested interests in the unequal distributional structure, among a variety of institutional shortcomings, and Akhbari & Nejati (2019) and Ganda (2020), demonstrated that *in developing economies corruption increases emissions*.

3 Methodology

This is a qualitative study, with a mixed strategy, formed by a Literature review, survey, and interviews.

The Literature Review provides:

1. A context for the hypothesis and the other methods of interaction with the participants, and for assessing the data resulting from these interactions (surveys, interviews), with respect to relevant information from the field of knowledge or key concepts until now.
2. The tools and knowledge already synthesized, to the outcome of the study and one of its objectives: an instrument to understand and manage the relationship of sustainability management with change agency and resistance to change, making visible the role that vested interests play in this relationship, beyond known but -according to this study- secondary barriers such as financial, organizational, technological, or technical; at least, in the context of a Latin American developing country.

3.1 Interviews

Closed and open questions in exploratory interviews –with a basic common framework- were oriented to:

- Current decision makers; public and private leaders and "signers" of contracts, approvals and recommendations, and institutional officers. (Leaders of sustainability, Ministers and Secretaries, Majors and Governors)
- Former decision makers
- Researchers and referents of inter-institutional relations, economics, politics and sustainable development.
- Persons dedicated to influencing the implementation of high-impact sustainable solutions and public policies.
- Out of the eight people contacted, four replied positively: two Decision Makers (one current Secretary of Environment and One Governor), one former decision maker (Secretary of Government until May 2022) and one world reknowned expert (creator of the concept of Blue Economy).

3.2 Survey

Closed and open questions were applied to:

- Innovators and Entrepreneurs working in solutions for sustainable management and decision making
- Current and former collaborators of relevant public and private entities in middle or high positions or areas related with any kind of decision making about technical implementations and purchases.

Due to the very niche characteristics of the profile requirements, high level job profiles and little availability, the number of respondents is 14, out of 30 invited to participate. As an addition to these methods, a Focus Group was held with 4 people who work with incidence in sustainable management and decision making, addressing the topic of Resistance to Change (RtC). The insights were processed and coded even though the Focus Group has not been an official method because the number of people or sessions is not significant (the 15 high profile invitees replied to the invitation, unfortunately only four were able to attend and the rest were excused).

Quirkos qualitative data analysis software was used to group and code the results of all the methods, based on the **axial coding** from the grounded theory (Corbin & Strauss 1990).

3.3 Approach

The entire study first follows a **deductive** path, from the macro of the theories and background, to the micro of the breakdown of its elements and the interactions with the participants. Returning from here, in an **inductive** path, towards the synthesis of the theory, and its provision in a new instrument, a "tool-box" to understand and manage resistance to change in Sustainability Management and the relationship with vested interests in the context of this **descriptive and analytical** study.

Figure 1. Thematical Selection (Mejía 2022)

Although the purpose is mainly to **apply some theories** such as Harich's (2010) statements that resistance to change is the crux of environmental challenges, it is also expected to contribute to the **foundations of Sustainable management**, of which there is not much literature in itself, creating its connection with change management, and resistance to change; and between this latter, and vested interests, proposing, as a practical and useful conclusion for the ecosystem, a hierarchy of barriers to "sustainability", -or in this case, to sustainability management-, already identified by other scholars, in order to gestate the real change and transition.

4 Results and Discussion

> *"We make paper from mining waste.*
> *That creates massive resistance*
> *from the traditional paper industry"*

The literature review and participants legitimized the **relationship between Sustainability Management and Change Agency**.

92.9% of the surveyed ISDM identify themselves as change agents, and 85.7% notice Resistance to -Systemic Sustainable- Change Often, or All the time, mostly in the public sector (57.1%), which might be related with its usual bureaucracy and conservatism.

4.1 Sustainability Managers and RtC

> *"I surf waves, I don't make waves,*
> *If there is resistance, I'm not there,*
> *I don't convince anyone"*

A central figure of Sustainability declared in respect to RtC he doesn't "create a wave of change" but only "surfs it when available".

This means important actors who could exert great influence on the resistance are not contributing to the structural, top-down Change (in capital letters, systemic, radical), but are doing businesses in a localized way (lowercase, incremental, change) creating leakages in the collective effort.

Sustainability Agents then relate differently with RtC. From "the surfer", that intervenes only where the chances are good; to the "activist" (entrepreneurs, innovators, independent consultants, scientists), who insists, and transforms the message and the strategy to achieve central change.

4.2 The Values of Sustainability

Starik & Kanashiro (2013) describe a set of "sustainability values" that contribute to the maintenance of life processes and efficiency: Innovation, learning, collaboration, tenacity, durability, adaptability, rationality, empathy, responsibility, among others. Many of these values, are also assigned to Change Agents.

4.3 -Non-evident- Barriers for sustainable decision-making.

The 201 codes yielded 4 main categories: all of them, alien to the nature of sustainability.

Fear	The Natural (Psychological) reaction of Fear of Change Distrust Legal Consequences Economic Consequences Social Sanction Institutionalized Fear
Models and Paradigm	Cultural Model (Habits and models of thought) Predominant Narratives Competition, Exclusivity, Confidentiality Ethical model and Rights Economic Model Legal Framework The Market Land Use Model Institutional Models Procurement Scoring Systems Lack of vision and understanding (short term view) Bureaucracy Administration Changes and Timeframes
Vested interests, convenience and ethics	Rigged Public Policies and Laws Regulatory Capture (Culture of) Corruption and Hidden Interests Lack of comittment, Indiference (EGO) Unbalanced preponderance to economics (wrong priorities) Conservatism despite Negative impacts (RtC) Power, Politics (and Economy) The Negative Feedback Loop Corruption-Natural resources
Lack Of Knowledge	There is a lot of ignorance. Mechanisms to implement solutions are often unclear Unclear whether capacities should be built in-house or should be subcontracted Weak business cases Communities lack knowledge that allows solutions appropriation

Figure 2. Barriers to Sustainable Managing and Decision Making beyond viability and readiness (Mejía 2022)

4.4 A legal framework with no chances for sustainable change and innovation

"The truth is that many public officials
make decisions based on fear
because this type of decisions
can end up putting you in jail"

The paradox of Colombia is to be pioneer in laws in the region but having so many regulations and entities that bureaucracy and lack of articulation makes it hard to act towards success stories, and a new economy.

Excessive surveillance

Too many control entities, based in inflexible protocols, create a very small margin of action, and increase fear in decision makers of legal or economic consequences. Despite the multiple green policies, the practice is defined by the public contracting and procurement law (Law 80), which prevents improvements in sustainability in different ways.

Scoring Systems of procurement, and Competition principle

In the bidding processes, innovative proposals:

- Show "documented uncertainty", reducing their chances.
- If they are not cheaper than the current practices, they won't be favoured.
- If they do not have competitors, they cannot be contracted or purchased directly, since control entities would judge it as favouring.

No space for creating incentives.

International experiences show that incentives like free collecting of biowaste are key to achieve behavioural changes, but in Colombia it is prohibited to provide public services without charge, which blocks the possibility of creating new dynamics.

The wide concept of convenience and vested interests

The results show that corruption is only a nuance of a model with poorly established priorities, with overvalued preponderance of the economic aspect, weighing better quick profit than wellbeing, prioritizing individual rights (EGO), over collective rights (ECO), to the detriment of what is responsible, or even efficient.

4.5 The impact of vested interests in the sustainable decision making and management

> *"For most growing economies that*
> *have large reserves of natural resources,*
> *corruption is widely known as the major cause*
> *of natural environmental destruction*
> *and it increases emissions".*

Most of the respondents located the importance of corruption, convenience and vested interests as a barrier to sustainable practices, in middle levels (being 5 the highest) with a small majority in level 4.

The ethical problem is subtle and wide, showing itself from open acts of blackmail, to the convenient handling of contracts, and laws to resist sustainability.

4.6 Regulatory Capture

> *"I cannot change the contracts*
> *until I am clear about how I solve the business*
> *for them, otherwise, what I take away is*
> *a crazy number of lawsuits"*

Regulatory Capture happens when traditional providers shield behind existing laws or contracts so as not to be replaced, asked to adapt, or invest in better technologies, materials, etc. perpetuating the linear, unsustainable practices, alleging menace to their heritage and "economic freedom".

Very often these contracts (such as waste collection and landfill management) are longer than the government periods so they prevent urban change in the framework of a government programme. This could be tackled with **contracts conditioned by objectives and results**, responsive to cleaner and more efficient ways of accomplishing them.

> *"The powerful have the facility*
> *to protect the laws*
> *that protect their interests"*

The fact that the existing legal framework legitimates the status quo, makes it complex to show the impact of particular over collective interests.

It is crucial to acknowledge this, conceptualizing the regime actors as actively resisting change, rather than seeing them as passive actors not supporting it (Geels, 2014). This is a significant contribution to the way of doing SM.

A Systemic Change is mostly not happening as there is no Leadership in governments and industries to take forward the endeavor it requires. The solutions look complex and unreachable because the institutions work from comfort, and resolution of day to day situations.

Without long term consequences understanding, and a clear value scale, there are not sense of urgence and drivers for acting intensely, locally and globally, (as in the Covid pandemic). There is a great lack of commitment, lethargy and inertia, both collective and individual, that bring a cycle of lack of cooperation constituted by indifference, or resignation.

4.6 Skills and Tools to create Top-down SSC and deal with resistance to it among decision makers

The coding of all the tools from the literature and other methods yielded a pool of tools categorized into 7 main, and 4 auxiliar categories.

Knowledge and Strategy	Acknowledging and identifying RtC	Communication & Pedagogy	Show success stories	Political & Institutional	Negotiations and agreements
	New mental and attitudinal models and narratives		Create good and new narratives and values system		Incentives and subventions systems (based on new narratives)
	New goods and services supply chain models (energy, mobility).		Teach tools and skills for transiting		Technical assistance
	Develop or improve negotiation skills		Spread a long term mindset and its relevance		Climate finance linking public and private resources
	Know the interests of the different actors		Expose Nature and Climate as a key risk to manage		Sectors feedback to public policies in order to promote sustainability projects
	Know and offer solutions and participation for all the actors in the system		Broadcast systemic thinking		Bioregional approach
	Master the knowledge of the economic implementation mechanisms and		Distribute educational materials for a basic concepts and terms understanding		Climate Finance Market Participation
	Master the knowledge of the economic consequences of not transiting to a low carbon economy		Show economic consequences of inaction		Nature and Climate risks management
	Create good environmental costs analysis models		Diffuse environmental, social and economic diagnosis of alternatives		Socio-environmentally responsible institutions and legal framework
	Green chemistry, science, techniques and technologies		Promote a balanced and equitable approach of Social, Environmental and Economic aspects in all public and private instances.		Good environmental costs modelling systems for public purchasing decisions
	Smart and whole weighing of risks and opportunities		Design Pedagogical strategies for all sectors and audiences		Long-term institutional positions and policies (independent of politicians in power)
	Environmental, social and economic diagnosis of alternatives		Empower communities -with knowledge- to oversee public expenditure		Strengthening institutions and governance systems
	(Overcome obstacles to) Create Successful examples		Encourage communal schemes of resources management		Monitoring of the results
	Long Term Strategy		Involve all actors and offer renegotiation instead of exclusion		Coercion or legal pressure
	Innovation Strategies		Break the myths: Show how alternatives cut costs, multiply jobs and optimize profit and productivity.		Resolve the duality of Collective Rights over, or vs. Individual Rights
	Knowledge difussion strategies		Share ecosystems approach creating a bigger scope for the businesses		A transparent system of public procurement and bidding
	Quality processes				Open legal framework to innovation and best practices
	Procurement laws and contracts that favour results and not specific technologies				Participation and overseeing mechanisms for legal framework
					State support to disruptive business models and solutions

Figure 3a. Skills and Tools to manage resistance to SSC (main categories) (Mejía 2022)

Leadership
Managerial support and effective leadership
Involvement and empowerment of the different actors
Generate interactions between stakeholders that allow to overcome administration changes.
Promote a change of paradigm from EGO to ECO.
Leaders networking for maximum impact and easiness of decision making
Transform the resistant actors in participants of change
Optimize resources and impact

Innovation
Ideas and innovation must be available to public and investment funds
Product, social, and public innovation strategies
Prepare market and legal framework for innovation
Widen traditional core businesses through innovation
Make innovators competitive in the market
Create success cases, surprise key decision makers
Take innovation results from the academy to the industry
Close cycles and generate value
Innovate with what is locally and regionally available

Networks
Generate interactions between stakeholders
Promote institutional systemic action
Create collective and inclusive plans and strategies
Every stakeholder contributes and take
Ideas and innovation available to all actors
Pursue science based targets
Strenght digital effective participation based in social networks
Create collective visions that enhance trust in change
Encourage communal schemes

Transparency
Participatory culture
Innovative and flat management structures
Governance
MRV mechanisms (Measurement, Report and Verification)
Effective channels for whistleblowers
Specialised due diligence
A transparent system of public procurement and bidding
Political overseeing
Human centered design
Open sources of information

Figure 3b. Skills and Tools to manage resistance to SSC (auxiliar categories) (Mejía 2022)

Tools can, like barriers, be classified, in order of importance into: governmental, financial, market, managerial -attitudinal-, organizational, informational, technological and skills . These tools, and the knowledge of the pool of barriers, can help individuals and work teams to tackle situations difficult to identify and approach, prioritizing solutions and designing strategies to improve from the business, organizational and institutional.

5 Conclusions and Recommendations

Acknowledging there is a resistance to a Systemic Sustainable Change is key for creating better and more assertive Sustainability Management and ensure articulated endeavours to counter the ecological crisis can bear fruit.

Awareness on the negative feedback loop Corruption-Less natural resources must be raised and generate different dynamics of power, production and consumption.
RtC is mostly systemic. There is no long-term vision in the institutions, but there are long term contracts that block the possibilities of change, and the current legal and institutional frameworks favour the status quo (regulatory capture). The right actors of the system might give space to change in the system, but to increase the chances of these decision makers contributing to sustainable change, the risk involved in making decisions must be divided or dissolved.

Urban Sustainability is seen as a luxury, especially in developing countries; it would gain support and legitimacy by tackling the main social and economic issues of the population like poverty, hunger, habitat and employment. This, with good environmental-costs analysis models and diffusion of successful and cost-efficient solutions would reduce skepticism and activate participation and empowerment.

Altogether, communal and Top-down schemes are needed simultaneously, both with pedagogy, governance and transparency. Sustainable Management is a form of decision making and needs to come from the centres of power. It is a vision of a system, the reflection of the values that move it or on which it is BASED.
The relationship RtC-SM is schematized in Figure 4.

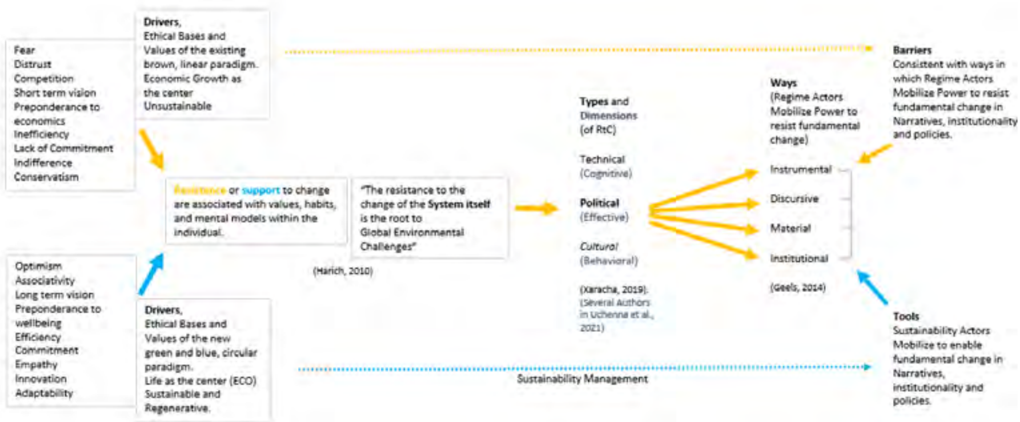

Figure 4. Breaking down the relationship RtC-SM (Mejía 2022)

Understanding that the management of the resources and the design of an economic model is an ethical matter is key to understand the values and drivers of the actors of resistance to sustainable change. All the barriers are derived from the ethical bases and priorities of the current paradigm and dominant narratives.

Resistance is essentially political and dwells at the centre of the system and the agendas of power, manifesting itself in various ways that materialize in the different barriers. Sustainable Management manifests itself through tools of different natures to favour a fundamental change in the system and the agenda of power.

Sustainability Managers are interdisciplinary professionals, but the way in which these agents experience and deal with RtC is essentially different, depending on external and personal variables.

A model of cycles in ascendant spiral (Fig. 18) is proposed for the seeking of a Systemic Sustainable Change, where the base is knowledge and the expertise in strategies for leading the change mobilizing different actors and interests through communication and pedagogy.

Figure 5. Ascendant spiral of SSC (Mejía 2022)

According to the current paradigm, the big solution to Resistance to the SSC must be economic. Economists and financiers have the greatest part in responding to the crisis in the terms that the current system is expecting it, managing resistance with an alternative economic model that is at the same time low in carbon and functional.

The successful management of this resistance has to do with the inclusion of the same centres of power in the benefits generated by alternative and sustainable economies.

Policies related to land use, public services and the use and impact of natural resources and ecological structure must be based on principles decided participatively, where the current ruler can only have a minor decisional power on logistical details which do not change in essence the collective policies and decisions without transparency for all the actors and technical and scientific support, as one of the main challenges of sustainability is to be understood as a technical matter and not an ideological matter.

Opportunities for future research are:

- Testing or discussing strategies that are (or not) being implemented, why they do (or do not) work, and their intervening conditions.
- The survey yielded results of greater resistance from the public sector. The sample is not significant enough and it would be interesting to further explore this topic.
- Some multinational giants are conducting market research to adapt their business models. Research is needed on how this transition from resistance to adaptation is taking place, beyond the understanding of new economic opportunities in the scope or imminent risks for their business. Also on what is the time curve of these actions of change, and how they affect the possibilities of a real transition.
- Politics as the scenario of power par excellence, and thus also the main praxis stage of sustainability management.

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Practical solutions to flood risk reduction

BERLITZ, FERNANDA

Live pole drains for cities (LPD4C)

an easy-to-build nature-based solution (NbS) alternative to conventional sustainable drainage systems (SuDS)

Live Pole Drain (LPD) is a plant-based drainage system deployed to drain the excess of surface water regulating soil water budget. LPDs have a great potential for cities, but they have not been explored in urban settings yet. The aim of this study is to propose LPD as an original NbS alternative to conventional SuDS. In this context, the developed Live Pole Drain for Cities (LPD4C) framework provides information on the main environmental criteria for LPD creation; delivers guidelines for LPD design and construction; and delineates the steps to assess the LPD eco-hydrological performance. A spatial, multi-criteria analysis identified that 28% of Glasgow/UK presents optimal conditions to accommodate LPDs. Moreover, findings on LPDs hydrological performance observed during a laboratory experiment showed that they can be effective towards urban flooding mitigation. This study successfully built pioneering evidence on LPDs eco-hydrological performance, which supports them as a suitable solution to mitigate urban flooding. The recommendations for LPD adoption presented can be useful for urban planners and decision-makers during the planning phase of projects seeking to manage flood hazards whilst enhancing the natural value of urban environments.

1 Introduction

Rapid urbanization and the intensification of weather events due to climate change are only some of the drivers leading to an unbalanced water budget in the soil. Consequently, the total volume of stormwater runoff rises together with its frequency and severity, placing human life, infrastructure and environment under risks, increasing vulnerability against landslides and floods. Thus, there is a need for efficient drainage systems capable to mitigate these hazards in cities. In this context, Nature-based Solutions (NbS) and Sustainable Drainage Systems (SuDS) are concepts which establish a green alternative to conventional grey infrastructure.

Under the NbS' umbrella, Live Pole Drain (LPD) is a less known SuDS. Traditionally, LPD is a soil bioengineering technique deployed to drain the excess of surface water, to regulate the water budget in the soil, and to promote ecological succession and landscape restoration (Polster 1989; Campbell et al. 2008). Despite the great eco-hydrological potential of LPD, it has not yet been explored in urban settings. LPD can be easily built and replicated — favouring community engagement throughout LPD's lifecycle — and uses locally available materials without the need of heavy machinery, resulting in a low-cost opportunity to address problems of excess of soil moisture, surface runoff, erosion, and slope instability (Schiechtl and Stern 1997; Campbell et al. 2008). Since LPD provides benefits aligned with NbS and SuDS philosophies (Ballard et al. 2015; European Commission 2021), it is a promising alternative for urban environments facing erosion, landslide, and particularly, flooding hazards. Based on the latter, the city of Glasgow (UK) could profit substantially from the strategic implementation of LPDs. The city has one of the highest rainfall rates in the UK (Met Office 2022) with a 68% risk of surface water flooding (SEPA 2015).

However, to the author's knowledge, there is a severe lack of evidence on LPD's performance. This could be due to the lack of an integrated framework that collects the myriad processes within the LPD SPAC. In addition, standard protocols for LPD design and construction do not yet exist. Therefore, urgent research is needed to gain insights into the eco-hydrological performance of LPDs and their ability to provide co-benefits and ecosystem services to human communities, and to establish standard approaches of design and construction that enable upscaling and reproduction. This research seeks to fill these knowledge gaps.

Following the hypothesis that LPDs can be effective within cities, the overall aim of this research is to propose LPD as an original NbS alternative to conventional SuDS for regulating the water budget in the urban environment. To attain this aim and fill the outlined gaps, this research

> (i) develops the first LPD framework, which will inform LPD design, set the basis for land suitability assessment for LPD creation and for eco-hydrological LPD performance assessment;

(ii) devises an approach helping identify opportunity sites for LPD creation at urban scale (with Glasgow, UK as case study);

(iii) assesses the LPD performance through the key eco-hydrological processes through a pilot laboratory experiment under controlled environmental conditions;

(iv) evaluates urban land suitability and capacity to accommodate LPDs; and

(v) provides further strategies and recommendations for future replications and upscaling of this NbS in the urban environment.

2 Background

2.1 LPD as a Soil Bioengineering Technique

LPDs are built from tied bundles of live, tree/shrub cuttings placed within a shallow trench. Both cylindrical bundles — also known as live fascines — and stakes are made of live branch cuttings from woody plants with easy rooting and propagation properties, such as willow (Salix sp.; Schiechtl and Stern (1997); Polster (2007). SRCD (2005) and Campbell et al. (2008) present LPD as a structure formed by three soil bioengineering techniques: lives fascines, pole drains and live stakes. Depending on site conditions and on the purpose of the intervention, these three techniques might be applied separately or combined. When combined, they result in the so-called LPD.
As independent soil bioengineering techniques, live fascines and live stakes have been studied separately by Li, Zhang and Zhang (2006), Prasad et al. (2012), Kamchoom and Leung (2018), and Recking et al. (2019). Although these studies confirmed live fascines and live stakes' potential to improve soil stability and to restore landscapes, literature review demonstrates lack of research on these solutions working together as components of LPD as a bioengineering technique.

2.2 LPD as a Sustainable Drainage System (SuDS)

As highlighted, no research on LPDs as a soil bioengineering technique has been found. However, previous research on other NbS with similar underlying features and processes, such as Subsurface Flow Wetlands (SFWs), could provide insights into the multifunctional performance of LPDs. SFWs may resemble LPDs in terms of their structure and functions. Even though SFWs mainly strive to provide water treatment functions, differing from the primary objective of LPDs (i.e., regulation of the soil water budget and debris collection), there are similarities between both NbS to establish a baseline upon which build understanding of the features and function of LPDs.

Accordingly, one can assume that LPDs will also provide a substrate for plant development and further processes related to eco-hydrological functions. As a system evolving over time, underground plant biomass and root system may facilitate the adhesion of contaminants to the plant, with further pollutants' aerobic decomposition and sedimentation (Ballard et al. 2015). Moreover, live cuttings could act first as a frictional structure decreasing surface water peak flow. As debris accumulate within the system, a sponge effect may result, retaining water, enhancing infiltration into the ground, and reducing surface runoff volume (Jones 1995; Schiechtl and Stern 1997).

2.2.1 LPD Eco-hydrological Processes for Performance Assessment

Identification and knowledge of the processes occurring at the SPAC within LPDs is essential to build holistic frameworks informing the assessment of the performance of this NbS. The eco-hydrological processes (Table 1) can be classified between those occurring under wetting (i.e., during or after rainfall events) and those occurring under drying (i.e., in the absence of precipitation) soil conditions.

Eco-hydrological Process	Definition	Source
Rainfall interception	Part of the rainfall that is intercepted by tree canopy. While foliage intercepts rainfall, a decrease on volume of water reaching the soil occurs, as well as a reduction of raindrop impact on the soil.	Rodriguez-Iturbe and Porporat (2005); Campbell et al. (2008)
Evapotranspiration	It refers to plant transpiration and evaporation from the soil by tree canopy. Roots uptake water from the soil, which is subsequently transpired by the leaves into the atmosphere.	Rodriguez-Iturbe and Porporat (2005); Campbell et al. (2008)
Throughfall	Part of the rainfall that passes through tree canopy, subsequently reaching the ground with less raindrop impact on the soil.	Rodriguez-Iturbe and Porporat (2005); Campbell et al. (2008)
Stemflow	Part of the rainfall that is intercepted by tree canopy and subsequently flows downs the branches and stem until reaching the ground.	Levia and Frost (2003); Gonzalez-Ollauri, Stokes and Mickovski (2020)
Rainfall infiltration	It refers to the volume of rainfall infiltrating the soil. It is directly related to rainfall depth and soil-water storage availability, which is also related to the volumetric soil moisture content.	Rodriguez-Iturbe and Porporat (2005)
Stormwater runoff infiltration	Stormwater runoff is a product of the rainfall depth and the degree of permeability of urban surfaces. It refers to the volume of stormwater runoff infiltrating the soil.	Rodriguez-Iturbe and Porporat (2005); Loughlin, Huber and Chocat (2010)
Debris flow deposition	Debris flow is a mixture of soil particles and water moving down the slope by gravity. Deposition of debris flow happens when debris is allocated in any surface acting as a barrier.	Berzi, Jenkins and Larcher (2010)
Surface runoff	When the rainfall depth exceeds the soil-water storage availability, the excess is converted into surface runoff.	Rodriguez-Iturbe and Porporat (2005)
Water retention	It is related to the capacity of the soil in retaining water, which is mainly governed by soil properties.	Rodriguez-Iturbe and Porporat (2005)

Eco-hydrological Process	Definition	Source
Debris sedimentation	Once debris is deposited, the sedimentation process starts. Debris starts settling, resulting in new layers of soil covering the previous surface.	Berzi, Jenkins and Larcher (2010)
Bundles decay	It refers to the process of decomposition of the live cuttings within the bundles. While part of the cuttings will survive and generate new above- and belowground vegetation, part will decay enhancing soil organic matter (SOM).	Rodriguez-Iturbe and Porporat (2005); Campbell et al. (2008)
Plant uptake	It affects the water budget by removing water from the soil. Root system uptakes water from the soil, which is subsequently transpired by the leaves into the atmosphere.	Rodriguez-Iturbe and Porporat (2005); Campbell et al. (2008)
Plant growth	It refers to the rate of plant growth, which is also determine by plant water and nutrient uptake. To ensure development and survival, plants need to maintain a sufficient volume of water and nutrients in their tissues. Continuous flux of water also affects the performance of processes such as photosynthesis and nutrient uptake.	Rodriguez-Iturbe and Porporat (2005)
Mechanical reinforcement	Roots provide additional mechanical support to the soil, by increasing its shearing resistance. Roots also bind the surface soil particles, reducing their susceptibility to erosion. Roots may penetrate a firmer substrate, thereby anchoring the upper soil layers.	Campbell et al. (2008); Gonzalez-Ollauri and Mickovski (2016)
Subsurface flow	It corresponds to the movement of water through the soil, and it is mainly correlated to the preferential flow governed by the presence of macropores. Plant roots and small organisms alter the soil by opening channels, increasing macroporosity. Through macropores, preferential flow occurs more easily by capillarity forces.	Bouma (1981)
Percolation	It refers to the downwards movement of water to the groundwater through the soil, and its layers, by gravity and capillary forces.	Rodriguez-Iturbe and Porporat (2005)

Table 1. Eco-hydrological processes of LPD within the soil-plant-atmosphere continuum (SPAC).

As a plant-based system developing throughout time, the ability of LPDs to provide eco-hydrological functions will likely change over the different stages of the LPDs life-cycle (Schiechtl and Stern, 1997). As for the lifecycle of LPDs, one could divide it into

(i) establishment (i.e., right after construction until sprouting);

(ii) development (i.e., juvenile and pole phases);

(iii) maturity (i.e., well-developed plant reaching the peaks of LAI and tree height); and

(iv) senescent (i.e., overmatured phase).

With a well-developed LPD system, further processes such as phytoremediation, urban heat island mitigation and habitat provision through vegetation community contribute to the delivery of co-benefits and multifunctionally of this NbS.

2.2.2 LPD Design and Construction Guidelines

Adequate LPDs design is paramount to realise their eco-hydrological performance. Selection of the right plant species is essential to realise the full performance of LPDs throughout their service life. Preference should be given to plant materials retrieved locally from native species and healthy plant stock, rather than to exotic species (Polster 1989; Schiechtl and Stern 1997). This approach encourages the adequate establishment of the vegetation cover and its adaptation to the local environment, facilitating natural ecosystem processes such as plant succession (Gray and Sotir 1996). Plants able to propagate from branch cuttings and water tolerant species with the ability to withdraw high volumes of water from the ground should be considered, too (Schiechtl and Stern 1997; Campbell et al. 2008).

As for the size (length and area) and shape (number of branches, herringbone, etc.), one can assume that the area and design required for LPD implementation are site-specific. The LPD might be applied in a herringbone pattern, depending on the drainage needs, topography and landscape restoration goals. Based on live fascines and pole drain potential to reduce flow velocity and to retain debris, building the LPD following flow paths — when readily observable — is recommended (Campbell et al. 2008). Alternatively, flow and drainage paths can be detected in the landscape using GIS approaches (e.g., Gonzalez-Ollauri and Mickovski (2017).

2.2.3 Environmental Criteria for LPD Creation

Local environmental conditions need to be considered to find adequate locations to host LPDs and ensure LPDs optimum functioning and sustainability (Rey et al. 2019). Thus, prior to constructing an LPD, identification and selection of the most suitable sites in the urban environment is required. Climate variables, soil properties, topographic conditions, proneness to surface flooding, land cover, proximity to greenspaces and to healthy vegetation are the environmental criteria considered in this research, as they play a crucial role throughout the three stages of LPD development, influencing plant growth and the eco-hydrological performance.

To identify opportunity sites for LPD creation in urban environments, the presented environmental criteria must be combined. Commonly applied by urban planners and decision-makers (Loc et al. 2017), the Multi-Criteria Analysis (MCA) is an approach for assessing simultaneously heterogeneous criteria and score the relative importance of each. Among the available methods, the Analytical Hierarchy Process (AHP), developed by (Saaty 1980), is one of the most popular approaches to MCA (Vaidya and Kumar 2006; Velasquez and Hester 2013) and aims to translate qualitative criteria into quantitative ones by weighting their importance among the decision criteria (Hill et al. 2005).

3 Methodology

This study combined qualitative and quantitative methods, and it was framed to provide the underlying knowledge to propose LPDs as an alternative to conventional SuDS for regulating the water budget in the urban environment. The first section of this study included a comprehensive review of the existing literature on LPDs — i.e., eco-hydrological processes within the soil-plant-atmosphere continuum (SPAC), design and construction guidelines, and environmental criteria for LPD creation — and which was utilised as a basis to build the first LPD framework. Based on this framework, two methods were then applied to illustrate its application:

(i) a spatial, multi-criteria analysis to identify urban land suitability and opportunity sites for implementing LPD. Here, Glasgow City area was used as case study; and

(ii) a laboratory experiment to assess the performance of the key eco-hydrological processes depicted under the LPD framework. Subsequently, both methods were subdivided into three phases:

(i) collection of primary and secondary data;
(ii) data processing; and
(iii) data analysis.

3.1 Glasgow City as Case Study

With circa 635,640 inhabitants living within an area of 177.3km², Glasgow is the most populated and largest city in Scotland, UK (GCPH 2022). The city is positioned 55.85° North longitude and 4.44° West latitude, within the temperate humid climate zone (Cfb: oceanic climate; Köppen (1884)). The mean annual temperature is 9.83°C with an average annual precipitation of 1,262.83mm (Met Office 2022). Glasgow City has been historically affected by severe weather hazards and it is identified as being susceptible and potentially vulnerable to different types of flooding (e.g., coastal and surface water flooding; GCC (2021)). According to SEPA (2015), 68% of the city area is at surface water flooding risk, while 32% could be affected by coastal flooding from the river Clyde and its affluents crossing the territory. The challenge to mitigate the impacts of such hydro-meteorological hazards (HMHs) gets deeper when the consequences of climate change (i.e., heavier storms, heat waves, rise of sea levels, etc.) are put into perspective (UKCCRA 2017). In order to address HMHs, the city of Glasgow has been working in partnership with different stakeholders to promote strategies and deliver initiatives towards a resilient and sustainable city.

3.2 Opportunity Sites for LPD Creation

In order to identify opportunity sites for LPD creation in the urban environment, a land suitability assessment was undertaken for the Glasgow City area. Accordingly, those areas presenting adequate environmental attributes related to the criteria identified during literature review were scored as more suitable that those that did not.

The environmental criteria considered to identify the opportunity sites for LPD creation are shown in Table 2. Suitability scores were applied to determine better or worse conditions among the environmental criteria for creating LPDs at a given spatial location. A suitability scores scale was created, ranging from 1 to 5 (i.e., (1) unsuitable; (2) low suitability; (3) mid-low suitability; (4) moderate suitability; and (5) optimal suitability). Therefore, environmental criteria with optimal suitability condition were scored with a value of 5, while attributes presenting worse conditions were scored accordingly with lower values. An additional "(R) restricted" score was attributed to classify urban land that cannot be transformed into LPDs.

Environmental Criteria	Class	Score
Soil Texture Type: Environmental Subtype: Soil Parent Material Data Source: BGS (2019) Raw Data Type: Vector	Clay to Sandy Loam Clayey Loam to Silty Loam Loam to Clayey Loam Clayey Loam to Sandy Loam Loam Loam to Silty Loam Loam to Sandy Loam Sandy Loam to Loam Sandy Loam to Silty Loam Sand to Sandy Loam Peat Varied, Locally Peat No Data Available	4 4 4 3 3 3 3 3 3 2 1 1 1
Slope Gradient Type: Environmental Subtype: Topography Data Source: SRSP (2021) Raw Data Type: Raster	0-1°; Flat 1-5°; Gentle 5-15°; Moderate 15-35°; Steep >35°; Highly steep	5 5 5 3 1
Slope Curvature Type: Environmental Subtype: Topography Data Source: SRSP (2021) Raw Data Type: Raster	Concave Planar Convex	5 5 1

Environmental Criteria	Class	Score
Slope Aspect Type: Environmental Subtype: Topography Data Source: SRSP (2021) Raw Data Type: Raster	N; North NE; Northeast E; East SE; Southeast S; South SW; Southwest W; West NW; Northwest N; North	1 2 3 4 5 4 3 2 1
Proneness to Surface Flooding Type: Environmental Subtype: Topography Data Source: SRSP (2021) Raw Data Type: Raster	0-100m 100-400m 400-700m 700-1000m >1000m	2 5 4 4 3
Land Cover Type: Socio-Economic Subtype: Land Cover Data Source: Ordnance Survey (2021) Raw Data Type: Vector	Amenity Greenspaces Buildings and Structures General Surfaces General Surfaces, Natural Green Corridors Natural/Semi-Natural Green- spaces Open Water Other Functional Greenspaces Parks and gardens Play Spaces and Sports Areas Rails, Roads, Tracks and Paths	5 R 1 5 4 5 R 4 4 3 R

Table 2. Environmental criteria and suitability scores.

To allocate suitability scores over the study area, a spatial multi-criteria analysis (MCA) was performed using secondary data. The relative importance of the attributes was allocated following the Analytical Hierarchy Process (AHP) method (Saaty 1980). The AHP was based on experts' opinions, which were obtained through an original survey and gives the relative importance of one attribute over another for subsequent combination through simple additive weighting (SAW; e.g., Gonzalez-Ollauri, Thomson and Mickovski (2020)) analysis. Following the implementation of SAW, only raster cells with scores between moderate (i.e., score 4) and optimal (i.e., score 5) suitability were defined as urban areas with acceptable conditions for LPD creation. Lower scores were considered unsuitable to implement LPDs. This reclassification resulted in the opportunity sites for LPD creation map. Data processing and analysis were carried out using the GIS software ESRI ArcGIS Pro 2.9.3.

3.3 Eco-hydrological Performance of LPD

In order to collect primary data to assess the performance of LPDs in terms of key eco-hydrological processes — i.e., surface runoff, subsurface flow, percolation, water retention, and plant growth, a pilot laboratory experiment was carried out in a growing chamber under controlled environmental conditions at Glasgow Caledonian University. Three treatments were established with three repeats each — i.e., a willow (Salix sp.) LPD

(W); a willow (Salix sp.) LPD with alfalfa (M. Sativa sp.; seeds, 100g/m²; W+A); and fallow soil as control (C).

During the experiment, rainfall simulations and a soil water mass balance (SWMB = 0; Equation 1) were performed to evaluate the potential of LPDs to regulate the soil water budget. The SWMB was assumed to have an equal balance between the water inputs (i.e., the sum of the rainfall cumulative water volume and water content in soil prior rainfall) and the water outputs (i.e., sum of water volumes derived from surface runoff, subsurface flow, percolation, and water content in soil post rainfall). If the SWMB was not balanced (i.e., SWMB ≠ 0), the remained water volume was assumed as water loss. Output values for each SWMB component were plotted through boxplots for visual comparison of the variations between treatments (i.e., W, W+A, and C) and scenarios (i.e., scenario A, soil at water saturation; and scenario B, soil at field capacity).

Eq. 1

$$\mathbf{SWMB = [CWV+WC_b\,]-[R+SF+P+WC_a\,]-[W_l\,]}$$

Where:
CWV = Cumulative water volume, in litres
WC_b = Water content in soil – before rainfall, in litres
SR = Surface runoff, in litres
SF = Subsurface flow, in litres
P = Percolation, in litres
WC_a = Water content in soil – after rainfall, in litres
W_l = Water loss, in litres

4 Results

4.1 LPD4C Framework

A comprehensive framework (Figure 1) to set the basis of Live Pole Drain (LPD) in the urban environment was defined. The Live Pole Drains for Cities (LPD4C) framework assembled the environmental compartments, the driving eco-hydrological processes and respective required variables delineating the information needed to design and assess the performance of LPDs. By building upon the understudied field on LPDs performance, the LPD4C framework supports the adoption of LPDs as a viable type of SuDS for cities. Five main environmental compartments were considered within the framework — i.e., atmosphere, urban surfaces, plant bundles & soil matrix, aboveground and belowground vegetation, connected through an array of eco-hydrological processes (arrows).

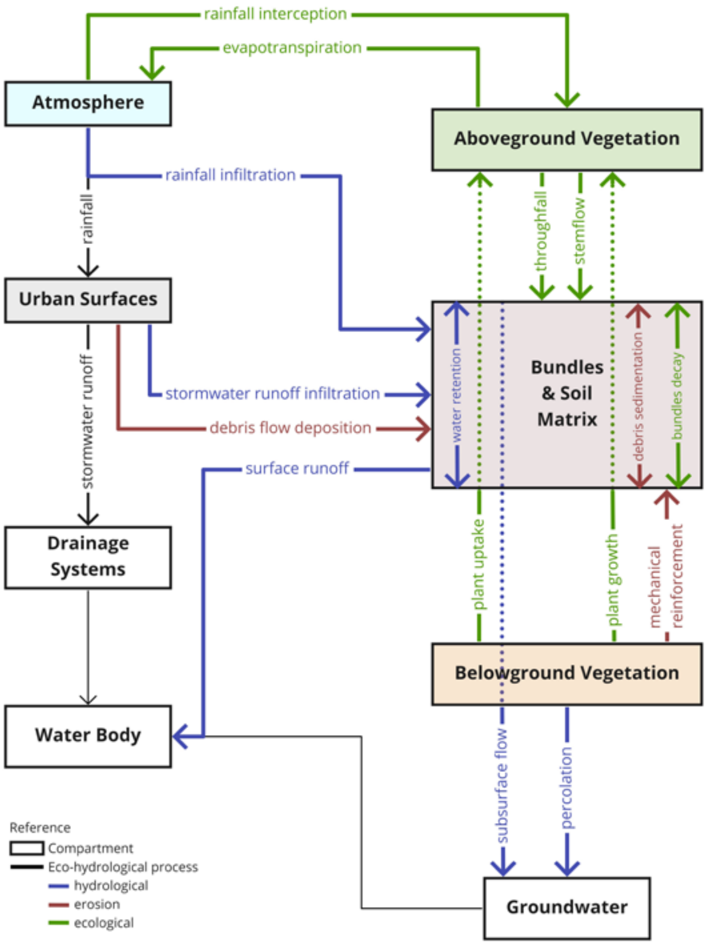

Figure 1. LPD4C framework. The framework illustrates the eco-hydrological processes (arrows) across the environmental compartments of a LPD in a city.

LPDs have not yet been explored in urban settings, which also highlights the originality of the LPD4C framework, in general, and of the present study, in particular. The LPD4C framework was built in a context of urban flooding, soil erosion and landslides, yet its dimensions and components are holistic, enabling its reproduction in other environmental contexts facing different challenges. For example, the LPD4C was conceived in line with the current policies and practice on SuDS (Ballard et al. 2015), which mainly focus on SuDS implementation within new urban developments. However, taking into consideration existent urban environments, the impacts of urbanisation and climate change, the LPD4C framework also considers the potential of LPDs while retrofitting SuDS. Still, the upscale and applicability of the framework, as well as the adoption of LPDs in urban environments, would benefit from changes in policies. Local planning authorities (LCAs) must update their policies to require well-designed, integrated SuDS, but also to embrace the 'connecting first to SuDS' principle instead of allowing direct connection of surface water to grey infrastructure.

4.2 Opportunity Sites for LPD Creation

The combination of the considered environmental criteria through the AHP and SAW resulted in the opportunity sites for LPD creation in Glasgow (Figure 2). Findings of this study demonstrate that Glasgow City has suitable land with optimal conditions to accommodate LPDs (27.94%). This percentage represents a satisfactory result when compared with previous studies on urban land suitability for SuDS. For example, Ariza et al. (2019) identified suitable land to implement infiltration basins, wetlands, and tree boxes, for 5.3%, 5.4%, and 58% of the study area, respectively; Joshi et al. (2021) identified 14% of land suitability for SuDS implementation; and Dearden, Marchant and Royse (2013) suggested that 34% of the UK is suitable for infiltration SuDS. Restricted areas (33.48%) were found based on the Glasgow's land cover map and on the assumption that the built-up environment and open water environments cannot be transformed into LPDs. Unsuitable areas for LPD creation accounted for the highest portion of Glasgow's territory (38.58%), which is directly related to the soil textures found in Glasgow – the third most important environmental criterion according to experts' opinions. Although Glasgow City did not present optimal conditions for LPD creation in terms of soil texture, it does not preclude their adoption, rather it does pose a necessity for careful consideration at planning stage.

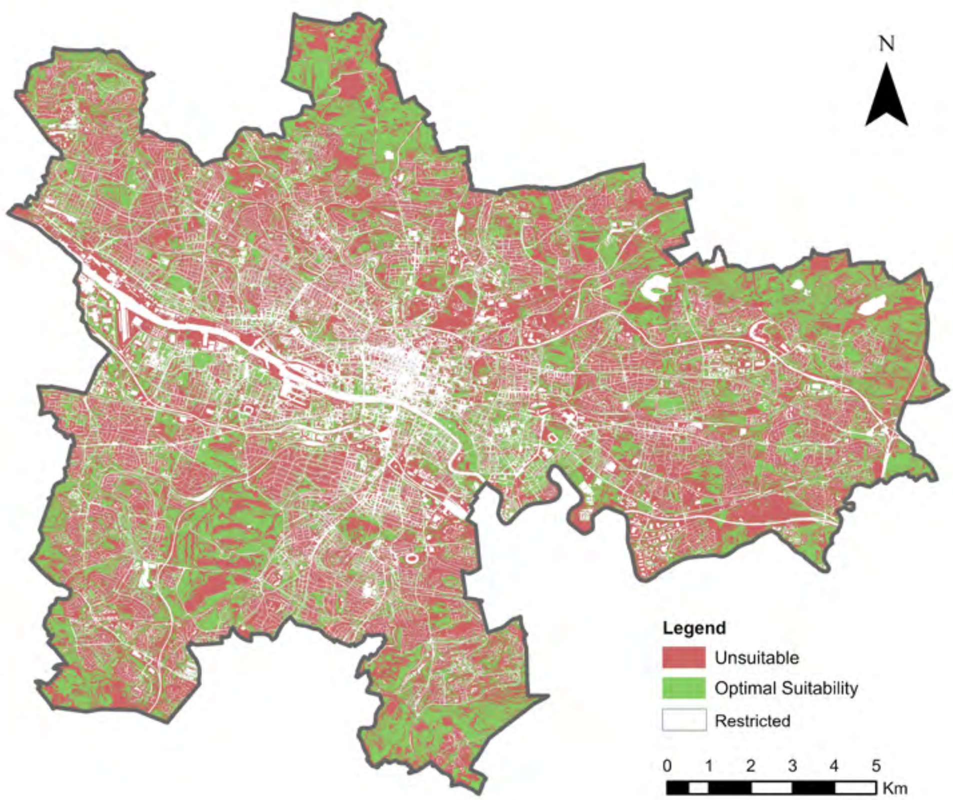

Figure 2. Opportunity Sites for LPD creation in Glasgow City.

It is worth noting that the identification of opportunity sites for LPD creation were directly affected by the environmental criteria defined in literature review, the weights assigned to each criterion in the light of experts' opinion, and the quality and reliability of the input datasets and experts' responses. On the one hand, selection and delimitation of the environmental criteria, as well the attributed suitability scores, were defined based on literature review. On the other hand, the relative importance of each environmental criterion against each other was based on experts' opinion. Although these approaches have been applied in previous studies (e.g., Gonzalez-Ollauri, Thomson and Mickovski (2020)), the AHP was based on the opinion of eight out of 141 invited experts, suggesting that the relative importance between environmental criteria shown herein should be taken with caution and thus further consultation is recommended.

4.3 Eco-hydrological Performance of LPD

The results for the different soil water mass balance (SWMB) components gathered through the experimental assessment of eco-hydrological performance of LPDs are show in Figure 3 on the next page. Key findings showed that this NbS is effective in draining the excess of surface water and in regulating the water budget in the soil. Particularly to LPDs hydrological performance, this research identified that LPDs, at certain design and environmental conditions, can decrease surface runoff up to 90% and water retention up to 54% when compared to fallow soil, while subsurface flow and percolation are increased up to 170% and 150%, respectively.

Greater surface runoff was observed under fallow soil when compared to vegetated treatments, which is in agreement with the findings reported in El-Hassanin, Labib and Gaber (1993) and Komatsu et al. (2018). Following the same pattern observed in surface runoff, fallow soil also tended to accumulate higher volume of water within the soil during wetting soil conditions. This suggests a challenge to cities with high rainfall rate striving to mitigate urban flooding (e.g., Glasgow). Fallow soil under a series of rainfall events with short periods of time between one event and another will retain more water, thus increasing its water saturation level, without enough time to dry out via evapotranspiration. Once fallow soil reaches its maximum water saturation level, stormwater is incapable to infiltrate into soil increasing the volume of surface runoff. As anticipated, subsurface flow and percolation under fallow soil was substantially lower than under vegetated treatments due to the absence of belowground vegetation. Conversely, both vegetated treatments presented considerable subsurface flow and percolation due to the higher number of macropores created by the living cuttings in the bundles and the growing roots. These results were in line with the findings from Gonzalez-Ollauri and Mickovski (2020), which demonstrated that vegetation (e.g., willows) can contribute to effectively drain the excess water from the soil. These findings are useful in a context of decision-making process towards strategies to urban flooding mitigation. LPDs not only decrease surface runoff but also quickly drains water surplus, making of this NbS a great opportunity to be applied as SuDS.

Differences between the two vegetated treatments were also found under the hydrological processes. W+A treatment had on average lower surface runoff, while subsurface flow, percolation and water retention were substantially higher when comparing to W treatment. These outputs can be attributed to the presence of the herbaceous,

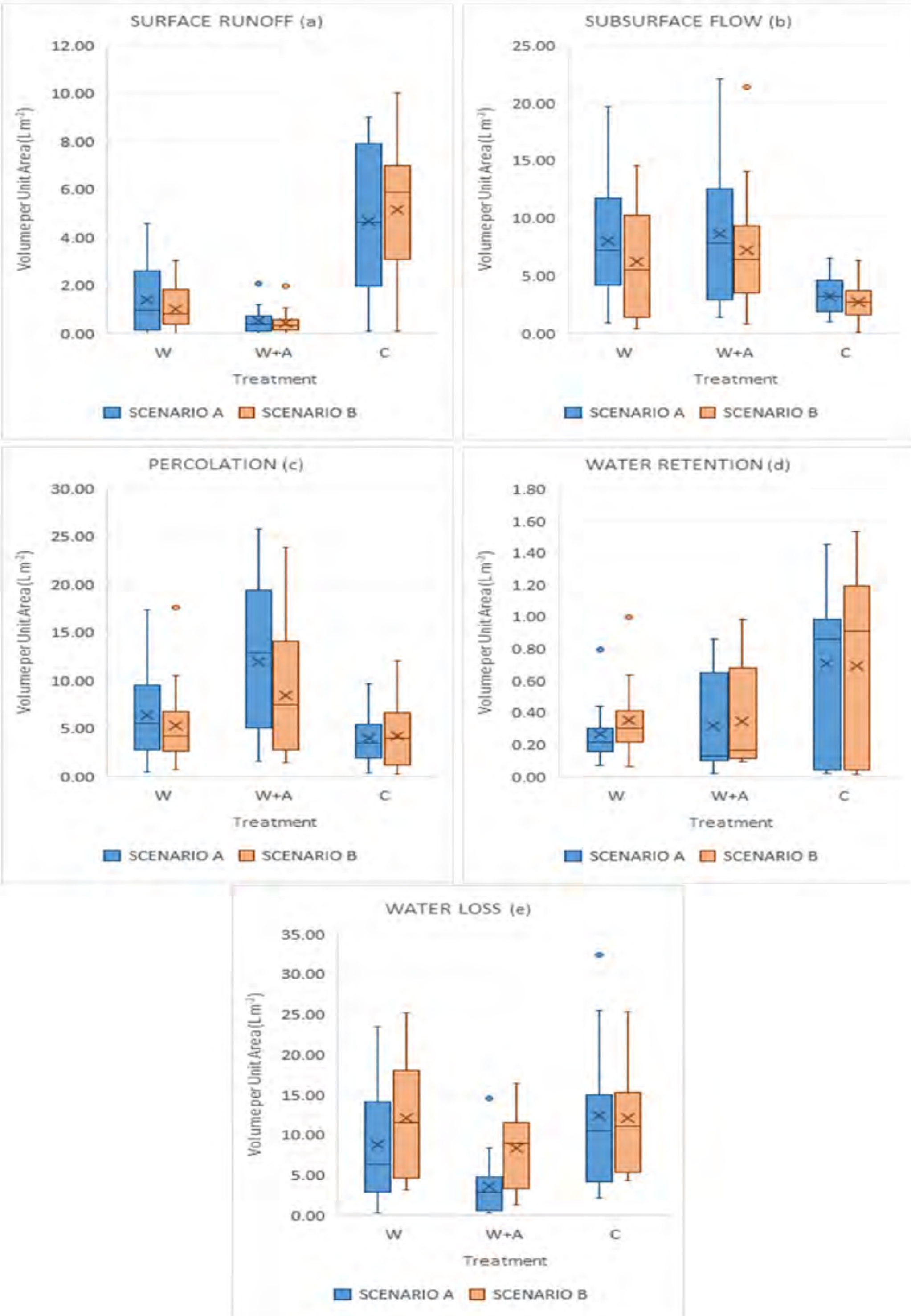

Figure 3. Soil water mass balance (SWMB). (a) Surface runoff; (b) Subsurface flow; (c) Percolation; (d) Water retention; (e) Water loss. Water volume per unit area (L m-2) under willow LPD (W), willow LPD with alfalfa (W+A), and fallow soil (C) treatments, at different scenarios (A: soil at water saturation; B: soil at field capacity).

non-competitive species (i.e., alfalfa). While aboveground vegetation of alfalfa increases soil cover and roughness thus decreasing surface runoff, belowground vegetation of alfalfa contributes to opening the soil creating channels enhancing preferential flow. In terms of water retention, denser root systems enlarge rhizosphere and amount of micropores, increasing the number of points where water can be hold within the soil matrix.

5 Conclusions and discussion

The aim of this research was to propose LPDs as an original NbS alternative to conventional SuDS, following the hypothesis that LPDs are a suitable for cities and an effective solution towards urban flooding mitigation. Based on the objectives set to determine whether the hypothesis is confirmed, this study gathered information upon the unstudied field of LPDs. As a result, the findings identified herein support LPDs as a viable type of SuDS for cities.

The Live Pole Drain for Cities (LPD4C) framework is unique in its nature and the first one developed for LPD. The framework provides information on the main environmental criteria for LPD creation. It sets the basis for informing LPD design and construction. It delineates the steps to assess the eco-hydrological performance of LPD at the soil-plant-atmosphere-continuum (SPAC). The LPD4C framework was conceived to support climate change adaptation (CCA) in urban environments, especially to address natural hazards such as soil erosion, shallow landslides, and floods. In addition, the framework can support effective SuDS decision-making process, increasing the chances for successful LPD implementation effectively delivering of ecosystem services to human communities.

Opportunity sites for LPD creation were satisfactorily identified for Glasgow City. Understanding the impact of environmental conditions on LPDs and then identifying the most suitable sites to implement them is crucial to ensure LPDs optimal performance and sustainability. Accordingly, the selected eight environmental criteria herein were chosen as these play a critical role throughout the LPD development stages, impacting on plant growth and hence overall eco-hydrological performance.

Understanding LPD eco-hydrological processes within the soil-plat-atmosphere continuum (SPAC) and its overall performance is vital to optimise LPD eco-hydrological potentials, which are directly impacted by deployed LPD design and local environmental conditions in which the LPD was built. This research not only confirmed the scarce information on LPD effectiveness, but also quantified its performance through the selected key eco-hydrological processes. However, caution must be taken when upscaling the results of the LPD hydrological performance obtained thought the laboratory experiment. The results cannot be directly extrapolated since the differences on LPD design and environmental conditions between indoor LPD and designed LPD at plot-scale will likely impact on LPD eco-hydrological performance.

This study also provided strategies and recommendations to support the adoption of LPDs as an effective SuDS within cities. Specifically, the reflections made on the research findings were elaborated so the user is able to interpret the results beyond the conditions set within this research. In general, recommendations were given based on the multiple interactions between LPD design, LPD environmental conditions in which it would be implemented, and LPD eco-hydrological function and performance. Understanding that all these factors are directly related, impacting on each other, is crucial for successful LPD deployment, survival, development and performance.

This research is not without limitations. Limited available information on LPDs resulting in a substantial knowledge gap; quality and reliability of the collected secondary data; lack of engagement from NbS experts during the AHP survey; timeframe to design, to build and to monitor a pilot laboratory experiment were few of the constrains found. To enhance reliability of the findings obtained during this study, further replications of the undertaken approaches are needed. By repeating the methods and by putting the LPD4C framework into practice, further evidence on LPDs performance and effectiveness within the urban environment can be gathered. Based on the solid foundation and evidence of LPDs created within this research, next steps were listed in order to explore LPDs, and the LPD4C framework, in a deeper detail. Further studies and application of the LPD4C will further validate the results obtained in this study.

This research successfully built pioneering evidence on LPDs eco-hydrological performance, which now supports LPDs as a suitable solution to mitigate urban flooding in cities. Within the LPD4C scope, the findings of this research can be useful for urban planners, environmental managers, policy makers, decision-makers, and contractors during the planning phase of projects seeking to manage flood hazards whilst enhancing the natural value of the urban environment. Specifically, this study delivered information for implementation of the first ever seen LPD in a city.

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CHATEERJI, SAYONTANI

A decision-making framework for suitability analysis of urban agriculture as a flood risk reduction strategy in vulnerable communities

A case study of Glasgow

Academic study emphasises Urban Agriculture's multifunctionality in its ability to address numerous benefits. However, at a time when natural/green infrastructures are becoming a preferred method of intervention in flood management worldwide, UA's multifunctionality has been limited to its provisional (food, fibre, etc.) or cultural (social participation, community development, etc.) benefits, with little to no research addressing its regulatory services. Many studies discuss the potential of its water management capacities, but little research exists in systematically exploring this, especially when viewed as a flood strategy. The research on the food system, flood risk, and urban agriculture is largely neglected, leaving numerous gaps that impede its applicability to flood management measures in urban areas. Given how flood hazards affect the entire food supply chain, particularly in already vulnerable communities, this relationship is crucial for addressing and evaluating the interconnectivity of rising flood risks and food systems. In the face of a hazard, both vulnerabilities and exposure dictate the extent of impact and therefore this study explores UA's potential in reducing vulnerabilities at the very heart of the flood-food nexus. To that purpose, this study defines common relationships between the two challenges, investigates their interdependencies in terms of both vulnerabilities and hazards, and proposes a framework for decision-making processes to identify prime intervention areas. Because the importance of urban agriculture and research in the global north is relatively limited, the assessment is carried out in Glasgow, Scotland, a city with high levels of land degradation, flood concerns, and food poverty.

The simulation exercises - conducted using InVEST and geospatial analysis - for the city of Glasgow exhibited substantial enhancements in flood retention and nutrition in the case study area. Thus, highlighting the potential of UA in addressing flood risk and food poverty. These findings, alongside the outcomes of a comprehensive literature review and expert consultation exercises (AHP), paved way for a decision-making framework. The framework is intended for use as a preliminary decision-making tool at the normal level for local governments and flood risk management practitioners while serving as a starting point for further research into UA as a flood risk reduction technique.

1 Introduction

Flood-related disasters are becoming more common as precipitation intensity and climate variability increase globally (FAO 2015), affecting the entire food supply chain from agricultural production to food consumption (Dubbeling and Halliday 2019; Atanga and Tankpa 2021). Weakened food systems further, have social and economic consequences (FAO 2015) from reduced capacities of a household to afford food (Atanga and Tankpa 2021), deteriorating chances for access and utilisation of food for essential nutritional value (Atanga and Tankpa 2021) affecting overall food security and nutrition. Food security as described by (FAO 2015) exists,

> *"when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life"*

While food production is not a primary concern of the global north's food security stance, some debates and research on the concepts of self-sufficiency and food resilience are underway (Mok et al. 2014), highlighting the issue of food dependency on rural or trans-boundary supply networks vulnerable to periods of low food supply caused by natural disasters (Dubbeling and Halliday 2019).

'Disasters' according to (Blaikie et al. 2014; Ulibarri 2017), are not caused by natural hazards but is usually a product of interlinked social, political, and economic demographics of a community (Berndtsson et al. 2019). Naturally, vulnerable households (urban poor or marginalised groups) in urban systems, have limited capacity to respond to a disaster and are affected disproportionately (Dubbeling and Halliday 2019). While investments in Disaster Risk Reduction (DRR) methods have shown a considerable reduction in disaster-related vulnerabilities (UNISDR and UNESCAPE 2012), the contrary has also been true. Investments made to minimise a disadvantaged group's vulnerabilities have been found to increase its potential to recover from and adapt to a disaster, thereby reducing risks (Huq and Hossain 2015; SEPA 2015; UNDRR 2017; Dubbeling and Halliday 2019) and therefore, a significant tool in Flood Disaster Management techniques.

The capacity of Nature-based Solutions (NbS) to reduce vulnerabilities and flood risks of social-ecological systems (Shah et al. 2020) make them suitable contenders for the provision of natural flood insurance in vulnerable communities (Ebissa and Desta 2022). (IUCN 2020) defines NbS as,

> *"actions to protect, sustainably manage and restore natural or modified ecosystems, which address societal challenges (e.g., climate change, food and water security or natural disasters) effectively and adaptively, while simultaneously providing human well-being and biodiversity benefits."*

Urban agriculture (UA) is one such infrastructure that has gained a lot of attention in recent years due to its 'multifunctionality' from its proven ability to address multiple urban issues (De Zeeuw et al. 2011; Artmann and Sartison 2018; Lucertini and Di Giustino 2021; Wadumestrige Dona et al. 2021); and yet, research on this including a critical evaluation of its ecosystem service delivery, remains largely unexplored (Artmann and Sartison 2018). To promote UA as a tool capable of supplying crucial regulatory ES, a method to evaluate key variables illuminating the flood-food-social vulnerability nexus is required. While various frameworks exploring the links between social factors and flood disadvantage exist (SEPA 2015; Sayers and Partners 2017), and similarly, those exploring links between food insecurity and social vulnerabilities exist as well, there is a need for a decision-making tool to comprehend the flood-food potential in terms of UA as discussed above.

This study attempts to build on this intention and conducts an overall assessment of the potential of Urban Agriculture and its flood and food services.

1.1 Aims and Objectives

The goal of this research is to investigate the multifunctionality of UA as a pre-disaster risk reduction strategy in communities with food and flood vulnerabilities, and to establish a process for identifying this convergence through a decision-making framework for UA

Objective_01: To develop a comprehensive understanding of aspects of agriculture that contribute to flood regulation.

Objective_02: To find suitable areas of intervention

Objective_03: To develop a framework that can be used to find communities suitable for UA for addressing the two challenges

2 Background

2.1 Risks in Scotland

Scotland faces risks of flooding from its coasts, rivers and enhanced surface runoff (Pluvial Flooding) with river floods impacting a substantial proportion of agricultural lands in recent years (Sniffer 2021b). The real threat however are pluvial floods or flooding enhanced surface runoff from intense rainfall and lack of a well-defined floodplain, made worse further due to a variety of factors (city drainage capacity, construction, etc.) (Houston et al. 2011). As these can occur without warning in areas that are not prone to floods, they are often considered an "unseen threat" (Houston et al. 2011). Hardest to manage due to their inherent unpredictable in nature, these floods alone cost the UK government £270 million a year on average, despite government investments in flood defences such as the £320 million invested in 2003-04. (Flood and Coastal Defence project 2022).

Weather extremes are becoming more common as a result of warming trends, changed rainfall patterns, and rising sea levels (Sniffer 2021b), as seen by the series of flash floods and severe storm events in the summers of 2019, 2020, and 2021. The rainfall trends, which are already above average in comparison to the rest of the UK, are anticipated to increase in winters by 7% by the 2050s and by 7% to 13% by the 2080s, and to drop in summers by 12% to 16% by the 2080s, depending on worldwide efforts to reduce greenhouse gas emissions (Sniffer, 2021b). Besides an overall shift in climate patterns, what makes Scotland susceptible to floods, is its generally low evapotranspiration levels, soils with poor infiltration rates and a moist temperate climate allowing the runoff rates to be at an average high, with flash floods in steeper areas, further exacerbating flood conditions in Scotland (Forbes, Ball and McLay 2015).

The Third UK Climate Change Risk Assessment (CCRA3) Report lists 61 climate change-related risks and opportunities in the UK of which 32 have been categorised as needing "more action" based on their level of urgency (Sniffer 2021a). The risks under examination for the review were chosen based on their relevance to present societal concerns in Scotland, including i) food security, ii) social deprivation, and iii) flood vulnerabilities. An area identified as "more action needed' is the 'Health, Communities, and the Built Environment' category with a particular focus on its sub-category H3 and H9 (Scottish Government 2020).

H3: Risks to people, communities, and buildings: This risk has been categorised as needing more action and is considered one of the most severe risks in Scotland (Sniffer 2021b). This category's associated dangers include death or injury, as well as long-term and severe mental health consequences. Development in floodplains, management of SWF (Surface Water Flooding) via Suds, and a lack of UK-wide norms are all difficulties for Scotland to address in order to mitigate this risk.

H9: Risks to food safety and food security: While weather-related pollutants threaten Food Safety in Scotland, access to healthy and cheap food is a problem due to stock shortages and higher pricing. Risks associated with food security will be partially managed in the future for Scotland (Kovats and Brisley 2021) but floods impeding rural production and food imports, can negatively impact health, as extreme weather patterns raise the likelihood of crop yield reductions.

2.2 Vulnerabilities in Scotland

Glasgow and the greater City Region are densely populated areas, making it one of the ten UK local authorities that account for half of the socially vulnerable people living in flood-prone areas (Sniffer 2021b). The Scottish Environment Protection Agency (SEPA 2015) through a National Flood Risk Assessment, identifies areas of flood disadvantage based on The Scottish Index of Multiple Deprivation (SIMD) that takes into account a relative measure of deprivation in Scotland to identify Potentially Vulnerable Areas (PVAs).

2.2.1 Urban Agriculture

UA can reduce vulnerability by

i) encouraging adaptive management within a community,

ii) diversification of food sources, with reduced food dependency during a disaster and

iii) income opportunities and skill development and providing, amongst other ways (De Zeeuw et al. 2011).

UA areas aid in disaster risk reduction (Aciksoz, Özbek & Dal 2021) and can be more cost effective as an NbS when compared to conventional methods of flood risk management (Ebissa and Desta 2022). Regulatory ES of NbS or GI in flood mitigation services is plenty (Dubbeling and Halliday 2019), but it is in the ability of UA to address food security (Opitz et al. 2016) that offers tackling urban challenges at the crux of social vulnerability. However, as a study evaluating ecosystem services pointed out, vegetation suited for production may not be favoured for climate regulation, reinforcing the need of crop selection processes (Artmann and Sartison 2018).

The study area of Glasgow City, with an area of 175 km^2 and a population of 635,640 in 2020 (National Records of Scotland 2021), is the most populous of Scotland's 32 council areas. 92% of people living in Glasgow live within 1000 meters of a derelict site, commonly characteristic of poor drainage and surface water vulnerabilities. According to the (Glasgow City Council, 2022), there are 954 hectares of Vacant and Derelict Lands as of 2019 and a percentage of which have been identified suitable for flood risk mitigation by the Open Space Strategy.

Under the Healthier City Theme, the government seeks to assist the development of Glasgow as a Sustainable Food City, with a focus on child hunger and mental health. (Glasgow City Council 2017). Existing Strategies and Plans and Actions for Local Food include 'The Climate Emergency Working Group' that recommends a Sustainable Food Strategy for Glasgow where food is encouraged to grow locally in new housing developments (Glasgow City Council 2020).

3 Methodology

This chapter includes the basis for the development of the framework and the valuation method employed in the study through a series of research phases.

The general methodological approach used for the research includes a scoping examination of literature, largely from 2012 to 2022, expert engagement, and spatial analysis of open data from the Scottish Government. This study primarily focuses on the micro (neighbourhood) level because many flood management initiatives already exist at the watershed level or the meso (national) level. The table below provides a summary of the data used in this research.

Table 1. Data and data sources

S.No.	Information	Data	Source	Coverage
1	**Flood Disadvantage**	Flood Disadvantage Index (FDI)	SEPA	2015
2	**Space to Grow based on ownership of land (public and private)**	Vacant and Derelict Lands (VDLs) Vector Data	EDINA Digimap Ordnance Survey Service [Improvement Service Scottish Local Government Data]	National (Scotland) 1:10000, 2021
3	**Native Species List of suitable food crops.**	Agricultural Census 2019	Digimap	City Level (Glasgow)
4	**Water Sources**		EDINA Digimap Ordnance Survey Service	City Level (Glasgow)
5	**Permeability Indices**	Qualitative Classification	British Geological Survey	City Level (Glasgow)
6	**Green Spaces**	High resolution maps from city data	Open Space Strategy	City Level (Glasgow)
7	**Topographical Attributes**	digital elevation model (DEM) dataset	Scottish Remote Sensing Portal	| a density of 4ppm (points per square metre) | LiDAR for Scotland Phase 5 - LAS
8	**Land Use – Land Cover**	Digimap | UKCEH Land Cover Maps	Digimap | UKCEH Land Cover Maps	National (UK) 2020 | 1:250000 (25m pixel dataset)
9	**Local Topography**		EDINA Digimap Ordnance Survey Service	City Level (Glasgow)
10	**Soil Properties**	Texture	British Geological Survey	City Level (Glasgow)

3.1 Finding a place to grow

UA's evidence of success has been on fertile soils (Opitz et al. 2016), a limiting element in the urban setting, the assessment begins with just finding available land regardless of its agricultural potential.

Three indicators at this stage were considered –i) zonal areas having high flood disadvantages towards any type of flooding (Fluvial, Pluvial and Coastal) for a 1 in 200 period year return period (low probability-high damage flood scenario), ii) vacant and derelict lands not privately owned and iii) with areas larger than 1Ha have been assessed using GIS and Weighted Overlay tools based on a suitability scale (See Figure 2).

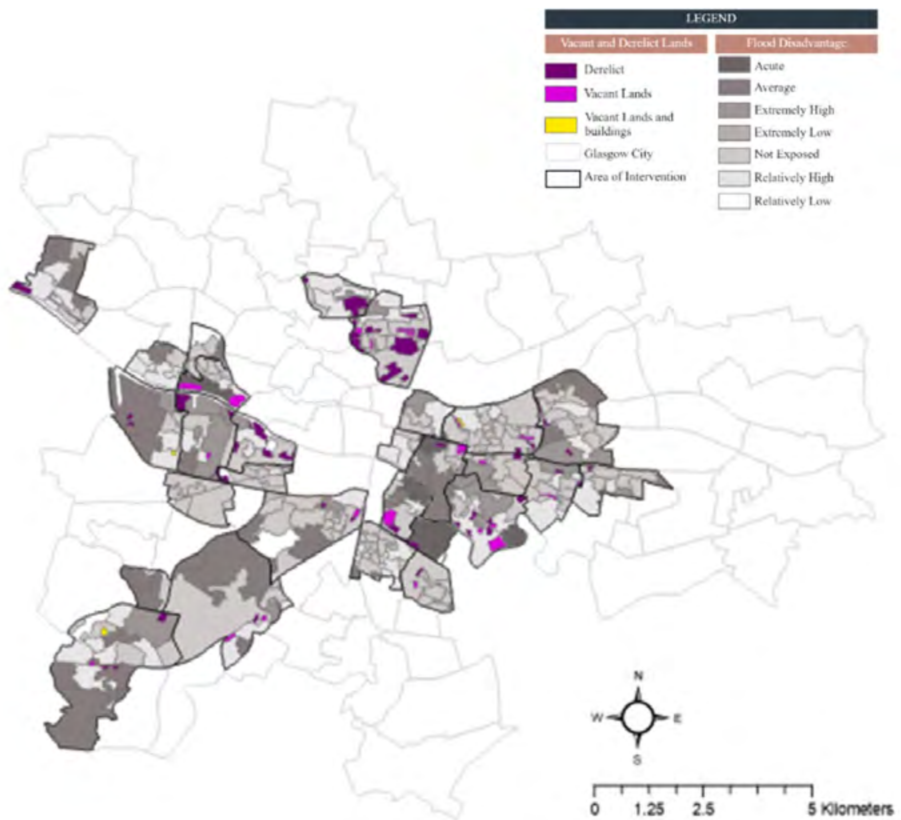

Figure 1. Areas of Flood Disadvantage and Location of Suitable VDLs

3.2 Exploring Themes

Utilizing a "Word frequency query" feature of the qualitative data analysis program NVivo 12, literature acquired as part of a preliminary assessment was examined based on recurrent ideas, concepts and terminology in agriculture and flood control (Bazeley and Jackson 2015). Through the software's "coding" capability, the topics were then grouped/"coded" to larger themes of hydrological processes, agricultural techniques, and vegetation features enabling a depiction of patterns sharing similar terminology or attribute. To determine the most pertinent themes, a cluster analysis of the codes (See Figure 22) was developed using the Pearson's correlation coefficient technique. An initial analytical framework was developed from this.

Agricultural Suitability

In the section 2.2, suitable areas of intervention were identified, but not every available piece of land can be used for food production (Cookson and Stirk 2019; Gulyas and Edmondson 2021), therefore, a land suitability analysis for UA in these land parcels is conducted in this phase using a suitability framework by (FAO, 1981). This step is essential for selection of crops and land management practice.

Indicators used for this stage were selected based on

i) sensitivity to management and reconditioning, and

ii) its sphere of influence on other agricultural productivity indicators.

Indicators selected from literature review were slope, soil permeability for drainage potential, depth and texture which were once again analysed through a weighted analysis classification in GIS.

Crop Suitability and Food Production Potential

Root Depth, Leaf Area Index, and Leaf Shape Factor were found as the most relevant qualities after doing a literature study, an expert score review, and an AHP pair-wise comparison to find relevant traits. These features were used to identify native crop species in Glasgow, and values for Total Yield of Crop Production and Total Nutritional Value were calculated at the ward level.

Land Management Potential

Land management practises contribute to increased runoff retention and agricultural productivity (Forbes, Ball & Mclay 2015), so a literature review was conducted to compile natural soil management practises suitable for urban soil conditions in order to improve their hydrological properties and, as a result, crop productivity. If appropriately assessed or managed, certain anthropogenic soil conditions have the potential to be altered and consequently utilised in urban agriculture (Weil and Brady 2015). Natural Flood Management measures, Best Management Practices (BMP) and Natural Water Retention Measures (NWRM) were summarised based on their goal of management of soil into short- or long-term management.

The indicators for agricultural suitability discussed in section (Agricultural Suitability), have been classified in into Ephemeral (Changes in routine management practises or weather can cause rapid changes from day to day), Intermediate (Subject to management over several years) and Permanent (Management has negligible effect on this because it is inherent in the soil profile or site) (Weil and Brady 2015). The classification allowed for the selection of indicators for the land suitability assessment based on how non-negotiable they were. Since other indications could be modified to some extent, permanent indicators were chosen for the final suitability assessment.

Flood Retention Potential

The Urban Flood Mitigation Model of the InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) programme was used for the hydrological modelling process to calculate runoff potential of the areas using the Curve Number Method (See Equation 1), with average rainfall depth values (160.69 mm) for the wettest month used for assessment. For the purposes of accuracy of assessment, the LULC raster map for Glasgow (UKCEH, 2021) available with broad habitat classes, was broken into subgroups with the use of topographic and green space maps to delineate permeability. Four scenarios were evaluated – i) Pre-assessment, ii) with crops iii) with land management practices and iv) crops and land management.

Equation 1: Curve Number Method

$$Q_{p,i} = \left\{ \int \frac{(P - \lambda S_{max_i})^2}{P + (1-\lambda) S_{max_i}} \; if \; P > \lambda . S_{max_i} \right\}$$

A 'Percentage Change' evaluation of the total volume of runoff produced is performed using Equation 2 to understand the extent of intervention for the scenarios, summarised in Table 3.

Equation 2: % change in Flood Volume Produced

$$F_{\%} = \left[\left(F_o - F_i \right) / \; F_o \right] \text{x } 100$$

Where,
F_o = Original volume of runoff produced without intervention
F_i = Volume of water runoff produced after intervention
$F_{\%}$ = Percentage change in volume of runoff
Food and Flood Production values were normalised by standardisation for assessment.

4 Results

4.1 Flood Retention Potential [FRP]

While the scenario using just crops exhibited little to none difference in the runoff retention, significant changes were seen in land management scenarios. The changes in scenarios 2 & 4 were mostly concentrated around the central part of the study area. This can be attributed to the combined effect of high VDL availability and LMP induced changes in the local hydrological conditions.

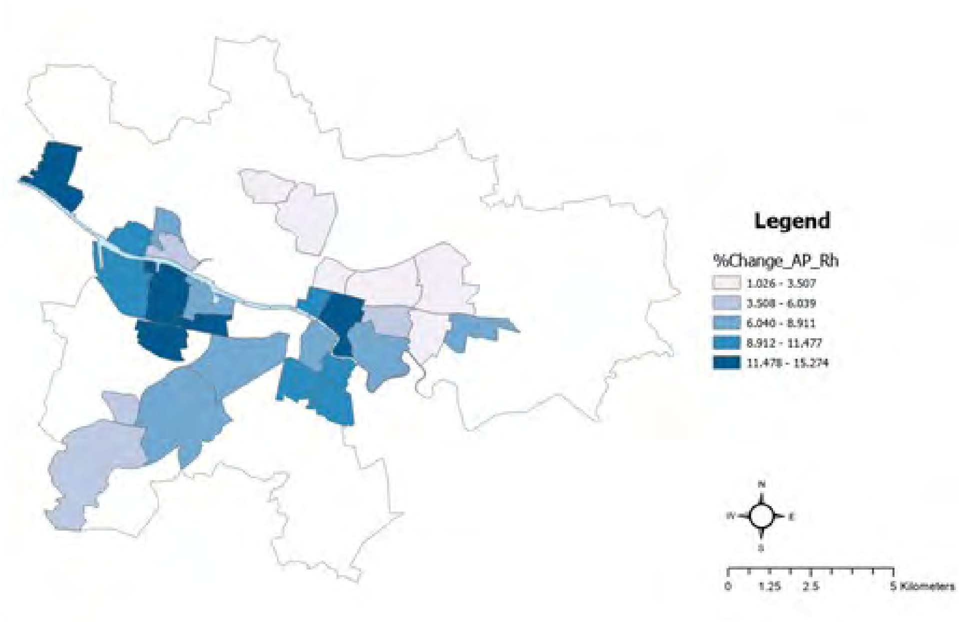

Figure 2. %change with Agriculture Practice and Crops

Table 2. Summary of Retention Values

Scenarios		Runoff Retention Index (%) [R_i]	Runoff Retention Volume per pixel (i) [$R\_m^3_i$]	Flood Volume (Total runoff produced in m^3) [Q]
1	Pre-Intervention	1.37	3504359.71	68028912.37
2	UA land-use	**1.380**	**3523263.283**	**68010008.060**
3	UA land-use with management	1.487	3803806.795	67729464.049
4	Land Management	**1.492**	**3804725.883**	**67728546.107**

Within the study area, the number of lands that are vacant is only 7 compared to derelict lands 15 in number, Vacant Lands were converted to agricultural lands but not derelict lands. Six of the 28 wards in the research region do not have any VDLs, and their assessment does not take into account enhanced hydrological soil conditions. The percentage change in flood volumes for each scenario presented in Table 3, represent the ability of UA in the adjacent areas to reduce flood runoff in these wards as well.

4.2 Food Production Potential [FPP]

The total Yield of Rhubarb from all the VDLs in the 22 council areas was estimated to be 303931.33 Kgs., whereas the nutritional value was found to be 63825.58 Kgs. 6 of the 28 councils do not have any food production potential and that aspect of reduced vulnerability is not addressed for them. A brief analysis of ward wise food production vs population shows, the largest % of households within the study area with 'dependent children and no adults in employment' produces only 86.32 Kgs per Ha, one of the lowest food production values. The wards producing the highest yields per Ha are mostly areas having the lowest income and health vulnerabilities.

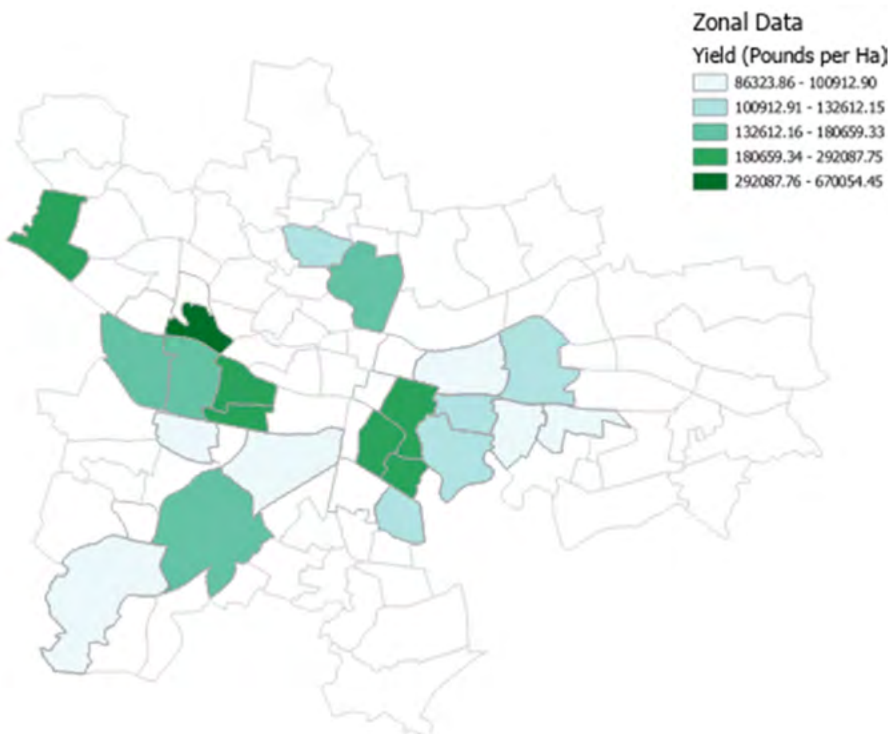

Figure 3. Rhubarb Production - Total Yield – (Gms per Ha)

The areas with highest production are not catering to the highest % of households inflicted with income and health vulnerabilities whereas the wards with the largest production yields are from derelict sites, since most of them fall into non-private ownership. This has potential for development but while there is space to grow, there also will be added costs of remediation, and that is why a cost benefit analysis is needed.

4.3 The Flood-Food-Potential Index [FFPI]

Therefore, for the development of the framework, key concepts relevant to the suitability of urban agriculture have been evaluated

i) Ecohydrological capacity of plants and

ii) land management practices in agriculture.

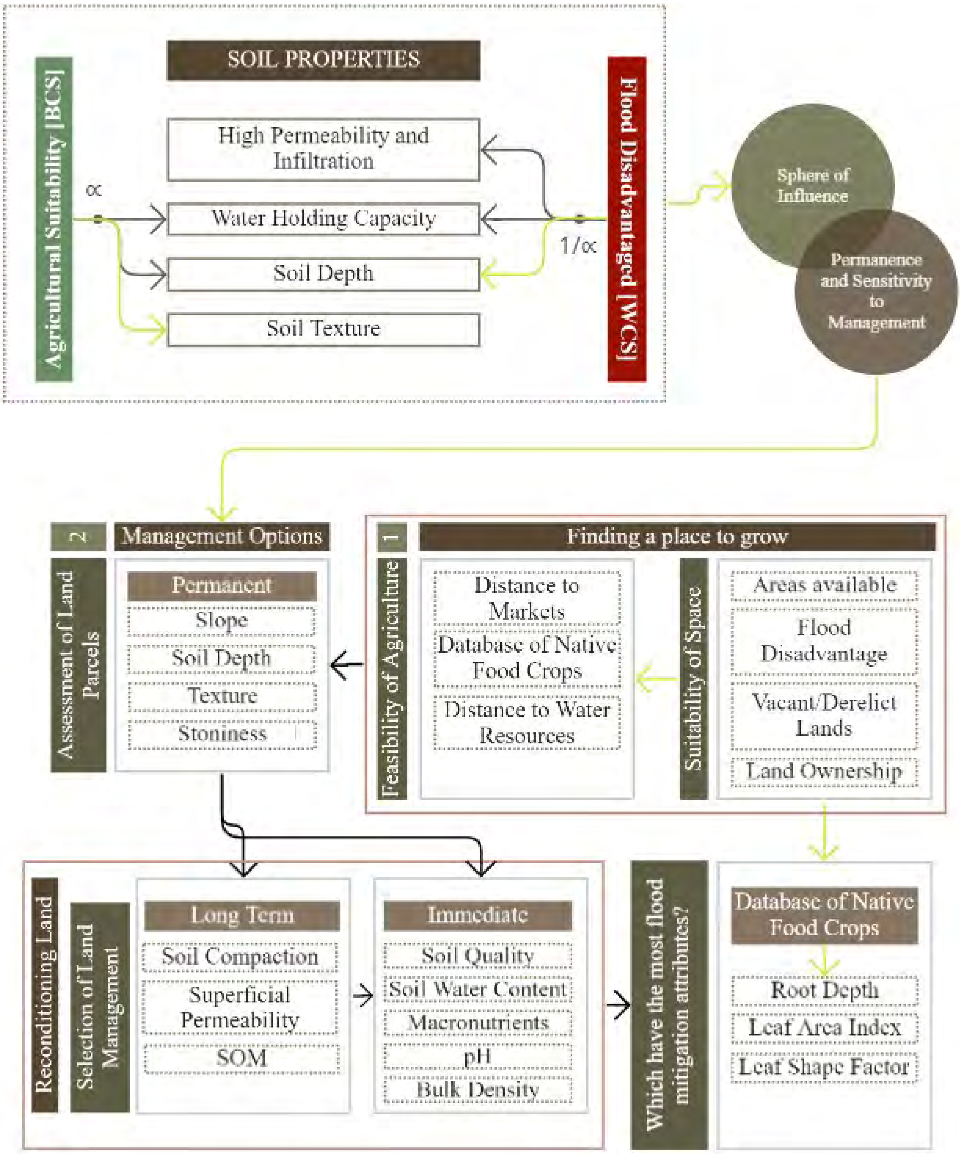

Figure 4. Processes engaged in the final data for framework

First, case studies and academic research were examined as a foundation for understanding how urban agriculture can reduce flood damage. Using the conditions of retention and production values, an integrative assessment framework is developed. The goal is to use the framework to identify regions where this intervention would be most effective in managing flood risks and food insecurity. The detailed findings of framework elements are organised into categories (Land Management Practices, Plant Morphological Traits, Suitability of Space and Agriculture).

The Flood-Food Potential Index is calculated from two sets of values i) the Food Production Potential [FPP] and ii) the Flood Retention Potential [FRP] and fed into Equation 3 to get unique FFPI Values.

Equation 3: The Flood-Food Potential Index

$$FFPI = f\ (\text{Average of Flood Retention \% Change, Food Production})$$

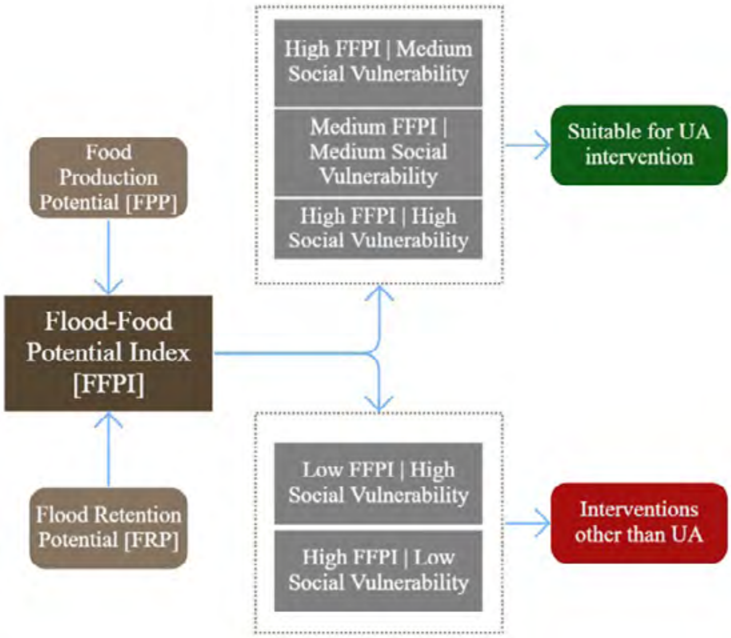

Figure 5. FFPI Framework for UA Suitability

The framework (FFPI) developed reflects vulnerability components of each of the societal challenges of flood and food disadvantage as well as the overlap of components and that UA shows capacity to address these.

The average size of areas of intervention having the highest FFPIs were found to be 21.5 Ha, most of the lands being derelict, therefore more cost of remediation. Seven of the twenty-eight wards do not have any VDLs but are within a buffer of 500m of other significant VDLs in neighbouring wards. So, while it won't have its ward wise production, it will partake in the benefits of percentage change in retention volumes.

The Food production values quantifying total yield per ha and flood retention potential providing values for % change in the total volume of flood retained. Based on the evaluation of land, various combinations of these sets of values can be achievers, guiding the decision for whether ward is suitable for a UA intervention or an alternative strategy.

5 Conclusions and discussion

Provisional Services: Two variables were consistently common across Food and Flood Disadvantage in the discussion (See Section 2). Income and health, while intertwined, each play important roles in shaping vulnerabilities. The results demonstrate production of food from both vacant and derelict lands in terms of area of production. The results are in accordance with the ability of UA's capacity to increase the quantitative access to locally produced sustainable food, thereby contributing to all aspects of Food Security - Accessibility, Availability and Utilisation, for low-income households of the global north. While UA plays a significant role in addressing the 'availability' component of food security, the results do not look at possibilities of crop diversification that can contribute to nutrition security. Furthermore, food production in the most vulnerable wards is under an idealised estimate of overall annual produce. The soil indicators selected for the framework are permanent indicators that are not affected by management or change. So, while these indications fulfil the production requirement, the total yield per VDL estimated is still reliant on a variety of other factors such as the usage of technology and the level of expertise employed (Opitz et al. 2016), as well as other soil conditions. and other soil conditions. Even in idealised scenarios, overall yield is insufficient to cover the whole food requirement of the entire population for each ward. However if individual plots of land's production capacities are insufficient to supply the food needs of entire populations, they provide urban regeneration chances with a 'economic multiplier effect' (Maantay, Park & West 2017).

Regulatory Services: When measuring flood retention in the study areas, the vacant land cover class was presumed to have undergone management akin to agricultural lands, with enhanced permeability. This scenario retained the most flood water, which is consistent with the concept that both urban and agricultural soils have the ability to manage hydrological processes when not compacted or sealed (Setälä et al. 2014).
Limitations

Despite the fact that UA can improve food security regardless of a community's income levels (Artmann and Sartison 2018), it does not take into account setting up costs - land reconditioning processes or infrastructure and support, which a community may be unable to afford. As a result, this intervention is suggested as a strategy for the local government in collaboration with local communities in a bottom-up approach.

5.1 Recommendations

The strongest benefits from floods are typically obtained by combining many different types of actions (Forbes, Ball & Mclay 2015). Therefore, this intervention will benefit the most when based on social data, as this intervention opens avenues of skill development, livelihoods, and income from food sale. Towards which, a toolkit that informs the framework developed in the paper, will ensure its sustainability in the long run. It is also essential that the intervention is supported by legal and regulatory frameworks.

5.2 Future Research

The analysis indicated that in untampered soil profiles, slopes had the largest influence dictating the formation of other soil indicators. Local anthropogenic influences, however, make these redundant by modifying the soil profile significantly, suggesting a local assessment of all available lands as a primary step for evaluation.

To build on the conclusions in Chapter 1, the study focused into UA's provisional (food) and regulatory services (water management). Despite these usually positive characteristics, literature shows unexplored trade-offs and synergies, such as cover cropping potentially boosting insects and pests (Artmann and Sartison 2018). As a result, in order for UA to be more efficient, a broader range of ecosystem services must be explored in order to determine which ecosystems will be delivered and which would be hindered when coupled with other urban ecosystems (Evans et al. 2022). Furthermore, because growing food in non-agricultural settings is a time-consuming and likely expensive operation, a cost-benefit analysis becomes essential. Furthermore, as growing food in spaces not designed for agriculture is a time consuming and probably expensive process, a cost benefit analysis is feels imminent.

Evapotranspiration Benefits: The study aimed at identifying patterns in the soil-plant continuum to improve the efficiency of agriculture but within the scope of the report, only assessed flood regulation through soil characteristics with evapotranspiration benefits largely unexplored. There is an opportunity for a scientific assessment of plant traits to generalise them in terms of their traits, which not only benefits agriculture but green infrastructure in general for disaster risk strategies.

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PAUDEL, SALONI

Reorienting SUDS

an integrated approach to urban regeneration and flood mitigation in Glasgow

Existing post-industrial cities frequently face a conundrum between urban renewal, addressing the demands for economic resilience and community well-being on the one hand, and coping with the unpredictability intrinsic with climate change-related risks on the other. Glasgow has many derelict lands that need redevelopment and a long history of urban flooding. This thesis investigates the implications of an integrated approach to strategic urban planning based on the amalgamation of Sustainable drainage systems for urban regeneration and flooding for meeting polycentric needs of today. Through multi-criteria decision-making spatial analysis, sites most suitable for using SUDS for regeneration and flood mitigation is found, which was 3.17 % of the total area of Glasgow. Dalmarnock is identified as a case study area and a microanalysis is performed using hydrology tool in ArcGIS. The rainfall data is analysed with climate change allowance of 40% and was found to increase by at least 31% in the next 30 years, and Dalmarnock lacks the drainage capacity to incorporate that amount of change. A cost-benefit analysis was done to compare SUDS and traditional grey drainage system. The kind of SUDS component to use for CBA was chosen based on SWOT analysis. Through analysis and expert interviews, the result inclined with retrofitting SUDS for urban regeneration & flood mitigation as decentralized SUDS provided not only drainage benefits, but benefits related to community, economy, and the environment.

1 Introduction

Cities have become separate entities due to their unique biophysical, thermodynamic, and morphological characteristics. (Bulkeley 2013) has affirmed that, even as the effects of climate change are already discerned, international and national policy-making communities remain more inclined towards mitigating these effects than adapting to them, which had formed the focus of the international climate change agreement in Paris in 2015. The matter remains troublesome as much of the current literature on climate change and cities focuses on mitigation rather than adaptation. The city of Glasgow, the host of COP 26 has gone through substantial changes in history, stemming from its industrial background. Like many of the European cities after WW2, it has seen immense Urban decline. The recent decades have brought plethora of positive changes in the city; but there is still a wide consensus about its existing obstacles. Two of the major concerns are urban flooding and urban regeneration. .The permeable surface on natural land is substituted by impermeable surfaces such as pavements and roofs (Ercolani et al. 2018; McGrane 2016), expanding regional impervious surface area, reducing hydrologic response time and eventually, increasing flood risk (Feng et al. 2021) For creating urban environments that can eliminate their negative impacts for achieving sustainability on a global level, while supporting human wellbeing in every aspect; there is an urgency to better understand how characteristics of the environment form people's everyday experiences. In an urban space, as the environment changes, so do the affordances of a neighbourhood, both in terms of what the area offers physically, by way of amenities, and in terms of scope for social interaction (Gibson 1979,19).

An unjust social relationship is based on an asymmetry of power or unequal value exchange between workers and their employers, which leads to labour exploitation (GCC 2018) and social inequality (Young 2011). Widened income gaps, growing inter-city disparities, suburbs that have been re-sorted into a wide array based on class and race or ethnicity, and many central cities which have assumed renewed importance within metropolitan areas are some of the features of contemporary cities (Nijman &Wei 2020, 6). The number living in urban centres has grown more than fourfold over the last 60 years; Today, the proportion of urban dwellers reaches 56.2%, compared to less than 15% in 1900 and 34% in 1960 (Satterthwaite 2021). The economy has shaped the environment and energy system, and the critical aspect of economy is, unfortunately, environmental destruction. There is a rise in inequality in cities worldwide, and some geographical regions will experience harsher climate change consequences than others. With more than half of the population dwelling in the cities, it is becoming imperative to design them in a way that the equilibrium between humans, natural ecosystems and socio-economy is uncompromised. In the 2030 agenda for sustainable development by United Nations, SDG 11 advocates making cities and human settlements safe, inclusive, sustainable, and resilient. This thesis will investigate two of the major issues in cities, urban flooding, and urban regeneration; through spatial and temporal lens, interviews, using site specific physical and historic factors.

2 Background

As the effects of climate change intensifies, the consequences of such urban problems are being more severe and imminent, risking the welfare of urban dwellers, especially in the areas of highest social deprivation. Urbanized areas of the world are in a dire need of a more radical vision that can effectively reduce the effects of climate change. One of the emerging ideas is to see urban regeneration and flooding as different sides of the same coin, as two mutually inclusive challenges that can be dealt with one single solution. The solution being the establishment of a different paradigm through the transformation of the hard infrastructures in the city into more natural landscape for the reduction in the ecological vulnerability. The overall objective of this thesis is to explore the surface water flood risk and urban regeneration to find their complementarity and is achieved through following design.

- To review and scrutinize the history of practice of SUDS and regeneration in Glasgow.
- To analyse the case of integrating SUDS with regeneration in Glasgow and develop insights
- To explore the commonality between urban regeneration and flooding.
- To advocate for a more equitable urban environment through wider SUDS implementation

Sustainable urban drainage systems (SUDS) are one of the most widely accepted Jargons for achieving the sustainability goals in the modern times. The pursuit of sustainability in urban water systems requires finding solutions that are valid now and are also able to accommodate future changes such as climate change or urban development, which is only possible through study and implementation of diverse adaptation measures (Lin et al. 2021). 61% of population in Glasgow live in 500m vicinity of vacant sites (GCC 2018). Vacant lands are given main priority in process of site selection for transforming these barren areas into a physically attractive, environmentally safe, and socially sustainable lands. Philosopher Mikhail Bakhtin, in his theory of the world as a "Shared Territory," states that life is dialogic, and a shared event; living is participating in the dialogue. Meaning comes about through dialogue at whatever level that dialogue takes place (Coghlan & Brydon-Miller 2014). Even though different actors can share meanings to an extent, their unique position will always create partially different interpretations. Similarly, the governments and businesses cannot solely determine the kind of infrastructure to use in any area for any purpose; Invention and collaboration must be present and transparent between the national, regional, and public levels for a sustainable development.

2.1 Green infrastructures

GI is defined by the (European Commission 2013) as "*a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services*". In the UK, GI is a broad term from green roofs and private gardens to the larger scale such as wetlands, forests, and agricultural land, according to the UK Green Building Council (2015). While doing so, stormwater gets collected where it is necessary to support urban vegetation; and this vegetation prevents the future runoff while engendering a range of environment, economic and social benefits. The Green Infrastructures/SUDS we will be looking at in this paper are Swales, Bioretention cells and Permeable Pavements.

Swales

It uses vegetated open channels, designed for conveyance of water. They are shallow with a flat bottom. They also provide aesthetic and biodiversity benefits. Mostly, they are used to drain a stretch of roads where it is convenient to collect the distributed runoff inflows. It can be used in place of the conventional pipework. A standard swale will facilitate sedimentation, filtration, evapotranspiration to further decrease the velocity of runoff flow.

Bioretention system

Bioretention systems are shallow depressions which are landscaped and often used in urban environments for treating water quality and to combat hydrological impacts of stormwater. They are very flexible with their size and therefore can be integrated into a wide variety of landscapes, ranging from a small area to a larger catchment area. They are also applicable to most developments, from residential to non-residential and even industrial.

Porous Pavements

Porous pavements provide the solution in creating a suitable parking/footpath area where the water when falls, infiltrates through the pavement and can be stored in the reservoir inside, causing no environmental consequences to the environment in times of heavy rainfall. Fully permeable pavements are characterized as that in which all layers are permeable

Cost Benefit Analysis

The application of SUDS retrofitting has been low due to lack of understanding of true costs and benefits and its maintenance. Even though the biggest part for total cost of SUDS is usually the capital cost, it also demands a long-term operation and maintenance cost. Cost and benefits of any SUDS scheme is highly contextual and will differ depending on the SUDS type, location, and site characteristics (CIRIA 2015)

- Net Value for project in N years= Net benefit in N years – Net cost
- Net cost (NC) =Present cost of Installation + maintenance cost (MC)

Benefit transfer

The benefit transfer method was chosen in this study for the valuation of benefits provided by SUDS. An increasing number of studies have been carried out in the UK to value amenities such as water quality improvements, the benefits of reduced air pollution and the value of ecologically important species (biodiversity) make use of other contingent valuation studies using a benefit transfer approach. When the characteristics of two study areas are similar, properties of one area can be a good indicator of the range of possible values another area could have, had the CV was performed in that area (Ballard et al. 2015).

Spatial Analysis Tools

Spatial analysis tool such as Weighted Overlay and Multi-criteria decision analysis were used to find site suitability of SUDS. Land suitability mainly deals with a large amount of data and involves multifactor. Weighted Overlay is performed by overlaying classified datasets (using reclassify tool), such as soil type, land cover, or topography, for a defined area, assigning a weight to each dataset, summing the values of each vertical cell stack, and then evaluating the resulting composite map (Collins et al. 2001).

3 Methodology

An inductive approach, which generates meanings from the data set collected to identify patterns and relationships to build a theory; and learn from experience, is used. Mixed methods allowed the use of qualitative and quantitative methods. Literature review and interviews helped curate existing research and expert advice, which informed the quantitative studies-spatial analysis, rainfall analysis and cost benefit analysis. The research follows a case study in Dalmarnock, to give a definitive answer to the research question- can we make a more sustainable Glasgow by using SUDS as a common solution to urban regeneration and urban flooding?

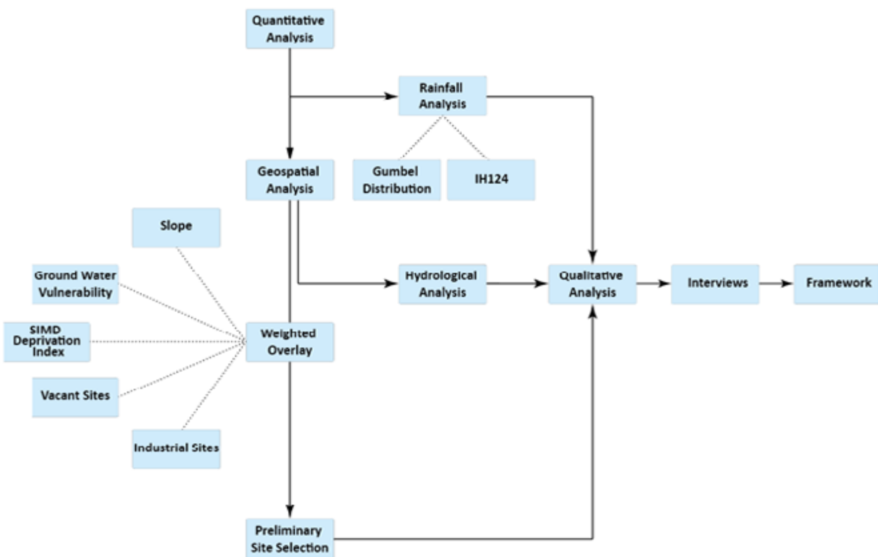


Figure 1. Methodological process (Paudel 2022)

3.1 Study Area Dalmarnock

Back in the early 1900s, Dalmarnock used to be Glasgow's industrial spine. The Deindustrialization after the second world war made this once thriving place, a ghost town. The population exponentially decreased from 50,000 in the 1950s to around 2000 because of post-industrial decline and dereliction.

3.2 Geospatial Analysis

3.2.1 Weighted Overlay

Readily accessible industry standard georeferenced data have been used during the selection process which has been adopted from (Charlesworth et al. 2016). Five criterions considered in the study were slope, distance from vacant sites, distance from industrial sites, groundwater vulnerability and Income deprivation (from SIMD maps) to perform a GIS analysis to design SUDS. Externally and internally, weights are assigned to each raster layer based on their relative importance as determined by expert opinion. Internal weights or rating values are referred to as class values, and external weights or weight values are overall weights of all layers that must equal 100. Each individual raster cell is reclassified into units of suitability and multiplied by a weight to assign relative importance to each and finally add them together for the final weight to obtain a suitability value for every location on the map; this can be interpreted by Eq. (1) (Eastman, 2005).

$$s=\Sigma w_i\ x_i \ \ldots\ldots\ldots\ldots\ldots\ldots \ (1)$$

where,
w_i = The weight of ith factor map
x_i = Criteria score of class of factor
s = Suitability index for each pixel in the map

The total weights of each pixel of the final integrated layer were derived from the following equation.

$$S= DI_f\, DI_C + SL_f\, SL_c + IL_f\, IL_c + VL_f + V\, L_C + GV_f + GV_c \quad \ldots\ldots\ldots (2)$$

S= dimensionless quantity that helps in indexing suitable sites for SUDS implementation in the area.
DI=Deprivation Index; SL=Slope; IL= Industrial Lands; VL= Vacant Lands; GV= Groundwater Vulnerability; f= weight of each criterion; c= weight of each class of individual factor

3.3 Hydrological analysis

One of the design features of SUDS is to harvest and use the rain close to where it falls, i.e. source control (Ballard et al 2015). With the in-built hydrology tool in ArcGIS, the areas with highest flow accumulation during the precipitation can be generated with these steps.

1. Obtain **DEM**
2. **Fill** DEM to filled to ensure that there are no irregularities that could affect the layer's outcome.
3. The **Flow Direction tool** is then used to calculate which direction water will flow along the topography using the Filled DEM as input data.
4. **Flow Accumulation** is observed using the newly developed Flow Direction Raster, which shows where water collects to form streams and basins.

3.4 Rainfall Analysis

It is not possible to find the exact runoff rate for rainfall at any site. The general objective of using an agreed method is to provide a consistent, reasonable, and ubiquitous estimate upon which storage design can be based (Ballard et al. 2015). Rainfall analysis was performed to find 1 in 30-year storm event using two different methods, Gumbel distribution and IH124 method.

Gumbel distribution

The Intensity Duration Frequency relationships is used in conjunction with the rational method to determine peak discharge from a catchment area for design of hydrological structures using the expression in 1

Q=CIA………… (1)

Where Q = the design peak runoff rate in m^3/s, C = the runoff coefficient, I = rainfall intensity in mm/hr for the design return period and for a duration equal to the "time of concentration" of the water shed, A = the watershed area in hectares.

Pt= P24*(t/24)^(1/3)
Xt=Mean+STD*kt
K=(Yt-Yn)/Sn
Yt= -[Ln.Ln(t/(t-1)]

Pt= required rainfall depth in mm at t-hour duration; K = Frequency Factor is a function of return period and sample size; Sn=Standard deviation; Yn= Expected mean

IH124 Method

$$Qbar_{rural}=0.00108AREA^{0.89}\ SAAR^{1.17}\ SOIL^{2.17}$$

Qbar= Runoff rate
Area - Catchment area
SAAR - Average annual rainfall in mm (1941-1970) from FSR figure II.3.1 or equivalent.
Soil - Soil index of the catchment from FSR figure I.4.18 or Wallingford Procedure Volume 3. Soil classes 1 to 5 have Soil Index values of 0.15, 0.3, 0.4, 0.45 and 0.5 respectively.

Interviews

All interviews were conducted virtually and recorded and transcribed with the permission of the interviewees according to standard process. Interviewees were asked semi- structured questions and transcripts were used to identify codes which were clustered into themes to distil key ideas.

4 Results

The highest rainfall was achieved through the IH124 method i.e 1143.36 l/s and 1789.06l/s, when climate change allowance of 1.4 was input; and this was chosen as the design storm intensity. It also meant additional 31% drainage capacity due climate change. The current drainage system in Dalmarnock cannot cope with any further increment in rainfall. Thus, we explored the alternatives in drainage management to choose the site-specific and most efficient option for Dalmarnock.

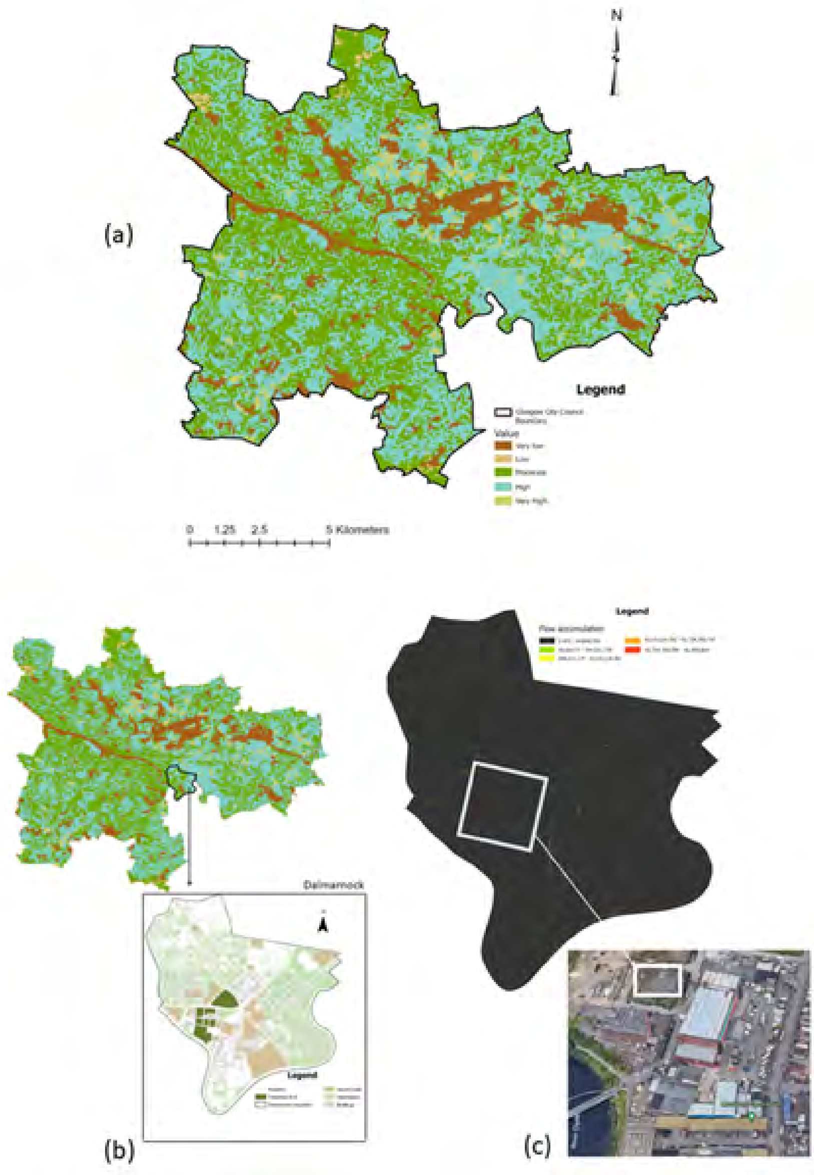
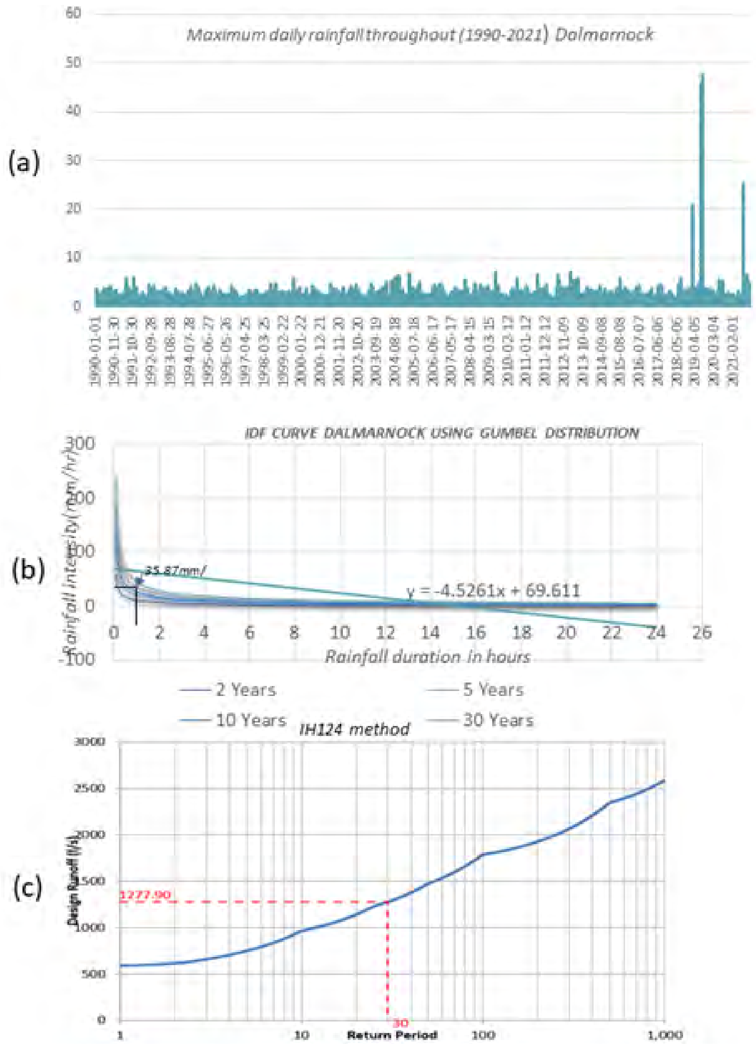


Figure 2. (a) Suitable sites for SUDS (land suitability analysis) (b) Land-use map of Dalmarnock (c) Flow accumulation raster and final site for SUDS (Paudel 2022)



(d)

1 in 30 years	Gumbel method	IH124 method	Remarks
Peak Rainfall	816.69l/s	1227.90l/s	
Climate change allowance (40%)	1143.366l/s	1789.06l/s	40%allowance(Susdrains, 2020)

Figure 3. (a) Maximum daily rainfall Dalmarnock (b) IDF curve using Gumbell distribution (c) Design runoff using IH124 method (d) 1 in 30 years peak rainfall with climate change allowance of 40% (Paudel 2022)

There is two options to choose from. One is expanding the traditional grey system and the other is using retrofit SUDS system to tackle the drainage problem. Moreover, what kind of SUDS component can be used to gain multitude of benefits? This question was addressed through a site-specific SWOT analysis of 3 SUDS components, Bioretention system, permeable pavements, and swales.

Bioretention system was found to be the most suitable SUDS in our site for three major reasons: (Ballard et al. 2015)

1. High runoff pollutants in the site due to existing morphology (parking spaces, Wastewater treatment plant and pharmaceutical pollutants)
2. Highly dense area with limited space.
3. To increase greenspace and enhance biodiversity.

4.1 Cost-benefit Analysis

From the unit costs of bioretention system obtained from guidelines (Ballard et al 2015), (DOEE 2018), (Stevens & Ogunyoye 2012) , benefit transfer framework (Flood Authorities 2013) and PESTEL analysis, it was evident that green infrastructures can provide a more holistic development in Dalmarnock, which will benefit the society, biodiversity, and environment, which grey alone cannot.

4.2 Interview Analysis

4.2.1 Infrastructure first approach

If blue-green infrastructure for water management is considered early as part of an "infrastructure first" approach, then Suds for flood risk control can easily be integrated inside urban regeneration. In the past, regeneration hasn't used an infrastructure-first strategy, thus any SUDS that were provided—if any were provided at all—were done so as an afterthought and weren't very good. The emphasis was frequently on keeping watercourses at the back of houses and burying them underground in pipelines or culverts. The water reaching the surface must follow gravity flow and to achieve that, the conveyance flow paths for water must be highly considered from the beginning of the design process. This will facilitate the integration of the SUDS with other regeneration components, such as public open space and access routes, to provide an integrated approach to blue green in the urban realm that can provide numerous benefits, including flood risk management, a habitat for biodiversity, urban cooling, battling pollution, noise reduction, and general health and wellbeing benefits.

4.2.2 Scaling up suds retrofit

The main issue facing Glasgow, like most cities throughout the world, is that most of the wastewater (sewer) network is a "combined" drainage system, in which surface water and foul flow are merged. As a result, it is insufficient to handle climate change and growing urbanisation, which will bring more heavy rain and overburden the system, leading to CSO overflows and flooding. Keeping this in mind, investment in retrofit SUDS for urban areas is increased, to attenuate flow to the combined system. Interviewee responded that SUDS delivery for new (re)developments is generally good, but SUDS retrofit for existing areas needs to increase in its scale and ambition. There is scope for better integration of blue-green approaches, rather than below ground storage areas and permeable paving, but often the choice of SuDS measure is dictated by the available space. Moreover, In Glasgow, and elsewhere in the UK, there is a lack of quantitative monitoring of SUDS, which means there is a lack of data on the long-term performance and benefits of SUDS.

4.3 SUDS in the city

In the case of regeneration in the city; for private investors to invest in SUDS, High quality delivery of SUDS remains a challenge as the density of development, for commercial reasons, is the main driver of regeneration. The public investors, nonetheless, do not have the commercial motive and hence can stay on the frontline and lead by example. Glasgow City Council has delivered a number of surface water management plans, the Avenues Project will deliver significant retrofit in the city centre, the Liveable Neighbourhoods programme should deliver SUDS, and the Active Travel programme should also deliver SUDS alongside active travel routes

Interviewee responded that it is a very practical approach to use SUDS for regeneration and flood mitigation. Furthermore, when it comes to funding, when we showcase the pay benefits together, it attracts more money.

4.4 North Glasgow SMART Canal project: A successful regeneration with SUDS

The current drainage system in North Glasgow is not fit for purpose because it has exceeded the combined sewer capacity, and therefore substantial amounts of land had been rendered unusable. The smart canal and SUDS approach will provide North Glasgow with a fully functioning drainage system which is able to dynamically respond to fluctuating precipitation, thus, freeing up previously unusable land to developers. It is estimated that almost 110 hectares land will be unlocked for regeneration, investment, and development. The Smart canal uses grid infrastructures such as sensors with Sustainable urban drainage systems. SUDS play a crucial role in slowing the water down so that the canal takes its time to get filled in the event of the rainfall. The interviewee responded that's deliberately regeneration. It's also connected to the Claypits local nature reserve, which is now very, very well used in terms of health. Furthermore, because of that, the NHS Scotland put in 100,000 so that there was a link between two of the health centres in the area. And they're deliberately using the local nature reserve as a therapy tool. What's even more great is Scottish government are trying to make these regenerated sites, a 20 mins community, promoting more sustainable living for the residents including active travel and social cohesion (Hayes & Ian 2022) (Hayes & Ian, 2022). The Smart Canal is helping to manage flood risk, allowing areas of the city to be regenerated whilst also providing safe active travel routes for people to walk, wheel and cycle.

5 Conclusion / Discussion

One of the major reasons SUDS type approaches is not a priority was simply because there is no pressure from the government for using redevelopment as an opportunity to reduce drainage load on conventional systems. (Evans &Jones 2008) argued that we need to avoid the meaning of sustainability to the assessment of predetermined benchmarks or policy goals, both within the regeneration literature and across studies of sectoral planning policies and begin a more wholesome practice. Even with a personal interest in these kinds of systems, no organization or person would push the matter if it were not a matter of compliance and was not a priority for the client. From the qualitative analysis we can derive that there is enough technical guidance and data to execute the use of new or retrofit SUDS but from interviews and literature study it's safe to conclude that there is a strong lack of institutional and political efforts.

Regenerated urban areas improve flood resilience and allow society to better weather potential flooding while at the same time providing a better living space The knowledge and needs related to the challenge or opportunity for SUDS for regeneration and flood mitigation was identified through literature, interviews, and analysis. Even though Scotland has not yet fully utilized its SUDS potential, it was found to be quite active in its strategies with it in recent years, especially Glasgow. As described throughout this thesis, SUDS can be an excellent adaptation strategy against climate proofing and adapting the cities against climate change. Additionally, SUDS benefits include the removal of pollution as well as possible co-benefits, such as carbon sequestration, support to biodiversity, social and economic use of spaces. Scotland has got the technical support to do this, but what it lacks is institutional and social pressures. Given the climate risk, identifying optimal opportunities to build, or retrofit SUDS must be a top priority for urban planners and governments.

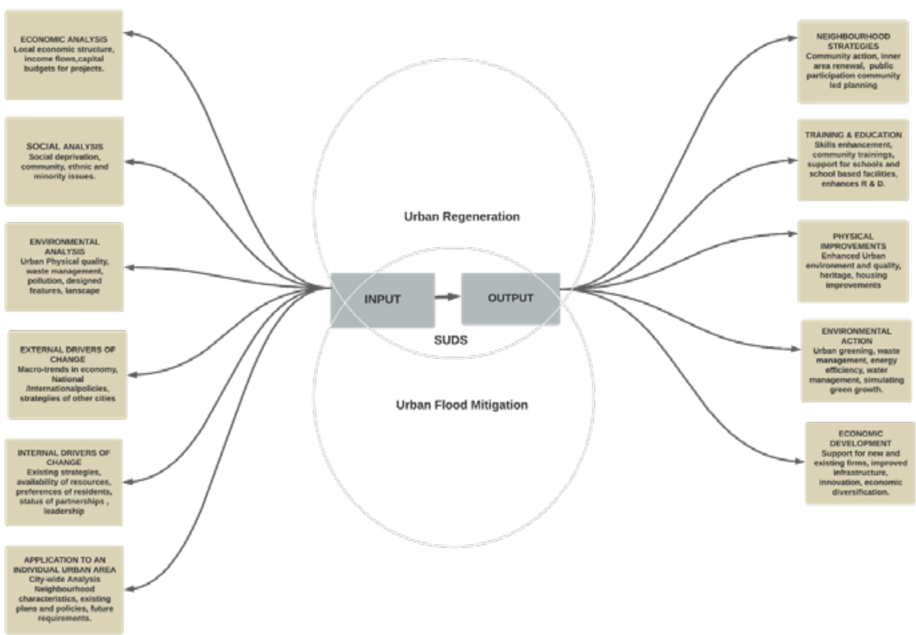


Figure 4. Adaptive system through SUDS for Urban regeneration and Urban flood mitigation (Conceptualized from Robert&Sykes 2003)

There seemed to be an inherent interdependent relationship between Urban flooding and Urban regeneration, an interplay, as one thing could not be achieved without another. SUDS used for regeneration provides flood mitigation benefits, and SUDS for flood mitigation provides amenity benefits, regenerating the area. Moreover, both uses for SUDS provide other similar and more comprehensive community benefits, neighbourhood resilience, environment revival, even economic benefits. Urban regeneration can be a more extensive umbrella of which flood mitigation is a part, and the sectoral policies should soon realize and incorporate it in cities.

- Some of the key challenges that were outlined was
- SUDS retrofitting is expensive and typically disruptive. Other than the Scottish Government Capital Grant and the Nature Scot Nature Restoration Fund, there aren't many financing sources available to implement retrofit SUDS.
- There is a lack of local government funding for maintenance of open spaces, including parks and SUDS.
- There is a scarcity of integration between Climate mitigation (net zero) activities and Climate adaptation activities. As climate mitigation actions are pushed forward to try to deliver 2030 and 2045 net zero goals, there is a lack of consideration of also delivering climate adaptation benefits. This lack of collaboration risks widening the 'Adaptation gap'.
- To find ways to introduce more private finance and urban green infrastructures.

Recommendations

1. Glasgow needs to come up with creative ways to allocate funding for SUDS. The issuing of green bonds from organizations like the Glasgow City Council, allowing investors to get a more secure return on their investment could be a way to attract more money for SUDS.
2. Because retrofitting SUDS is disruptive to the ground, the utility service providers and SUDS professionals are recommended to have a better coordination.
3. Due to the growing risk within FRM, regeneration initiatives call for collaboration among all parties involved in the risk chain to proactively reduce risk and improve the city's and citizen's health.
4. Rather than fragmented or governance strategies, there should be deeper integration between flood management and regeneration; and this thesis suggests we achieve it through SUDS.

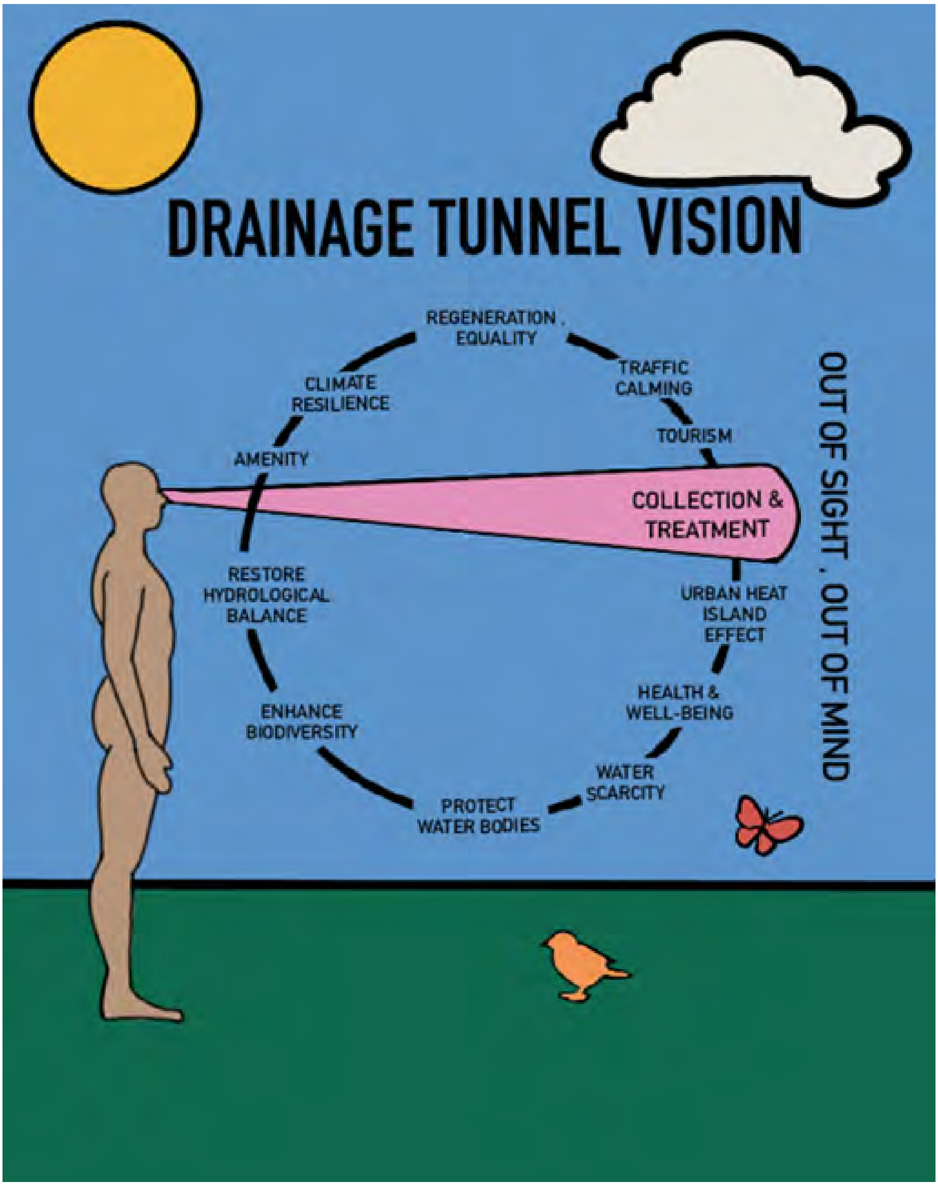


Figure 5. Drainage tunnel vision (Paudel 2022)

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Climate Change Management

AMIR, KHADIJA

Evaluating climate change consideration in the Pakistani EIA framework

This research project aimed at evaluating the integration of climate change impacts and adaptation into the Environmental Impact Assessment (EIA) process Pakistan. The research analytically reflected on the role played by EIA in addressing climate change in development decisions. The project also critically looked at the planning process, if and how climate change is considered, and what are the practical difficulties in integrating aspects of climate change impacts and subsequent adaptation. Based on the results of the empirical research, and on the identification of best practices, possibilities for incorporating climate adaptation in EIA was explored by developing a framework for possible entry points.

1 Introduction

Climate change has become a serious global challenge to sustainability. Human-induced climate change has resulted in widespread adverse impacts on human and natural systems that is beyond the natural climate variability, pushing them past their ability to adapt (IPCC 2022). In addition, society's vulnerability to impacts induced by climate change make it a serious economic development threat (Agrawala et al. 2012). The seriousness of the potential impacts has led to many researchers calling for an urgent response. The need to consider climate change and associated impacts in development decisions (including spatial and sectoral policies, plans, programmes and projects) has been recognised widely (Agrawala et al. 2012). In this context, Agrawala et al. (2012) suggested that "the project level is critical for the consideration of climate change risks and for incorporating suitable adaptation measures".

National governments, development co-operations and international financing agencies have developed methodologies and tools to screen projects for climate related risks (e.g., climate proofing). However, most of these tools are used as stand-alone products and lack harmonisation. In this context, both Strategic Environmental Assessment (SEA) and EIA are well-established environmental decision-making support instruments, with legal requirements in many countries. Both EIA and SEA can be a key instrument in addressing climate change issues in a more standardised way (Sok et al. 2011, Agrawala et al. 2012). Jiricka et al. (2016) have referred to several studies that explained impact assessment tool's potential suitability for integrating climate change impacts and adaptation considerations within existing project, plan and programme modalities (design, approval and implementation).

EIA is defined as 'the process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made' (International Association for Impact Assessment 1999). Since 1969, EIA has emerged as an important instrument for decision-making globally, recognising human-induced environmental change (Morgan 2012). Considering implementation, EIA being a systematic and publicly accepted process worldwide, inclusion of climate change impacts and adaptation into existing EIA process can lead to positive change.

EIA's potential suitability for addressing climate change impacts and adaptation is supported by the available professional literature. In this context, Hands and Hudson (2016) identified the need for further research on "how to consider climate change impacts from existing developments and activities and should evaluate the lessons learnt from integrating climate change into impact assessment". So far, there has been limited research into the consideration of climate change impacts and adaptation (Larsen 2014; Hands and Hudson 2016) particularly in an urban climate context. Therefore, identifying and evaluating the effectiveness of climate change adaptation approaches is an important step towards incorporating climate change impacts and adaptation into EIA practice.

1.2 Aim and Objectives

This research project aims at evaluating the current practice in considering climate change impacts and subsequent adaptation as part of the EIA process. The study attempted to address the following objectives:

1. Evaluate the planning and EIA process/tools for projects in UK and Pakistan (current practices).
2. Identify EIA case studies and evaluate the role and effectiveness of EIA tools in consideration of climate change impacts and subsequent adaptation.
3. Identify entry points for climate change impacts and most suitable adaptation approaches in EIA (including recommendations for regulatory framework).

2 Background

Given the changing climate, the need for people to adapt is undeniable, making room for adaptation to become a central focus of climate policy (Khan and Roberts 2013). Numerous stand-alone methodologies and screening tools have been developed to identify risks posed by climate change associated with major activities (Hands and Hudson 2016). However, integrating climate change consideration into existing project modalities such as EIA, in combination with SEA (Fischer et al. 2011), is considered a more effective approach (Agrawala et al. 2012, Jiricka et al. 2016).

Countries world-wide are implementing measures to achieve CO2 emission reductions, in an attempt to meet the universally agreed target of 'holding the increase in the global average temperature to well below 2 °C above pre-industrial levels' (Paris Agreement 2015). However, there is growing concern that the national targets are not reflected in regional or state-level plans as these are not considered in SEAs conducted as part of the planning process (for example in sectors such as housing, transport, agriculture, energy) (Wende et al. 2012). There has been attempts by states (UK, Australia, the Netherlands, Canada, Ireland), international organisations (IEMA, The Environment Agency with Natural England, UNDP), and academic literature in highlighting the role SEA can play in incorporating climate change consideration into spatial and sectoral planning (Yang et al. 2021). At the project level, a systematic process to assess the environmental impacts of development actions in advance (Glasson & Salvador 2000), EIA is practiced in nearly all close to 200 countries and is enforced legally in over a hundred countries (Fischer and Nadeem 2014). Where a legal requirement for EIA is absent, it is practiced voluntarily or through financing requirements such as those by development banks e.g., the World Bank, and Asian Development Bank (Fischer and Nadeem 2014). Hence, EIA's global acceptance has rendered it one of the more successful policy innovations (Sadler 1996).

The potential of integrating climate change (both mitigation and adaptation) into EIA has received much attention recently (Larsen 2014). The EU Directive 2014/52/EU on EIA recognised climate change as an important new challenge. A number of researchers have looked into the possibility of addressing climate change issues through EIA and SEA and proposed methods for doing so (Byer and Yeomans, 2007; Wende et al. 2011; Agrawala et al. 2012; Sok et al. 2012; Larsen et al. 2013; Ohsawa and Duinker 2014; Larsen 2014; Jiricka et al. 2016; Hands and Hudson 2016). Byer and Yeomans (2007) reviewed environmental assessments in Canada and concluded that climate change received inadequate coverage and proponents faced major problems in effectively addressing the uncertainty of changing climate into the assessment. The outcome of a study conducted by Agrawala et al. (2012) highlighted several challenges such as gaps between the intent to incorporate climate change adaptation in EIA and actual practice and the availability and uncertainty linked with climate change data at project scale. However, the study also demonstrated the potential success of incorporating climate change impacts and adaptation within existing project modalities such as EIA. Yi and Hacking (2012) suggested that including requirements for GHG emissions assessment in EIA will encourage low carbon developments and meet the Sustainable Development Goals.

Ohsawa and Duinker (2014) proposed that reviewing previous EIAs can play an important role in understanding the challenges of estimating GHG emissions from individual projects and the associated uncertainties, therefore the review may help identify practical approaches to GHG emissions at project level. The research examined 12 EIAs conducted in Canada under national legislation to see how GHG emissions were dealt with. It is common practice within the Canadian EIA system to assess GHG emissions from projects and propose suitable mitigation to offset the negative impact. The study concluded that large emitters proposed concrete measures, typically in the form of new technology for emission reduction. However, other measured proposed are marked with ambiguity and determining the actual impact of these measures proves to be difficult in terms of real effects. Another challenge identified was the ambiguity and/or inconsistency with respect to the definitions and significance of GHG emission levels.

Similarly, Jiricka et al. (2016) explored the inclusion of climate change into the existing EIA practice in Austria and Germany, two EU member countries where consideration of climate change in regional and urban/local planning has been suggested in various instances. Various EIA stakeholders have found that dealing with climate change in a specific local context is a challenge and this study attempted at tackling the existing "science-policy-practice-divide" with regard to climate change consideration in EIA in Austria and Germany. The study concluded that both the Austrian and German EIA practice shows that climate change is addressed to a limited extent only. Throughout the cases reviewed, climate change was considered at explicit steps in the EIA and not throughout the EIA process as a whole. Several concrete links were made in EIAs of both countries to meteorological phenomena that could be affected (climate change stressors), potentially leading to climate change impacts. As for climate change adaption, any direct reference to adaptation within the EIAs is still quite limited. The results deduced qualitatively demonstrate occasional consideration of climate induced impacts which receive an occasional mention (1-2 times) without being mentioned in every chapter of the impact statements therefore not integrated through EIA process in its entirety.

Underwood et al. (2021) reviewed current practices in considering greenhouse gas emissions in SEA and EIA in Scotland, UK. As part of the project, 10 EIAs and SEAs each were reviewed across a wide range of projects to ascertain a) methodologies used to assess GHG emissions impacts; b) level of details included in EIA and SEA; and c) reporting and further communication on these GHG emissions. The review of EIA case studies (2009-2019) showed that majority of the EIA studies did not include GHG emissions baseline data. Two studies only included GHG emissions data for the national, drawing more on wider impact rather than project-specific impacts. Of the 10 case studies evaluated, six incorporated some level operational GHG emissions quantitatively. As for details on the GHG emissions - direct, indirect, and embodied emissions, only four cases provided these details. The study demonstrated an indication of good practice where quantification of GHG gases in EIA is concerned. It is a noteworthy finding given the fact that the requirement for incorporating GHG emissions in EIA was formalised in 2017 only. As this is fairly recent, the study also indicated that EIA practitioners are invested in advancement of their experience in GHG emissions impacts assessment.

The current professional literature calls for more action in terms of research into integrating climate change consideration within the EIA framework. The integration of considerations of climate change impacts and subsequent adaptation within EIA framework is a complex endeavour and poses fresh logistical and theoretical problems.

3 Methodology

The project entailed an extensive review of available literature to familiarise with the planning processes in Pakistan and UK (for best practice), climate change adaptation approaches and how these can be integrated into the EIA system.

The next step of the analysis comprised of a detailed study of EIA reports for selected projects from Pakistan and UK. A simple review checklist was developed for these reports to gauge the extent of climate change impact and adaptation coverage. Review checklists are commonly used in impact assessment. Finally, key issues were identified from literature and expert interviews. Six semi-structured interviews with relevant EIA stakeholders (for example, project developers in the applicable sectors, impact assessment authorities, practitioners and consultants) were conducted. The data was analysed qualitatively (for example, as in Jiricka et al. 2016).

Once the analysis phase was successfully completed and several potential solutions were identified, possible approaches and entry points for climate change assessment and subsequent adaptation were put together for integration into the EIA processes. A detailed review of the of the regulatory framework (including obligations under international and national agreements to address climate change) and practice (EIA reports) was conducted to identify gaps within the legislation and recommendations were made to address these gaps. Based on this information, entry points were identified for inclusion of climate change impacts and adaptation approaches.

3.1 Key Method: Systemic Literature Review

As mentioned above, systemic review of published literature was conducted for published work between 1990 and 2022. This included a mix of academic and non-academic publications in the form of research papers, legislation, guidance documents and reports prepared by industry for best practice.

The review identified 32 articles, 15 guidance documents, 23 legislative pieces. The systematic literature review conducted for this study and the findings have informed the results and discussions presented in the following chapters.

3.2 Key Method: Analysis of EIA Documents

A simple review checklist was developed based on the checklists commonly used to determine the quality of environmental assessment reports (Baker and Wood 1999; McGrath and Bond 1997; Sandham and Pretorius 2008) as specific checklists for evaluating the integration of climate change into EIA have not been established yet.
In order to determine how and to what extent climate change is evaluated and subsequent adaptation currently considered in EIA practice in the UK and Pakistan, a comprehensive review of EIA reports was conducted. The evaluation of EIA reports was conducted through a comprehensive list of search terms developed by Jiricka et al (2016).

3.2.1 EIA Sample

A total of 18 EIAs were evaluated from Pakistan and 17 Technical Summaries the UK. The type of reports reviewed included documents from the project approval stage and were part of the following:

- EIA reports (Pakistan)
- Technical Summaries (UK)
- Technical Documents
- Statements from authorities

3.2.1 Content Analysis

The content analysis was a two-stage process as adopted by Jiricka et al. (2016). First, all the EIA documents were searched for direct reference of climate change. This was done to determine the relevance of these terms to climate change and EIA. These terms included:

- Climate change
- Climatic change
- Climate change impacts
- Climate change adaptation
- Vulnerability
- Scenario (connected with climate change)

In addition to direct reference of climate change, an analysis of climate stressors was also performed. These include meteorological phenomena that are known to be exacerbated by climate change for example heavy precipitation or storms and the associated impacts both at present and those that could have an impact in the future as well. Climate stressors were identified based on national (IEMA and EPA) and international climate change adaptation strategies (EU Commission 2013 b,c), outcomes of previous research projects and literature review (Dalhammer et al. 2015; Jiricka et al. 2016; Balla et al. 2017).

3.3 Key Method: Stakeholder Engagement

Stakeholder engagement is an important aspect of this study as it helps canvas views of experts in the field. The main objective of stakeholder engagement was to understand:

- The challenges and limitations associated with current approaches to collecting data and reporting on CC impacts particularly GHG emissions in EIA.
- Any good practice EIA examples, particularly in terms of format and detail.

Semi-structured interviews were conducted with stakeholders to understand their perspective on potential integration of climate change impacts and adaptation into the EIA framework and what issues and challenges they anticipate. The interviews were conducted to primarily get expert views on the following questions based on their experience with impact assessment tools:

- Has climate change and associated impacts been considered in project planning and IA tools?
- If yes, what stages of the planning process and EIA are these impacts considered and how?
- What type of data is collected throughout the planning and assessment process to gather relevant information re climate change impacts?
- For future consideration, what kind of necessary support will be required to consider impacts of climate change in EIA?
- At what stages of EIA is it important to include assessment of climate change impacts and associated adaptation?
- What are the practical difficulties in integrating climate change impacts and adaptation in EIA?
- What aspects of the planning process needs to change in order to allow for integration of climate change impacts and adaptation?

3.4 Legal Framework for EIA in Pakistan

Environmental management and development of related legislation has gradually gained importance since the 1970s. Pakistan was among the first countries to regulate development decisions through introduction of EIA in the country (Fischer 2014). In

terms of national regulations, EIA was initially recognised in the Pakistan Environmental Protection Ordinance, 1983, which was also the first piece of environmental legislation in Pakistan. The next step came in the form of establishment of the Pakistan Environmental Protection Agency (Pak-EPA), the central government institution responsible for managing environmental issues. This was followed by establishment of provincial environmental protection agencies and associated departments. The Pakistan Environmental Protection Act (1997) was the most important and quintessential piece of legislation promulgated to ensure environmental protection in the country. The Act further legitimised the Ordinance and the agencies and established rules and regulations.
The subject of environment is now predominantly assigned to the provincial governments as a consequence of the 18th Amendment to the Constitution of Pakistan that came into force in 2010 . All provinces were required to promulgate laws that are applicable to their specific provincial jurisdiction. The legislative process across country was supported by The National Impact Assessment Programme (NIAP) that ran from 2009 until 2014 and implemented by International Union for Conservation of Nature - Pakistan. This project was funded by the Netherlands Embassy in Pakistan and technical support was provided by the Netherlands Commission for Environmental Assessment (NCEA, 2019). The list of environmental legislating in each of the corresponding jurisdictions is given in Table 1.

Table 1. Legal Framework for EIA in Pakistan Across Jurisdictions.

Jurisdiction/ Province	Act	Regulations/ Rules	EPA	Applicability
Islamabad Capital Territory	Pakistan Environmental Protection Act 1997 (Amended 2012)	IEE-EIA Regulations 2000	Pakistan Environmental Protection Agency	Islamabad Capital Territory
Punjab	Punjab Environmental Protection Act 2012	IEE-EIA Regulations 2000	Punjab EPA	Punjab
Sindh	Sindh Environmental Protection Act 2014	IEE-EIA Regulations 2014	Sindh EPA	Sindh
Baluchistan	Baluchistan Environmental Protection Act 2014	IEE-EIA Regulations 2020	Baluchistan EPA	Baluchistan
Khyber Pakhtunkhwa (KPK)	KPK Environmental Protection Act 2014	Environmental Assessment Rules 2021	KPK EPA	KPK
Gilgit Baltistan (GB)	GB Environmental Protection Act 2014	IEE-EIA Regulations 2000	GB EPA	GB

Further details on project categorisation were laid out in the Pakistan Environmental Protection Agency Review of IEE and EIA Regulations (IEE-EIA Regulations) 2000. The regulations lay out necessary details on the preparation, submission, and review of IEE and EIA reports. The IEE-EIA Regulations 2000 stipulate a list of projects requiring an IEE in Schedule I and projects requiring EIA in Schedule II – mostly based on size or cost of project. For example, a thermal power generation project with a total capacity of less than 200 megawatts will require an IEE, whereas one larger than that will require an EIA.

3.5 Institutional Framework for EIA in Pakistan

The Ministry of Climate Change (MoCC) at the Federal government level is the highest authority on environmental management in the country. Although the mandate is focused on the environmental matters at the Federal level (this includes handling all matters related to international multilateral and bi-lateral environmental agreements applicable to Pakistan), the Ministry also looks at the inter-provincial environmental matters. Where EIA is concerned, the EPAs are principally responsible for implementing environmental legislation and the EIA processes in their respective provinces/administrative areas. The EPAs serve as policy-making and regulatory institutions in charge of the overall environment in their respective jurisdictions. Their role is to regulate, coordinate, monitor and enforce environmental laws.
Climate Change Consideration in Pakistani EIA

A total of 18 EIA reports for road projects across different provinces/administrative areas were analysed. The evaluation of EIA reports showed a very low number of hits with regards to direct reference of climate change within the text of the reports. Whereas direct reference to adaptation is almost non-existent. There is more discussion related to climate stressors – meteorological phenomena that are more likely influenced by climate change at present or have a future potential. Keeping decentralisation in mind, results and discussion of EIA report analysis for the provinces/administrative areas are summarised individually. This is to establish difference in practices and how this impacts the possible integration of climate change and subsequent adaptation across provinces/administrative areas and eventually at a national level.

The analysis of EIA reports in Pakistan shows that climate change has been considered to a very limited extent in EIA legislation and practice. There are inconsistencies within and across provinces/administrative areas and inclusion of climate change is only limited to mentions of policies and international treaties and conventions to which Pakistan is a signatory. The EIA reports provide no details on how these policies and conventions are applicable to the projects and what the implications for non-compliance are. Only one report from Balochistan (Kuchlac-Zhob) refers to project applicability for each of the conventions listed. Similarly, Climate change adaptation is non-existent in the Pakistani EIA system.

GHG emissions appear to be a recurrent theme in EIA reports. However, except for one project in Sindh (Karachi Bus Rapid Transit) which commissioned a study on GHG emissions calculations, none of the reports have presented GHG emissions calculations for projects but list down mitigation measures. As road projects, where GHG emissions are mentioned, there is a statement on negligible impact from the project emissions. Moreover, the reports claim a net positive impact on GHG emissions as a result of the road project as it shifts traffic from smaller roads to the highways thus a decrease in emissions is expected. There is no qualitative evidence to support these statements and are mere generic references to a positive impact.

4 Conclusions

Although Pakistan is not major emitter as it's national GHG emissions account for less than 1% of the global GHG emissions but it faces serious consequences because of climate change. Pakistan stands amongst the top 10 most vulnerable countries to climate change risks. This makes it imperative for Pakistan to streamline climate change impacts and subsequent adaptation into development decisions. This study attempted at investigating as to where Pakistan stands in terms of how it considers climate change within the EIA framework. EIA is a decision-making support tool that identifies environmental and socioeconomic impacts from projects that may have a significant impact on the environment and proposes management solutions to mitigate and monitor the negative impacts and enhance the positive impacts. Methods included literature review of existing literature (academic and non-academic), review and analysis of EIA reports and stakeholder engagement.

Analysis of EIA reports provided an overview of the state of climate change consideration in Pakistan taking examples from the transportation sector – road projects EIAs. It is an important sector to look at for Pakistan as it's the third largest in terms of GHG emissions after agriculture and manufacturing and construction (Ministry of Climate Change 2021). The analysis showed a significant gap in climate change consideration in terms of both impacts and ensuing adaptation. However, it also presents an opportunity for Pakistan to make efforts towards incorporating climate change impacts and adaptation into development decisions across provinces/administrative areas. One of the challenges in considering climate change has been the lack of consideration within the legislative and policy framework of EIA.

With decentralisation of environmental matters where each of the provinces/administrative areas is required to make their own laws, climate change remains a challenge as Ministry of Climate Change responsible for all matters climate change related only operates at the federal level and has no jurisdiction in the rest of the country. Although decentralisation has given provinces/administrative areas the autonomy to promulgate environmental protection legislation and policies including those pertaining to climate change. The potential to harness this opportunity remains largely underused amongst all provinces/administrative areas even a decade later. Another major challenge is the lack of coordination amongst the provinces/administrative areas and Ministry of Climate Change. This was highlighted in the interviews as well. Stakeholders mentioned that issues like climate change are best handled centrally to ensure uniform implementation across the country. There will be issues that are province-specific, and those can be handled internally by each province but there is a need for a national framework for climate change integration within EIA. Transboundary impacts are also important in this regard (particularly for road projects traversing through different provinces), which needs extensive communication and coordination which is largely lacking at present.

There are differences across provinces/administrative areas as to how they deal with climate change impacts. As for direct references to climate change, the integration is merely limited to references to specific policies and international conventions ratified by Pakistan. There is no explanation on how these treaties and conventions are relevant in the project's context or what are the obligations that the project needs to consider. In some instances, the reports have mentioned GHG emissions, although it is more in the context of how road projects will have a negligible impact because of GHG emissions abatement thus creating a net positive impact. There is no qualitative evidence to support these statements and are mere generic references to a positive impact. Only one project provided GHG emissions calculations while selecting the optimum options for a rapid transit project and GHG emissions from the project operation. SAs for climate change adaptation, it is practically non-existent in the Pakistani EIA system.

Although the existing consideration of climate change impacts and subsequent adaptation presents a bleak picture. It can be considered as an excellent opportunity to look at possible entry points for climate change impacts and adaption into the Pakistani EIA framework. It is critical for implementation that climate change impacts and adaptation are embedded within the legal texts. Every project requiring an EIA must be carried out with an evaluation of climate change impacts, both in terms of the impact the project can have on climate change (such as GHG emissions during construction and operation), and vulnerability of the project to climate change (climate stressors/ extreme weather events). Furthermore, there is a need for producing specific guidelines (including sectoral guidelines such as for road project) that deal with climate change impacts and adaptation within EIA.

Results pertaining to meteorological phenomena and potential climate change impacts showed that 'flooding' is the most common recurrent theme as far as climate stressors are concerned. Despite the differences in topographic conditions across Pakistan, flooding is a very important factor that affects most of the country. Therefore, it has received most attention in EIA in all provinces/administrative areas. However, there is a need to consider other relevant climate change impacts such 'glacier melt', 'human health', 'flora/fauna/habitat' which have been rarely considered so far. Guideline documents framing practice and specific planning systems such as river basin management plans, biodiversity management plans etc.) can be important entry points. It is important for guidelines to highlight where and how climate change impacts and adaptation can be integrated at each step of the EIA process. This starts at project screening and scoping, assessment of alternatives, baseline, impact assessment and mitigation measures and finally cumulative impact assessment.

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Developing Climate Change Adaptation Plans for the Health Sector at Subnational levels

The Case of the NHS GG&C

Climate change impacts represent threats to the population worldwide, and the health sector, responsible for taking care of their life and health, will also be impacted. Therefore, health adaptation planning to climate change is crucial to building climate-resilient health systems. This research proposes an approach to developing a Health Adaptation Plan at a sub-national level by analysing several guidelines and tools provided by the WHO and other organisations and existing Health Adaptation Plans. The findings of this analysis included four elements and sixteen steps for developing Health Adaptation plans. Later the steps of the first element, "Lay the groundwork and address gaps", are applied in the case of the NHS GG&C. This study founds that the NHS GG&C has enough tools to start developing a health adaptation plan; however, there is a need to take more action regarding adaptation. This research also concludes that following these first steps is essential to guarantee a good start and an uninterrupted health adaptation planning process by gathering information related to adaptation, engaging stakeholders from the beginning, and addressing the gaps in undertaking climate change adaptation planning. Further, it can be stated that considering the structural and quality aspects is vital to developing a successful Health Adaptation Plan. Other organisations at subnational levels might find this research's findings, analysis and approach helpful.

1 Introduction

Climate change has been described as the potential biggest public health threat that present and future generations face (Costello et al. 2009). As a consequence of climate change, extreme events such as heatwaves, heavy rain, storms, wildfires, and others have increased in the last decades. Luber (2014) mentions that these events directly impact the morbidity and mortality of the population worldwide and indirectly in the fluctuating distribution of vectors, the increment of pollen counts, and the increment of air pollution (Shimamoto & McCormick 2017).

To address the impacts of climate change on health, all the country's stakeholders must work together to adapt to climate change. One of the most important among them is the health sector since they are responsible for caring for the population's health and helping improve their quality of life. As it is stated by Costello et al. (2009), the response to climate change requires a multidisciplinary and multisectoral public health movement that works together with other stakeholders, including academic institutions.

Nevertheless, despite the importance of the participation of the health sector in developing climate change adaptation plans, there are still some barriers to it. After conducting interviews with health employees, one study (Shimamoto & McCormick 2017) concluded that institutional barriers obstructed the development of health adaptation strategies since they felt that the health sector was not perceived as an important stakeholder in adaptation planning discussions. Furthermore, financial barriers, lack of communication and knowledge about climate change topics and limited leadership are typical constraints present in climate adaptation in the health sector (Holmes et al. 2022).

In this regard, the WHO (2014) affirmed that national and regional plans need to be bolstered to enable the development and implementation of health adaptation actions. National governments regularly state that they are preparing comprehensive health adaptation programmes. Nonetheless, they do not address specific health risks, likely because national-level efforts and regulations are designed to lead more focused activities at their subnational level (Austin et al. 2016). Since national plans are developed on a large scale, tracking a region's specific needs is difficult. Therefore, each region should develop its health adaptation plan to recognise specific vulnerabilities and needs to identify special requirements such as budget, infrastructure, and others. However, what happens when the sub-national level does not have a national plan to align from? Here is when the importance of developing an approach for the subnational levels that helps elaborate adaptation plans takes place.

As the consequences of climate change are affecting the communities worldwide, this issue is not indifferent to the reality of Glasgow City Region, that despite the efforts of its NHS Greater Glasgow and Clyde on mitigation and adaptation to climate change, they do not have a Health Adaptation Plan. Hence, with an approach for developing Health Adaptation Plans at a subnational level, this NHS health board could start elaborating its plan.

On this basis, the research question emerges: how to develop a climate change adaptation plan for the health sector at a subnational level?

2 Background

2.1. Climate Change and Health

A rising number of studies show the alarming effects of climate change on human health. As the World Health Organization (WHO) reported, over the last 30 years, global warming and heavy precipitations have already claimed the lives of 150,000 people yearly (Pinkerton & Rom 2014). Besides, the WHO calculated that between 2030 and 2050, an extra 250 000 people might die annually due to climate change's effects (Watts et al. 2015).

According to the IPCC, changes in extreme climate events increase the risks of climate-related diseases or even mortality rates (Smith 2014). Regarding the effects of climate change on human health, they have been categorised as direct and indirect (Watts et al. 2015). The first can result in morbidity and mortality due to the increasing frequency of hazards such as floods and heat waves due to weather changes. The indirect effects are water quality, air pollution, and land-use change, which in the future are more likely to increase their presence in cities (Sheehan et al. 2021). Thus, the increase in the number of disasters due to climate change can augment the population's risks of illnesses like respiratory diseases, allergies, and dengue, among others (Patz et al. 2014; Haines & Patz 2004; Costello et al. 2009).

Furthermore, climate change is harming the infrastructure needed to safeguard communities' health and well-being and impacting the operation of healthcare facilities (Tonmoy et al. 2020). Different hazards can affect in diverse ways hospitals' infrastructure and services. For instance, extreme temperatures such as heat and cold waves can affect a hospital's ventilation system, and storms can cause energy loss in the building premises (Balbus et al. 2016).

Therefore, it is critical to estimate the impacts of climate change on health by applying a proper health risk assessment. Once the risks are recognised, applying different strategies in the health sector is crucial to be prepared and respond to the possible occurrence of adverse events to guarantee healthcare service continuity.

2.2 Adaptation to climate change in the health sector

One of the strategies to tackle climate change is "adaptation". As Patz et al. (2014) stated, adaptation to climate change refers to reducing its effects on health. For example, preparing health authorities and medical facilities for extreme events can minimise mortality and morbidity. Likewise, public health epidemiological surveillance can detect infectious illness outbreaks in susceptible locations, which is necessary for timely response (Pinkerton & Rom 2014).

Strengthening the health sector to be climate resilient not only contributes to responding appropriately to the effects of climate change but also to pandemics or other risks (Romanello et al. 2021).

2.3 Health Adaptation Plans

After recognising the value of identifying climate-related health risks and the development of climate change adaptation actions, this information must be gathered in a single document. Here is when the importance of developing adaptation plans in the health sector occurs. In 2010, the UNFCCC initiated the National Adaptation Plan process, recognising the need for adaptation planning and developing the technical guidelines to facilitate this process. In these guidelines, the UNFCCC established four crucial elements of the formulation of National Adaptation Plans (NAPs) and the steps under these elements: Lay the Groundwork and address gaps, Preparatory elements, Implementation Strategies, and Reporting, Monitoring, and Review. (UNFCCC 2012).

Aligned with the UNFCCC guidelines, the WHO developed a Guidance to Protect Health from Climate Change through Health Adaptation Planning (henceforth referred to as WHO Guidance in this research), describing the concepts of the planning process, key elements, and steps (WHO 2014).

Besides, the WHO's experience in assisting countries in designing and executing health adaptation plans and addressing hurdles in HNAP development since 2012 allowed them to develop another critical tool to elaborate adaptation plans for the health sector: the WHO Quality Criteria for Health National Adaptation Plans (henceforth referred to as WHO Quality Criteria in this research). This publication contains good practice examples and quality criteria for health adaptation planning, providing policymakers and ministries of health with essential tools for their plans (WHO 2021).

2.4 The health adaptation planning gap

Despite the importance of adaptation, there is a limited worldwide number of health adaptation plans (henceforth referred to as HAPs in this research) and scarce information about how to develop them. This crucial gap constrains the health sector from preparing for and reacting to future climate-related health impacts.

Another gap is the knowledge about developing a HAP at a subnational level if the national level has not yet elaborated on one. Considering that many countries do not have a HAP developed, it is difficult for sub-national level health organisations to take the initiative to elaborate one if they don't have a model to follow, which in the end, delays the start of the adaptation planning process or, even worse, this process never starts.

This is the case in Scotland and its health sector. The NHS Scotland has neither developed a HAP nor its health boards, including the NHS Greater Glasgow and Clyde (henceforth referred to as NHS GG&C in this research). The NHS GG&C is responsible for assisting 1.2 million people, including the people of the city of Glasgow, a greater urban area, employs 44,000 workers, and has 35 Hospitals of different types, which is why it is the largest NHS organisation in Scotland (NHSGGC 2022).

One of the reasons why the NHS GG&C needs to develop a HAP is the size of the population it serves since climate change's consequences on people's health in large cities are higher than in other less populated locations (Shimamoto & McCormick 2017).

Another reason is that Glasgow dwellers are particularly vulnerable to climate change. It is estimated that by 2043 the population over 50 years old will represent 36% of the total population. Moreover, an issue that has been recognised and highlighted is Glasgow's population's economic opportunity and health inequalities (Whyte et al. 2021).

Therefore, it is necessary to tackle these gaps using different guidelines and tools, such as those provided by the UNFCCC, WHO and other organisations, by adapting them to the regional contexts.

3 Methodology

The thesis assumes a pragmatic position and uses an inductive approach and qualitative multi-methods to reach the aim of this research.

3.1. Data Collection

3.1.1 Document analysis

This study searched for information related to the following:

- Guidelines and tools or elaborating climate change adaptation plans.
- Existing health adaptation plans from different UK cities, non-UK cities, countries, and worldwide organisations.
- Adaptation to climate change and health in NHS GG&C documents, such as policies, adaptation Plans, and Climate Change Risks Assessments of Glasgow City, Scotland, and UK Governments.

Search Strategy

Different academic and scientific databases were used to get the information needed to complete the investigation, such as Science Direct and The Lancet. Since the HAPs guidelines and tools are not published in journals and bibliographic databases, the search for this information started on the World Health Organization webpage (www.who.int) and in the country or city-specific databases. Besides, other organisations' websites developing guidelines related to adaptation to climate change were consulted. A snowball search was carried out on the found books and journals' reference lists to make this search optimal.

3.1.2 Interview data

The type of interview chosen for this study was the semistructured one, which allows flexibility in all questions, but is guided by a list of topics to be explored. (Merriam & Tisdell 2015).

The participants were mainly the NHS GG&C employees of the departments such as sustainability, public health, and resilience. Additionally, another participant from NHS Lanarkshire was selected to compare the advances in health adaptation topics between them, and another interviewee from sustainability charity Sniffer, with expertise in developing adaptation plans, was also interviewed.

Since the health adaptation planning process involves workers from all hierarchy levels in an organisation, the interviewees from the NHS GG&C were selected considering Pezzica et al. (2021) levels of decision-making during disasters. At least one participant per level was interviewed in the NHS GG&C. These levels correspond to a degree of control in the decisions and changing time horizon: strategic, managerial, and operational.

3.2 Data Analysis

3.2.1 Thematic Analysis

In the process of qualitative data analysis of this thesis, thematic analysis was used. This analytic method entails searching for patterns of meaning in a data set. (Clarke & Braun 2017).

Coding

This was done for the data obtained from the interviews' transcripts and the documents. The type of coding used in this research was descriptive coding, which assigns labels and groups similar topic data. (Wicks 2017). To generate codes, the qualitative data research software QSR NVivo was used to guarantee a good quality analysis of the information. (QSR NVIVO International 2022).

Themes

The resulting codes were grouped to conform themes. Due to the nature of this study, an inductive approach was used to analyse the codes created, and they were combined into main themes. (Braun & Clarke 2006).

3.2.2 ADAPTE process

The approach for elaborating HAPs was developed by using the ADAPTE process, which applies the concept of guideline adaptation. The Guideline International Network defines guideline adaptation as "the systematic approach to the modification of a guideline(s) produced in one cultural and organisational setting for application in a different context." (Wang et al 2018). In this research, the first steps of the ADAPTE process were: to define the health question, search and screen guidelines, assess guidelines, and decide and select. (The ADAPTE Collaboration 2009).

3.3 Phases of the research

In line with the above methods, this study was developed in three phases. The first phase started with Adapting Guidelines and Tools using the ADAPTE process by collecting, assessing and selecting guidelines, tools, and existing HAPs. The selected documents were analysed in the second phase to determine the elements and steps for developing Sub-national Health Adaptation Plans. Finally, in the third phase, the case study of the NHS GG&C was developed using the previous information obtained as guidance to collect data for analysing the four steps of the first element for developing HAPs, "Laying the Groundwork and addressing the gaps", through further documentary analysis and interviews. To conclude with an initial approach for developing HAPs at a sub-national level (See Figure 1).

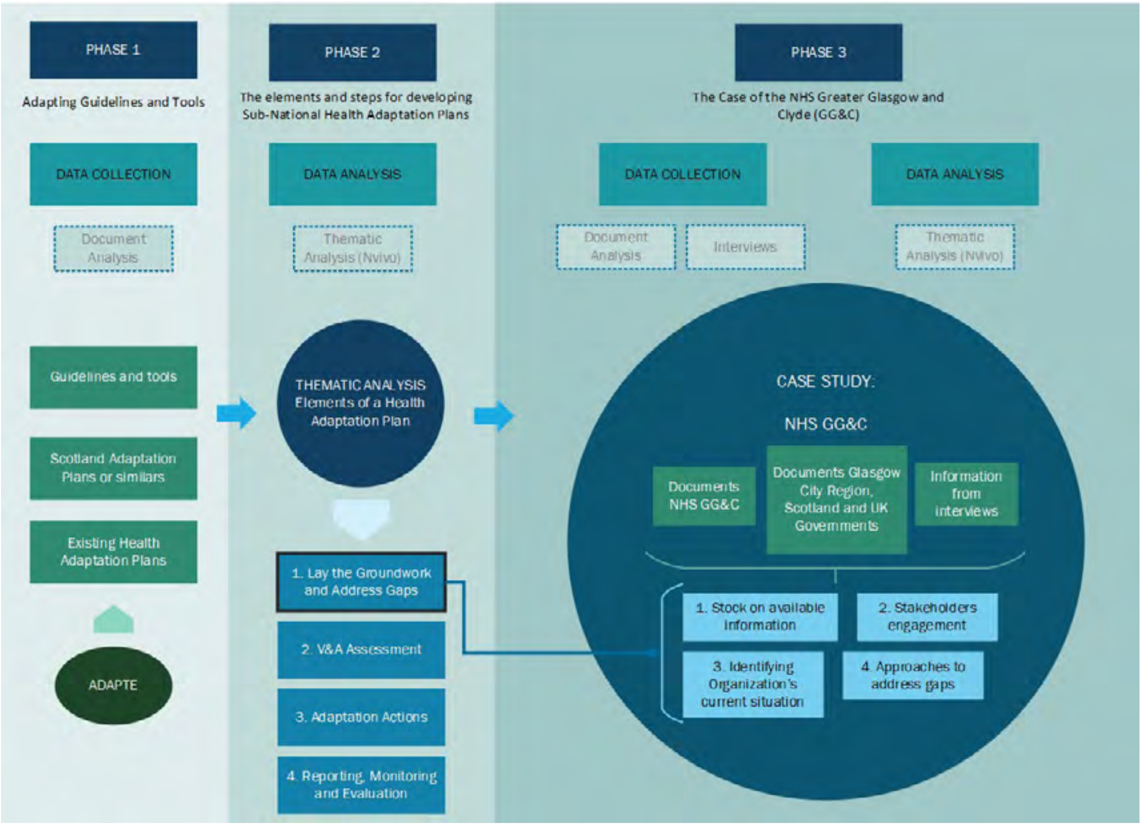

Figure 1. Phases of the research.

4 Results and Discussion

4.1 Adapting Guidelines and Tools for developing Health Adaptation Plans

The WHO Guidance and the WHO Quality Criteria deliver complete information about developing a HAP and what quality criteria should be undertaken for its success. The first one describes, in brief, the elements and steps for developing HAPs, whereas the second one was developed to be used in tandem with the mentioned guidance.

4.1.1 WHO Guidelines and Tools

Additionally, the WHO Guidance and Quality Criteria documents provide links to other tools that help carry out different steps during the elaboration of the adaptation plans. Figure 2 presents the relation between these documents and which tools feed the elements of the WHO Guidance, assisting the elaboration of HAPs.

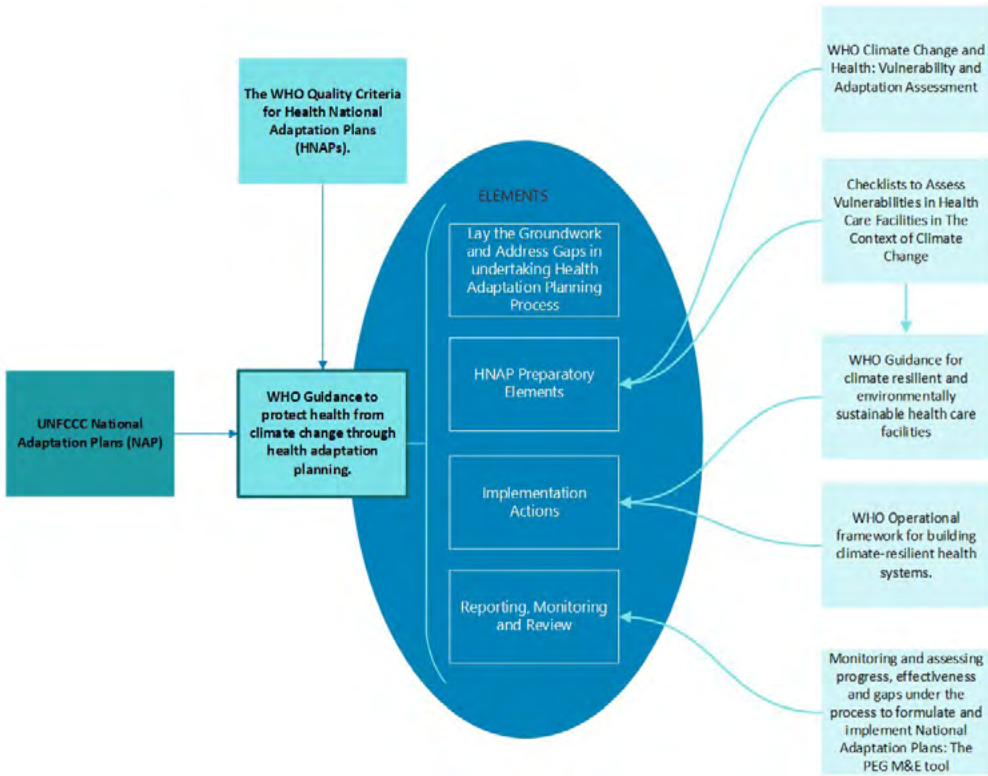

Figure 2. WHO Guidance - UNFCCC and WHO Tools relation.

4.1.2 Other Adaptation Planning Guidelines

In addition, guidelines to elaborate sectoral adaptation plans from Scotland and other countries were searched to analyse their content that helps their different sectors, including the health sector, to develop their plans. However, information related to these documents is scarce, obtaining only guidelines from Scotland, Ireland and the Santa Lucia Governments.

Even though these guidelines present different approaches to developing HAPs, each of their phases can be aligned with the WHO Guidance's elements since their contents are similar.

4.1.3 Existing Health Adaptation Plans

This research also analysed three national-level plans from the governments of Ireland, Tanzania and the Former Yugoslav Republic of Macedonia and Italy and two subnational-level plans from the NHS Bristol, North Somerset and South Gloucestershire - UK and Queensland – Australia.

From the analysis of these documents, it was noticed that the difference between them is that while the national level recognises general climate change impacts on health and programme actions of a wide spectrum, the sub-national level focuses on specific health impacts, and the actions programmed are more specific.

4.2 The elements and steps for developing Sub-National Health Adaptation Plans

The previously mentioned documents were analysed by applying inductive coding using the software NVivo. These codes were grouped in themes according to similarities and the mentioned elements of health adaptation planning defined by the WHO. The themes identified were the elements, while the codes were the steps (see Figure 3).

Figure 3. Elements and Steps for developing Health Adaptation Plans at a Subnational Level.

4.3 The Case of the NHS Greater Glasgow and Clyde (GG&C)

The NHS GG&C has been working on sustainability-related topics and making efforts to be Net-Zero. Nevertheless, more needs to be done regarding adaptation to climate change. This organisation does not have a HAP, and their work in that matter is just starting.

Therefore, this section applies the steps of the first element of the Health Adaptation planning process: Lay the Groundwork and Address Gaps.

4.3.1 Stock on available information

4.3.1.1 NHS GG&C Information

This information involves NHS GG&C (subnational level) and NHS Scotland (national level) documents. A total of six documents were found on topics related to climate change adaptation. The existence of few documents or research regarding health adaptation demonstrates that the NHS is just beginning to take its first steps towards climate change adaptation.

4.3.1.2 Adaptation Documents of Glasgow City, Scotland, and UK Governments

This data was searched at a local, regional and national level to gather information related to identified hazards, health risks, existing policies and programmes, and stakeholders in the health-determining sectors. For example, Figure 4 shows the policies found in the analysed documents.

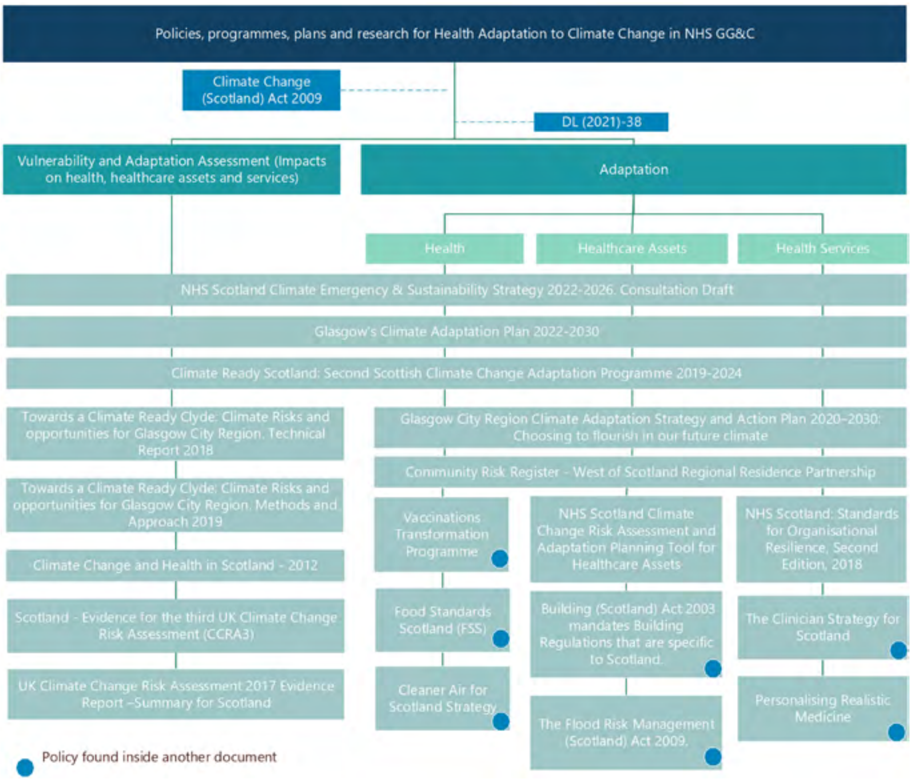

Figure 4. Policies, programmes, plans and research for Health Adaptation to Climate Change in NHS GG&C.

4.3.2 Stakeholder engagement

Stakeholder engagement has three key aspects: identifying, assessing and engaging stakeholders. (Jisc 2014).

Identification of NHS GG&C's stakeholders:
Among these stakeholders are the ones that belong to the health sector and are part of NHS Scotland as a whole organisation, such as NHS National Services Scotland (NSS) and NHS Public Health Scotland (PHS), among others. Other stakeholders would be the local authorities and organisations like Climate Ready Clyde, Scottish Ambulance Service and charity organisations.

HAPs also involve participation from other sectors, such as Scottish Water, Scottish Power, and Police Scotland. Institutions with knowledge and expertise in climate change topics, like universities, could provide consultancy during the plan's development.

Assessing the stakeholders
According to the WHO (2021), a stakeholder mapping tool helps assess relevant stakeholders to "inform an engagement strategy and plan", such as the influence-interest matrix. The use of this matrix could help to recognise the key players during the development of the HAP (Jisc 2014).

Engaging the stakeholders
Adaptation requires the participation of the government, stakeholders and citizens, and different organisations (Füssel 2007). Further, a successful HAP is anticipated due to the active participation of health-determining sectors during its formulation and execution (WHO 2021). In this regard, a helpful model to address this idea is the concept of a "Ladder of Citizen Participation" (Arnstein 1969). Using this ladder could help the NHS GG&C determine which rung of the ladder their stakeholders are situated on and in which one they want them to be.

4.3.3. Identifying the Organization's Current Situation
The WHO (2014) recommends performing a SWOT analysis and considering the organisation's potential institutional barriers and capacity necessities to identify gaps in implementing its plan.

The SWOT analysis helps assess the organisation's internal and external environment by recognising its strengths, weaknesses, opportunities, and threats. (Sammut-Bonnici & Galea 2015). The SWOT was developed with information obtained from the interviewees' answers and document analysis findings (see Figure 5 on the next page).

4.3.4 Approaches to Address Gaps
After the SWOT analysis and identifying the main gaps, it is vital to recognise the approaches to undertake to deal with them. This step is helpful to guarantee that the organisation's decision-makers have the tools to carry out the health adaptation planning process effectively. (WHO 2014).

Brainstorming could be a good start to developing strategies to tackle gaps, using information from stakeholders and documentary analysis.

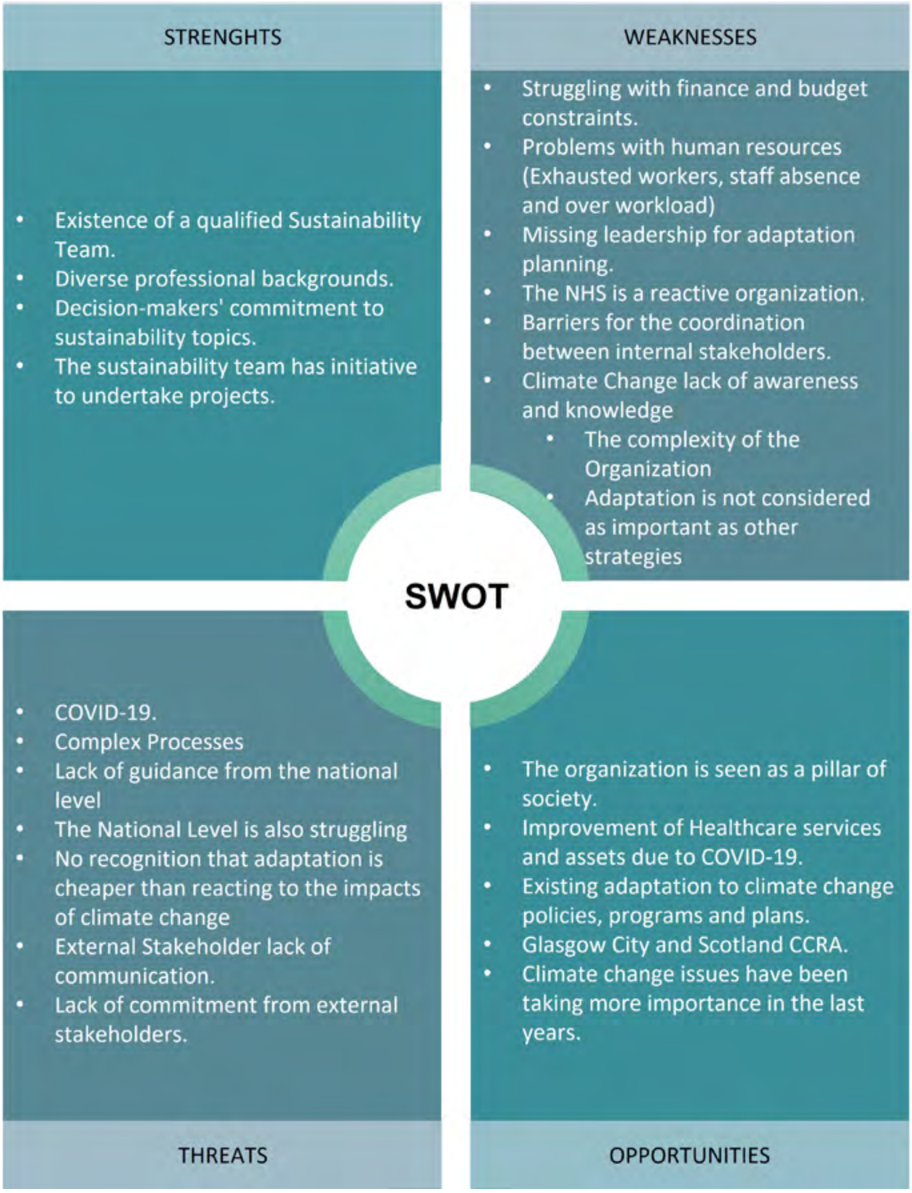

Figure 5. A SWOT Analysis of the Heath Adaptation Planning Process of the NHS GG&C.

4.4. The Health Sector and the Health Adaptation Planning Process

The case study findings lead to the starting point: why is there no adaptation plan in the NHS GG&C? If the reason is not identified and addressed, the start of the planning adaptation process could be delayed, and the approach to developing a HAP could be useless.

While reflecting on the reasons for that inaction, several insights surfaced. One finding is that the NHS GG&C does not expect climate change impacts in the short term and hence, does not consider adaptation a priority. The NHS GG&C must reflect upon this disinterest as a barrier to adaptation to climate change. Besides, the need for guidance from the national level was another insight from this research.

5 Conclusions

The case of the NHS GG&C

The urgency of developing a HAP in the NHS GG&C is undoubted. Although they have tools to start one, like the existence of CCRAs and policies, and have taken initial steps towards adaptation, more action is still needed. The NHS GG&C must go from a passive position to doing something about it actively. Therefore, elaborating on a HAP can help them in this adaptation process.

An approach to developing HAPs in the health sector at a sub-national level
The case of the NHS GG&C sets a good example of an organisation of the health sector at a subnational level that has still not developed its HAP and struggles in starting its elaboration. Deficiencies in the system, such as lack of leadership, prioritisation of other activities and lack of human and financial resources, are some barriers that could also be found in other subnational organisations.

Applying the first element for developing HAPs in the case of the NHS GG&C allowed seeing the importance of gathering existing information that can feed the plan, engaging stakeholders from the very beginning, recognising the current situation of the organisation regarding adaptation and identifying how to address the gaps found to undertake the development of the plan. Indeed, it was shown that by "laying the groundwork and addressing gaps", an organisation could have a good plan start. Besides, the case study analysis differentiated two main aspects for elaborating adaptation plans, the "structural" and "quality" aspects.

Regarding the structural aspect:

According to the present study's findings, a sub-national health organisation could follow the steps of the elements presented in this research. Therefore, it should contain, as a minimum:

- Policies supporting the health sector's adaptation process.
- Stakeholders involved in the planning and implementation of the HAP.
- Identified climate-related health risks.

- Programmed feasible adaptation actions outlining responsible, timeframe and financial resources needed for carrying out the activities.
- A concise "Monitoring and Evaluation plan".

Regarding the Quality Criteria:

The plan's success could lie in applying the WHO Quality Criteria, a valuable resource for elaborating an efficient HAP. From the application of the first element for elaborating HAPs in the case study, it was understood that there are two main quality criteria involved in that stage.

The first one is leadership, which, as stated by the (WHO 2021), is vital to the HAP process. Leaders helping the organisation recognise that climate change is a threat to public health and boosting the prioritisation of adaptation is fundamental for developing and implementing the plan. The second one is stakeholder engagement. The cross-sectoral synergy and coordination are also critical for the plan's success. (WHO 2021).

Adaptation to Climate Change in the Health Sector:

From the meagre information regarding health adaptation planning, adaptation seems to have been put at the end of the health sector's agenda worldwide. However, there is a necessity of awareness that adaptation must be undertaken now to ensure timely responses to the effects of climate change. Furthermore, there is a need for consistency between the plans from different governance levels to guarantee coherent public health adaptation planning.

The climate change adaptation journey might be full of potholes and bumps. However, proper planning can help make it easier. The most critical aspect is that the organisation develops a HAP in any way or form possible, identifying the climate-related health risks and programming and executing actions to be prepared for and respond to the imminent impacts of climate change.

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HUMAYUN, AROOJ

Decarbonizing Operational Built Assets in Healthcare Systems

This study investigates how hospitals in Glasgow can reduce their operational emissions using Gartnavel Hospital as a case study. The site and its available emission metrics were scrutinized to identify five high emission streams: energy, waste, water, Anaesthetic gases, and transport. On-site surveys and interviews were conducted to determine why these streams were so conducive to the emissions count. The findings revealed dilapidated infrastructure, lack of energy-efficient technology, wasteful practices, insufficient amount of staff skill development in sustainability, resource division, lack of monitoring and targeting, and an unclear governance hierarchy to be the cause for the high emissions count on site. A qualitative literature review using NVivo software helped identify best practices and themes for emissions reduction in the commercial built and healthcare setting. The findings from this review were correlated with the problems identified onsite for Gartnavel Hospital and translated to recommendations for site improvement. Interventions for each stream were highlighted in the form of an Action Research Framework with 4 phases: Planning, Acting, Observing and Reflecting to aid future decision making for the local healthcare board. Building an emissions inventory, infrastructure upgradation, onsite renewables, freight consolidation and waste segregation were recognized as necessary interventions for emissions reductions.

1 Introduction

Climate change has been labelled the most critical public health concern of the twenty-first century due to its impacts on human health (Costello et al. 2009). Yet the delivery of healthcare itself is extremely carbon intensive than most commercial or service industries with heavy reliance on fossil fuel systems (McGain and Naylor 2014). Healthcare systems, therefore, are major drivers of climate change, which ultimately affects the demand for their services. Healthcare's climate footprint, a whopping 4.4% of the net global emissions, is expected to rise unless action from outside and inside the sector is initiated. (Karliner et al. 2020). The National Health Service (NHS), as one of the largest publicly funded bodies in the UK, is obligated to follow the government's plans for sustainable decarbonization, which will also act to reduce the rising pressure on NHS services. And while several areas require work across the system, hospitals, the source of majority emissions, need immediate attention. As a city with one of the lowest life expectancies in the UK, it is important that Glasgow invest in improving its healthcare infrastructure to avoid further decline of its citizens health and increased demand for services.

Aim

Use an existing NHS Scotland (NHSS) built estate to explore the development of a framework to address the NHSS Net Zero Vision to decarbonize existing hospitals.

Objectives

a) Study Gartnavel Hospital and its existing emissions data to identify areas of high carbon footprint in the operational agenda

b) Identify best practices for emissions reductions in healthcare and other commercial buildings through literature review.

c) Critically examine the Gartnavel building stock in the case to identify infrastructure and governance problems

d) Recommend framework guidelines for future implementation on existing built stock based on analysis of collected data, to aid decision-making for decarbonization in the organization.

This research used the provided data and combined it with on-site interviews and observations to produce a framework to aid decarbonization at Gartnavel Hospital as a pilot study. The framework targets areas such as utility management, onsite vehicle fleet, governance structures and waste management – all of which are the highest carbon emitters for NHS Estates. However, post-implementation study of the framework was beyond the scope of the project due to associated time constraints.

2 Background

2.1 Emissions Management for Commercial Buildings

Advent of the first international standard on carbon emission metrics for existing buildings, ISO 1674 (Kanneganti et al. 2017) reflects the lack of standardisation of carbon management in commercial built assets. As a result, the standard itself is not widely implemented yet. The use of a common standard for carbon management across the commercial sector on national/global levels will play a vital role in bringing forth better opportunities for learning and comparison. Thorough investment may result in improved energy consumption patterns and, in theory, lower carbon emissions during operation, but resource waste and occupant behaviour (demand for comfort) may negate those efforts and offset the savings brought forward. Hence occupant awareness training should be part of any measures being introduced. Use of building efficiency systems such as BREEAM has been recommended in recent literature to make evaluations of built structures such as hospitals (Stevanovic et al. 2017).

Most studies on carbon management focus on reducing energy consumption and offsetting carbon. The approach used to reduce energy demand and consumption varies and is dependent on individual building characteristics. During the design phase, incorporation of sustainable building fabric and passive strategies goes a long way towards reducing energy demand for heating/cooling purposes (Twinn et al. 2019). Efficient fabric, shading design, natural ventilation, natural daylighting has been shown to be quite effective in curbing excessive energy usage in a commercial setting. Improvements targeting occupant behaviour and awareness while managing ‘peak loads’ are also effective in enhancing the efficiency of a building system. Twinn et al. (2019) in their report on ‘Net Zero Carbon Buildings’ put forth the idea of annual public disclosure of in-use energy consumption in buildings. The existing UK building stock is old. There is likely to be a ‘performance gap’ where modelled energy performance does not always correspond to actual consumption. Measurement and reporting of in-use commercial building energy consumption, with clear boundaries for the scope of reporting, will fill this gap and address its carbon impacts, particularly for organisations such like NHSS where most buildings have existed since the 1990s. Reports suggest that emissions arising from the NHSS estates can only be brought down to zero through onsite energy generation, optimisation of existing estate (Torjesen 2020). Travel and transport are also areas with significant room for improvement. The healthcare transport fleet is the second largest contributor and falls within the scope of its built assets (Bhopal and Norheim 2021). Firm strategies will be required in the future for active travel to be widely adopted among staff and clients. Another under-studied area of healthcare emission is anaesthetic gases. Anaesthetic agents such as Nitrous oxide are identified as a highly potent greenhouse gas (Rasheed et al. 2021). The NHS nitrous oxide emissions are excessive enough to make up 80% of their carbon footprint equivalent. Wise (2021) found in her study that consumption of nitrous oxide was exceptionally low compared to the actual wastage of the gas - leaks and poor stock management is leading to an oversupply and contributing to the emissions.

2.2 Net Zero Hospitals Today

The commitment to net zero healthcare has seen the advent of several innovations for hospitals in recent years. While some of these interventions are large-scale and use a systemic approach, others are smaller-scale and rely more on employee initiative than administrative contingencies. Kaiser Permanente, a leading healthcare organisation in the US, recently announced its achievement of carbon neutrality (Boyd et al. 2021). While there are significant improvements and savings in their hospital resource consumption (water, energy, waste, food etc.), heavy carbon offsets (Boyd et al. 2021) neutralise the dependence on natural gas on site. To achieve true neutrality, this dependence needs to be eradicated. In Rwanda, a 150-bed hospital was recently constructed as a low carbon building which uses natural daylight and ventilation along with optimised fans and UV light to minimise energy consumption (Boyd et al. 2021).

Butaro District Hospital, a 150-bed facility located in the Northern Province of Rwanda, was constructed as a low carbon building in collaboration with Partners in Health, the Rwandan Ministry of Health, and MASS Design. Butaro Hospital minimises energy consumption using non-permeable continuous flooring, natural daylight, natural ventilation, and optimised fans and UV lights to ventilate while minimising transmission of airborne infections. Many of the materials for the construction of the facility were sourced locally (including volcanic rock from the Virunga Mountain chain), and targeted labour practices were implemented so that 4000 jobs were created for residents and 85% of the costs of building construction were channelled into the local economy, resulting in substantial economic savings compared with other Rwandan hospitals. Similarly, the Nacional Hospital Dos de Mayo in Peru (Alexander et al. 2022) used passive design strategies (high ceilings, large windows etc) to reduce energy consumption across the premises. In South Africa, the Western Cape Government eliminated existing coal and oil-fired boilers from 53 hospitals leading to carbon savings of worth USD3.3 million on an annual basis (World Bank 2017).

2.3 Setting the NHS context

NHS has earned worldwide acclaim for the accessibility of their services to the public. However, they face the challenge of operating effectively while eliminating carbon emissions (Tennison et al. 2021). NHS Scotland (NHSS) currently has 1250 buildings that cover 4.7 million square metres (Scottish Government 2021). Only a small percentage of these assets were built within the last decade, leaving many operational hospitals with resource-intensive technology and practices in place (NHSS 2017). NHS recently became one the first national healthcare organisations to commit to achieving a net zero target within the next 2 decades (Torjesen 2020). NHS Scotland went one step ahead with its ambitions and committed to achieving Net Zero healthcare by 2038, an earlier deadline compared to its counterparts (Scottish Government 2021). This target, however lofty, can only be met if the organisation can eliminate process emissions from its current hospitals.

2.4 Research Gaps

According to the reviewed literature, there is a lack of building carbon assessment systems for in use hospitals, making it difficult to establish standards and benchmarks or conduct comparative studies between institutions. BREEAM sheds some light on hospitals but only on pre and post construction overlooking the operational aspects. While several calls to action have been made to reform healthcare practices, no noteworthy progress to eliminate emissions from the process have been made so far. Studies have been done on individual aspects such as mixed dose inhalers (MDIs) or pathology but the entirety of the hospital as a systematic body with internal processes governing every day running are still lacking. Reducing the impact of healthcare activities requires stronger focus on innovation that goes beyond environmentally preferable alternatives or the 'less bad choice.' Metrics need to be designed not to measure and reinforce the status quo, but to influence existing projects and policies, investments, and management decisions towards a better, smoother system. Innovation should aim at preventing undesirable consequences and achieving superior outcomes. A significant research gap therefore is the translation of carbon mitigation strategies in an integrated approach towards the operational side of healthcare estates. This is the gap that this review will aim to fill using Glasgow Gartnavel Hospital as a case study.

3 Methodology

The study area is NHS Glasgow's Gartnavel General Hospital. GGH is currently governed by NHS Greater Glasgow & Clyde (NHSGGC), one of the 14 regional NHS boards in Scotland and forms an important part of Glasgow's public health and urban footprint.

For literature, the aim was to adhere to published works from the past 5 years. However, in some cases, pieces from the past decade were also studied due to their relevance to the theme of current research. Reports on how healthcare system pathways for decarbonization (WHO 2017; HCWH 2020) were vital in setting functional comparison benchmarks as well as aspirational goals in this context. Based on initial themes analysis in literature, a few operational streams of the hospital's primary function were shortlisted for further scrutiny during the project. Doing so was also necessary in defining scope boundaries for the project that allowed for selection of quantitative data requested from NHSGGC later. The in-depth interviews helped elaborate issues identified previously and founded the premise for site functionality and availability of related statistics. These interviews allowed the participants to give their expert (yet subjective) opinions on the workings of the selected healthcare institute. It is also through these staff that existing primary data such as CO2 emission generation on site, energy consumption, water consumption, anaesthetic gas tonnage stats were acquired. By identifying problem areas based on initial baseline data, a site survey was also conducted. A technical walkabout of GGH aided in making real-time observations about existing conditions and connecting those to problems identified through quantitative analysis.

Statistical evaluation to identify potential areas of interest was performed using Excel plots. Best practice solutions for the selected streams were examined to address the first research question of the project. All of the above were combined together to feed into the formation of the Action Framework.

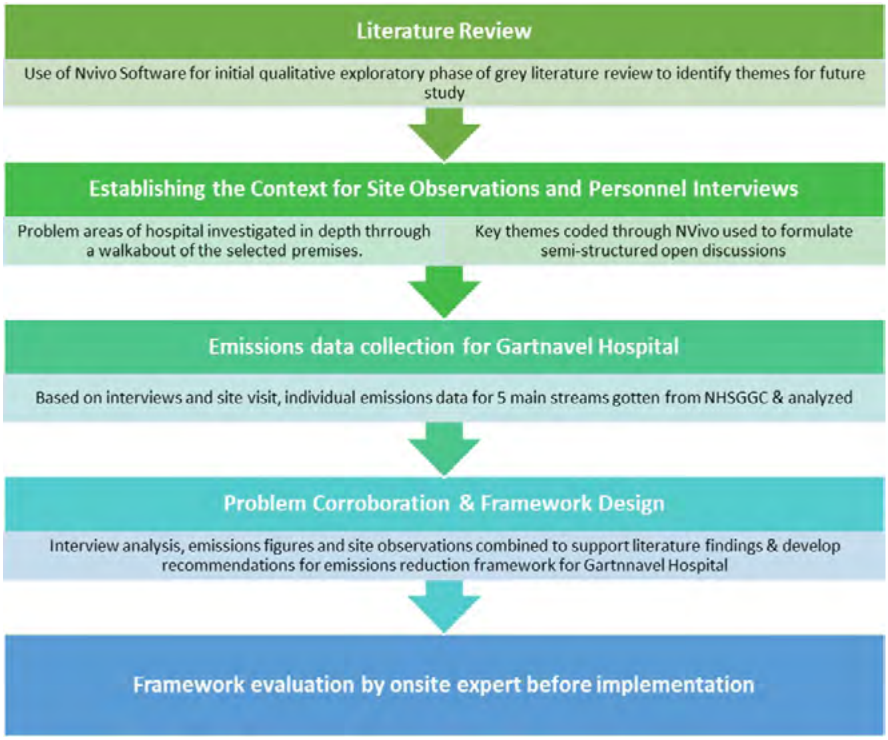

Image 1. Methodology Chart for the Project (Humayun 2022)

3.1 Results

While the initial hospital grounds date back to early 1960s (Blakeman 2015), a continuous expansion has resulted in the addition of more services and care facilities, the most recent being the Beatson Cancer Center (Mcllory 2021). A few older substandard buildings are scattered throughout the site, the vast bulk of which remain in operation well past their realistic life expectancy. A few buildings have been decanted but are now filling up again due to space and functional needs (e.g., facilities offices housed in the old laboratory building). A probe into the Estate & Assets Management Systems files for the site revealed many ongoing and backlog maintenance issues which contribute to additional pressures on the site. Over the years, new builds, extensions, and other similar projects have also contributed to increased resource consumption, often without any improvements or capital contributions to the infrastructure. Asbestos exposure was pointed out by interviewee E as being a risk in planned works throughout the site pushing back timelines in many cases.

3.2 Energy

There is no onsite electricity generation and power is supplied by the grid. The site is currently served by a single High Voltage (HV) electric ring. Heat provision varies across the site depending on the age and location of the plant; for the main hospital buildings, an existing central steam heating system (with three steam boilers) is used, with a few smaller boilers scattered around the premises to serve the rest. The central heating system is original to the building and dates to the 1960s. There is also a hot well tank which is fed by a condensate line. The produced condensate is collected and returned to the boiler house's hot well tank via receiver and pumps. There are a few backup diesel generators onsite for emergency power disruptions. These generators, while well-maintained, are at least a decade old. The main spaces on site are in continuous use 24 hours a day. This causes significant delays in backlog work and other planned upgrades, especially if they interfere with the hospital's day-to-day operations.

3.3 Waste

There was a lack of waste segregation in the wards. Previously, the site housed autoclaving facilities, which are no longer operational. On-site decontamination is limited to immediate use articles, with further processing performed at an external decontamination facility. Food waste generated in canteens is separated into purple bins and collected by an individual contractor to be disposed of through anaerobic digestion. A recycling policy has now been constructed and is in the early stages of implementation.

3.4 Water

Water supply in the building is through flat-pipped copper fixings which were part of the original infrastructure. Cleaning, sanitation, laundry, and space heating and cooling are common uses throughout the site. Water supply, like other utilities on the property, is monitored by a central meter at the source. There is no further exploration into independent water consumption focusing on buildings, making targeted interventions more challenging to implement.
Anaesthetic gases

The only data currently available was CO2 tonnage consumption for isoflurane, desflurane and sevoflurane from adult operation theatres across all territories under the NHSGGC banner. A Green theatre Project, focusing on initiatives to reduce waste, GHG emissions and energy use in operation theatres, is currently in the pipeline for Gartnavel Hospital To summarize, the major problems identified with onsite Anaesthetic gas management are:

- Lack of data collection and management
- Lack of skilled personnel with a sustainability background
- Little insights about baseline studies.

3.5 Transport

There are currently 12 electric and 13 conventional vehicles onsite for operational logistics and deliveries. Charging points are plenty and scattered across the site; these are however only available for transport personnel use. Conventional diesel vehicles are used more commonly due to higher mileage and less maintenance issues – especially for long haul journeys. electric vehicles have lesser battery life and are more likely to be exhausted to the end of life sooner than conventional ones; this is a big barrier in going carbon free in terms of vehicles. Hybrid vehicles also reflected a safety issue for mental health patients onsite – left to charge overnight, these vehicles were a suicide hazard stated. CO_2 emissions are seldom measured or monitored; the only figures available are annual fuel consumption, which can be converted to CO_2 tonnage.
Staff Engagement

noted how sustainability issues were seldom brought up in budgetary or other board meetings. net zero agenda had begun at the board level, they had yet to filter down to individual site management made based on cost/efficiency parameters usually discounting impacts on emissions. While formal training about NHSS commitment to net zero has not been initiated, some staff members show quite a lot of awareness about reducing individual carbon footprint. Due to inconsistent division of duties, staff uncertainty also comes into play – lack of clarity on responsibilities as well ambiguity of outcome makes staff wary of committing to new projects
Governance

several bureaucratic hurdles must be jumped before a project can be implemented. A new sustainability governance framework has been established for the site, and its post-implementation effectiveness is still being monitored. the sustainability responsibilities are divided among the staff. Typically, duties pertaining to the site's sustainability governance are divided among people who already have other primary roles.
Onsite Emissions

Emissions data was collected and processed to produce this graph which summarizes individual contributions from each stream towards the emissions count at Gartnavel Hospital.

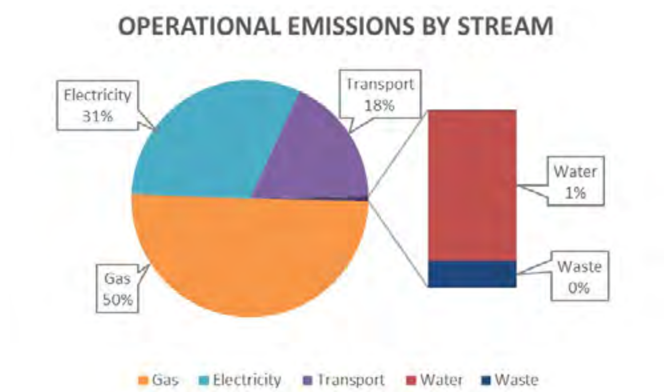

Image 2. Contribution of emission generation by each stream based on collected data (Humayun 2022)

4 Discussion & Conclusion

Hospitals can act as enablers of transformational reform by integrating new models of care and extending the use of their resources beyond their walls. Solutions implemented for hospitals can facilitate in the creation of a sustainable culture, the advancement of consistent and valid carbon metrics for other commercial/public body institutions, and the development of an explicit reduction trajectory and accountability processes.

The most common theme identified through literature study and conversations with NHSS professionals was energy. Energy for the site is provisioned through several sources and is therefore a common cause of dissent amongst all the selected streams. Space and water heating, lighting, equipment, water consumption, waste disposal all consume energy. While investing in renewable technology may appear to be an obvious solution, site experts disagree. The need for a systematic change in managing emissions generation was a recurring theme in all interviews conducted as part of this research.

Another commonality in all interviews was the stress on behavioral changes and governance practices at the hospital. Lack of input from onsite experts familiar with everyday practices reduced the efficacy of any sustainability practices being introduced. Structured training is required to familiarize staff with decarbonization strategies and bring about behavioral change. While most staff are aware about climate change, they might not understand their personal contributions to it. Better governance with more staff engagement in decision making will formulate the kind of collaborative approach required to ensure the site meets its emissions targets.

The absence of benchmarking and monitoring methods for their built stock - buildings older than 50 years – was also identified as a major NHSS challenge in this research. This problem is exacerbated by a scarcity of good practice examples for healthcare institutions to emulate. As highlighted in Section 4.3, standards used for benchmarking in a healthcare context are either too old (CIBSE GUIDE F 1996) or have not been identified properly (in the case of Anaesthetic gases). The way forward for NHSS is to initiate benchmarking studies using their own infrastructure. For this case, it is important to remember that the built stock is designed after different hospital archetypes and therefore resource consumption demands may vary due to external and internal design, occupancy, and departmental use for each building. In the case of Gartnavel, the Beatson Cancer Research Center and the Center for Integrative Care will have different consumption habits - the primary functions of these buildings define the type and patterns of resources expended. Consumption patterns for a newly opened Net Zero Hospital based in Orkney (Summers 2021) could provide a starting point of reference for such studies. Although the comparison may not be completely appropriate due to the generational gap between the two hospitals, Balfour Hospital may be able to fill some benchmarking gaps for the GGH.

4.1 Action Research Framework

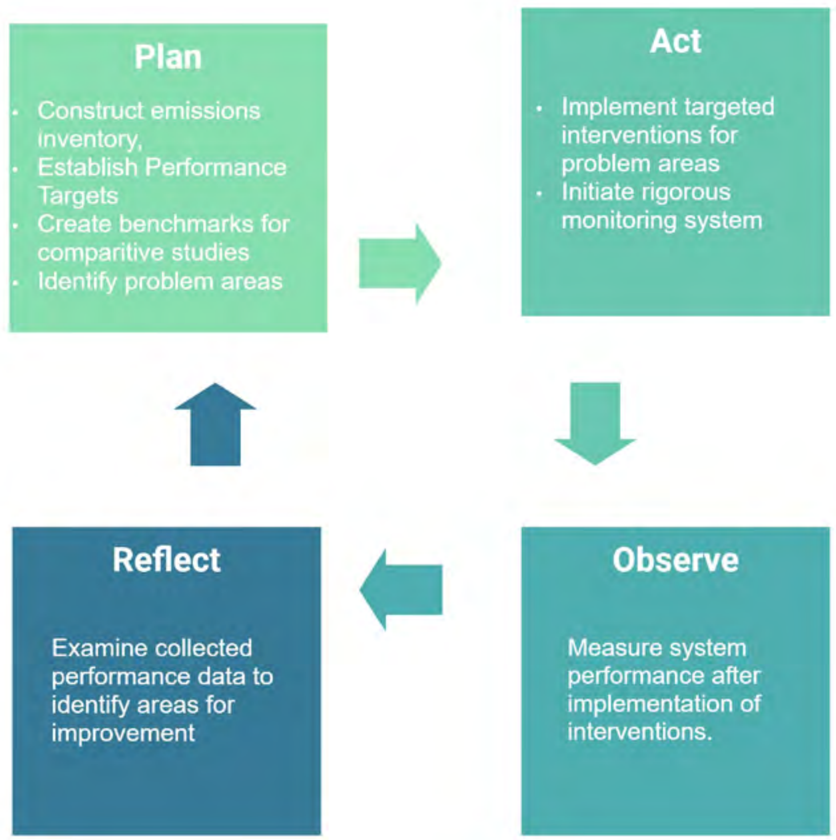

Image 3. Flowchart for recommended Action Research Framework (Humayun 2022)

The framework is divided into 4 main processes as showed in the figure, each of which is highlighted as follows:

Plan: The first step for effective implementation of the framework would be to categorize and construct an emissions inventory that meets guidelines set forth in existing protocols (PAS 2050) for all streams.

Act: Technology upgradation, policy revision, skilled labor provision and behavioral adaptation are just a few ways to reduce emissions and improve onsite practices. The table highlights recommended actions for each stream.

Observe: An emissions inventory updated on a regular basis will serve as an important tool in identifying further opportunities for reducing emissions and implementation of related policies.

Stream	Plan	Act	Observe
Anaesthetic Gases	• Standardize stock control and flow from central stores to calculate accurate consumption metrics. • Identify medicinal gases which can be replaced with healthier alternatives (e.g., Sevoflurane instead of Desflurane) • Set individual site consumption targets on a monthly and annual basis formed by accurate measurement of consumption	• Reduce gas wastage in operation theaters through capture & destroy technology (Example case studies NHS England) • Upgrade dilapidated gas supply equipment to avoid transfer loss • Stronger monitoring of onsite usage to avoid employee abuse for recreational purposes.	• Collect and analyse monitoring data by comparing with already established benchmarks • Categorise use-based consumption of gases as to identify alternatives/replacements for climate heavy choices
Waste	• Active involvement with contractor for waste disposal • Improve quality of emissions data. The current numbers are not accurate for a hospital this size. • Set performance targets for recyclable and Domestic Waste generation. • Map out trainings for staff to disperse knowledge on contamination principles in a healthcare setting to reduce wrongful waste disposal	• Improve waste segregation through colour coded disposal bags (currently only clear and black) • Follow protocols used by other prominent health bodies in UK • Signpost waste bins to enhance disposal clarity for patients. • Discourage use of single use plastics and unnecessary PPE equipment • Expand service courtyards to facilitate better onsite waste segregation	• Produce onsite waste production measurement system for better monitoring
Water	• Measure wastewater generation onsite to get accurate emissions stats, calibrate end disposal mechanisms • Non-potable water treatment e.g., from laundry services etc., can be directed for site irrigation). • Currently no data for end of line wastewater making it harder for actual quantification of emissions -Establish Performance Targets for Water consumption (which will need to be reduced, wastewater treatment (higher if possible) & disposal (low emission sources).	• Introduce greywater treatment & non-potable use on site (irrigation, heat transfer etc.) • Replace faulty, leaky pipes (part of the original site infrastructure) with stainless steel fittings. • Low flow faucets for everyday use -Efficient washing systems in laundry houses and kitchens	• Leakage detection systems (currently sporadic), needs a more systematised approach • Daily/monthly/annual demand profiling for enhanced monitoring accuracy
Transport	• Construct and Calibrate inventory for transport (Scope 3) emissions • Map better travel routes for active transport through cycling lanes, renting spots, staff incentivization • Emissions stats need to be more detailed than just fuel numbers. • Develop route optimisation plans to reduce fleet mileage	• Use GPS systems to employ freight consolidation plans • Replace existing diesel vehicles with EV fleet • More onsite provision of charging points for staff and patient vehicles • Apply for an eco-star review/rating	• Monitor Vehicle demand & mileage as well as collected emissions data to evaluate vehicle performance • Map all journeys to make room for future consolidation on frequent routes
Energy	• Set benchmarks for energy performance • Measure energy consumption on building level with frequent metering • Set performance targets using Balfour Hospital (Orkney) and CIBSE Guides.	• Invest in onsite renewable generation integrated with efficient heating and cooling systems • Introduce passive design technologies to meet temperature regulation needs. • Higher rated medical equipment to cut electricity consumption	• Performance evaluation by comparative analysis between benchmarks and collected monitoring data.

Image 4. Key Recommendations for GGH based on the Action Framework

Reflect: Effectiveness of implemented changes is checked to either evolve/eradicate or keep processes as is. KPIs combined with comparative analysis with already established benchmarks are the key variables for this process. The following decision chart shows a basic layout for all options in this process:

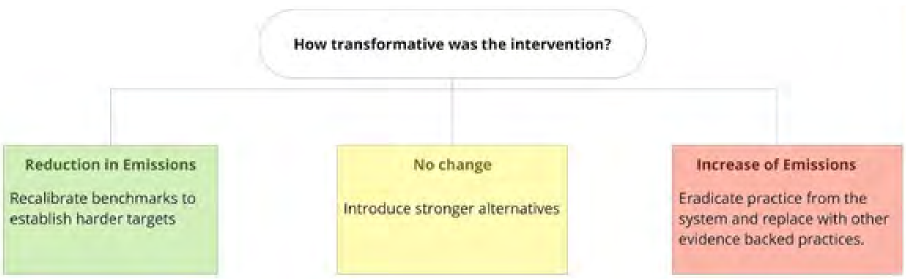

Image 5. Decision Making for Action Framework (Humayun 2022)

5 Conclusion

Every large-scale organization's agenda for the next two decades includes achieving net zero emissions. Decarbonization in the healthcare sector is critical not only for reducing carbon emissions, but also for future demand of services due to deteriorating human health. As a city with one of the lowest life expectancies in the UK, Glasgow must invest in preventing further declines in its citizens' health. Using Gartnavel Hospital as a model, this study investigates how hospitals in Glasgow can be decarbonized. GGH is a sprawling estate filled with buildings that have been a part of the original infrastructure since the 1960s.

Gartnavel Hospital needs to reduce energy consumption through infrastructure upgradation, invest in onsite renewable generation, practice freight consolidation, and enhance waste segregation for immediate emissions reductions.

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Active Travel

ARRIETA SOLÍS, JOSUÉ

MaaS as a driver of sustainable planning

an evaluation of Dumfries' readiness

Mobility-as-a-Service, MaaS, strives to reduce car ownership by integrating different transport modes in a single interface, and thus provide seamless connectivity. The settlement of Dumfries, the regional capital of the Dumfries and Galloway council area, to the Southwest of Scotland, was evaluated on its readiness to implement MaaS. Using the Modified MaaS Maturity Index from Thanos (2018), Dumfries' MaaS readiness resulted in a score of 2.42. This means Dumfries' current transport system, ICT, demographics, and regulations, are useful to a MaaS implementation, but are below of what should be desirable to a fully supportive MaaS delivery. The main barriers relate to the rurality Dumfries is immersed in where there is a significant reliance on personal vehicles, a fragile and fragmented PT, an ageing population, low employment rates and personal internet usage, plus an absent legal framework to regulate MaaS development. On the positive side, there is a population highly engaged with AT and willing to give up their cars should a more efficient PT be put in place. To improve Dumfries' MaaS preparedness, multi-modal transport master planning processes were revised, and 4 small-scale MaaS concepts were proposed.

1 Introduction

Cities are expected to shelter a 68% of the world's population by 2050. As they grow, the overall living context becomes more active. Particularly, mobility and transport systems get more chaotic. This poses sustainability challenges, which along with a current climate crisis, call for urgent action (UN-Habitat 2022).

The transport sector accounted for 15% (8,700 $GtCO_2$-eq) of the global net greenhouse gas (GHG) emissions in 2019. A 70% of those transport emissions were from road vehicles (IPCC 2022). In Scotland, transport accounted for 35.6% (14.8 MtCO2-eq) of total 2018 GHG emissions, the largest emitting sector. Cars were the most emitting mode thereof, with a 39% share (Transport Scotland 2020).

Citizens' movements are essential for a thriving society, but today's mobility needs to be challenged, transformed worldwide. Cities can reduce current transportation models' negative impacts by combining more compact land uses, with less polluting and less car-dependent mobility alternatives. In doing so, technology can provide various solutions through digitalisation (IPCC 2022), the Internet of Things (IoT), the Information and Communication Technologies (ICT), and big data. One of these solutions is Mobility-as-a-Service (MaaS).

The Scottish Government committed in 2017 to a £2 million investment fund to support the testing of MaaS trials across the country, in Dundee, Inverness, St Andrews, and East Lothian (Transport Scotland no date). Those projects in the North and Southeast of Scotland, englobe its urban-rural mixed nature. However, the Scottish Southwest side, represented by the Dumfries and Galloway (D&G) council area, one of the largest rural areas of Scotland, is yet to see MaaS deployment in their region. The transportation sector in D&G was the second largest GHG emitter in 2018, generating 517 ktCO2-eq, right after land use, responsible for 2,286 ktCO2-eq (Dumfries and Galloway Council 2021).

Current research on MaaS has been mostly focused on urban areas, leaving gaps on rural MaaS case studies. For that reason, D&G presented a good opportunity to address such gaps. The focus, however, was narrowed down to Dumfries, the regional capital, as it is a focal point for transport, having the most developed part of the bus network, and the busiest railway station of the area (Stantec 2022). Dumfries, is the largest settlement, classified as an "other urban area" (Scottish Government 2022). Dumfries is immersed in a rural setting, capturing that Scottish mixed urban-rural nature.

These characteristics presented Dumfries as a relevant study subject for analysing whether a likely MaaS implementation can be useful for future transport digitalisation efforts and a more sustainable land planning. Thus, the aim and objectives of this master's thesis were as follows.

Aim:

Run a thorough evaluation of Dumfries' current transport conditions to foster a MaaS scheme to enrich its sustainable planning.

Objectives:

Analyse Dumfries' modal shares, and town planning state of the art.
Propose a framework to evaluate MaaS readiness in Dumfries.
Evaluate Dumfries' readiness to foster MaaS strategies.
Propose a set of measures for Dumfries' MaaS implementation.

2 Background

2.1 Breaking conventional transport systems with technology

Mobility is linked to cities' life, their activities, and their land uses (Rodrigue 2013). As cities evolved, the transport systems suffered more fragmentation, while forecasting methods and planning were not able to provide the appropriate solutions (Cruz & Sarmento 2020). This led to a prolonged and ongoing environmental, societal, and economic deterioration; a sustainability crisis, demanding the breakage of the traditional transport models. Nascent technologies such as shared mobility services or ride-sharing are a promise to revert those negative effects, transforming the way people move (Hensher et al. 2020e; Kamargianni et al. 2016; Signor et al. 2019). Stemming from such innovations, Mobility-as-a-Service (MaaS) stands as the way to unify transport services and offer travellers to satisfy all their mobility needs, while encouraging them to a more sustainable lifestyle (Bharule et al. 2022; Signor et al. 2019).

2.2 Link between Planning, Transportation, and MaaS

Building upon Song, Guo and Zhang (2022) who stated that transportation is the basic framework of urban spatial form, jointly with Rodrigue (2013) and his statement about how changes in transportation technology lead to changes on the layouts of cities and towns; an interplay between the spatial form, transportation, and MaaS, is created. Thus, converging to the premise that MaaS, as a technological disruptor, can transform current transportation schemes, ultimately driving the transformation of the spatial form and planning of cities and towns (see Figure 1). To achieve that, the outdated automobile-orientated vision of cities shall be displaced by the influence of MaaS perspective of user-centredness and sustainability (Nikitas 2018; Song et al. 2022; Vergragt & Brown 2007). Cities and towns devoted to people, not to cars.

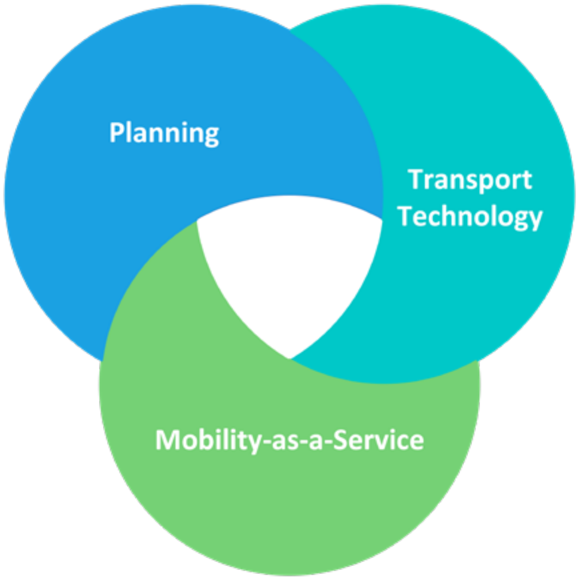

Figure 1. Interplay between planning, transport technology, and MaaS.

2.3 Conceptualising MaaS

That user-centredness perspective is one essential component of MaaS, trying to satisfy all mobility needs, thus reducing private vehicle ownership (Heikkilä 2014). MaaS aims to integrate into one single interface (e.g., a smartphone app) the different transport modes in an area, while also integrating journey planning, booking, payment, and ticketing. So, the traveller just inputs into the app where they are travelling to and from, and the app should offer the different transport options, timetables, prices, real-time data, and more, according to their travel requirements.

2.4 MaaS outputs, sustainability, and barriers

On its quest to reduce car ownership, it induces a decline in traffic congestion, favouring the decarbonisation of the transport sector. By promoting Public Transport (PT) and multimodality, it allows a shift towards more sustainable alternatives to private car, favouring electric mobility and encouraging active travel (Alyavina et al. 2020; Jittrapirom et al. 2017). MaaS benefits can help cities to improve transport safety, find solutions to social inequality, accessibility, and inclusivity (Li 2020). All this, proving to be a sustainable development measure (UN 1987), directly linked to SDGs 11 and 13. All those MaaS benefits are dependent upon users' will to use such platforms, and a robust PT system. If citizens are uninterested in supporting these initiatives, MaaS is likely to fail (Ho et al. 2018). Older age groups show less engagement with digital platforms and are less keen to give up their private vehicles. In addition, if by facilitating mobility, users switch to more automobile options like ride-hailing or carsharing, the decarbonisation opportunity will be missed (Alyavina et al. 2020). On the other side, sustainable mobility is fundamentally built on PT, and so must MaaS (Signor et al. 2019). To fulfil its purpose, PT must be efficient, appealing enough to minimise car dependency. Inaccessible, unaffordable, low quality PT systems obstruct MaaS deployment (ITF 2021).

2.5 MaaS developments, research, and assessment

Case studies cover cities in Europe, Asia and North America. The Whim app in Helsinki, Finland; UbiGo in Gothenburg, Sweden; illustrate urban MaaS cases. Shobara MaaS and Emot in Japan, are some rural MaaS examples (Smith et al. 2018; Fenton et al. 2020; Hensher et al. 2020c, 2020b; World Economic Forum 2021). In Scotland, several trials started operating after the opening of the MaaS Investment Fund in 2018. Scottish trials offer services in both urban centres and rural areas, also trying to create connections between them, like in the East Lothian or the Highland and Islands (Transport Scotland no date; Cassidy 2022). However, as they recently began operations and are still under evaluation, there is limited information about them.

MaaS research has studied the willingness of people to use MaaS and change their travel patterns. Alyavina et al. (2020), and Ho et al. (2018), concluded that despite considering MaaS as positive, people are not willing to change their travel behaviours. Research has also undergone an assessment of how well prepared a city or area is to foster MaaS schemes, or how interconnected the transportation system is to operate under MaaS structures. Integration indexes and levels of integration were developed and employed by Kamargianni et al. (2016), Kamargianni and Goulding (2018), Sochor et al. (2018), Thanos (2018), and Lyons et al. (2019). These instruments provide a starting point for evaluating MaaS potential in cities. Despite being on early stages, the essential use of these tools in the assessment of MaaS potential in cities is unequivocal. Higher maturity indexes mean more ground for MaaS, while more integration is more appealing for travellers (Kamargianni et al. 2016), consequently, better harnessing of MaaS benefits.

2.6 Research Gaps

MaaS is a nascent technology with a broad array of study opportunities. However, most of current MaaS research has been focused on urban areas. This presents thereupon, the opportunity to build knowledge on the likeliness of future MaaS strategies in rural areas, as cases in those territories are scarce and concerns of whether such areas would be suitable for such initiatives are manifest (Hensher et al. 2020d, 2020a). Moreover, there is limited mention on the usage of MaaS as a tool for planning. This is how Dumfries offered a good research opportunity, since it is immersed in one of the largest rural areas in Scotland and no MaaS projects were being rolled out there. Dumfries fusion of urban-rural features captures that same Scottish mixed nature, and allows to address the research gaps, while also allowing to apply learnings from urban settings. Such features presented Dumfries as a relevant case study given the research gaps identified on MaaS in rural areas and as a tool for sustainable planning.

3 Methodology

This research tried to shorten the research gaps regarding the scarce examples of MaaS implementation in rural areas, and the limited study of MaaS inputs for sustainable planning. The analysis, focused on the area of Dumfries, tried to address the gaps through three main questionings. Firstly, what are the current conditions preparing Dumfries, immersed in a rural area, to adopt a MaaS strategy. In second place, what conditions are obstructing a successful adoption, and thirdly, what measures could increase Dumfries' preparedness to implement MaaS and reap sustainability benefits.

Responding to those research interrogations looked at a philosophical stance that aimed to make sense of the subjective and socially constructed meanings about the likeliness of MaaS being implemented in Dumfries (Saunders et al. 2019). It related to an interpretivist philosophical standpoint. This research followed a mixed approach of qualitative and quantitative methods. This required deriving meanings from documentation and the citizens and authorities' perceptions and views on mobility, while also required numeric data and indicators such as tonnes of GHG emissions, kilometres of cycle lanes, or socioeconomic variables as age and income. It followed a case study structure, being the object the analytical frame of MaaS and its drive of sustainable planning, while the subject was centred on Dumfries (Thomas 2017).
Three methods were employed for data gathering: Documentary Review, Interviews, and Observation. The Documentary Review covered an examination of a range of archival material, using secondary sources like reports and strategy statements, governmental documents, and more, associated with transportation, sustainability, planning, and related topics. The Documentary Review allowed to select the Evaluation Framework for the MaaS Readiness Evaluation, plus, it helped with the identification of the stakeholders to be interviewed. The Interviews comprised conversations with different mobility stakeholders from the D&G council area and the whole of Scotland. Furthermore, the settlement of Dumfries was visited to obtain first-hand information on the transport and planning system. With all the data gathered; a Readiness Evaluation was run on Dumfries to assess its preparedness to implement MaaS.

3.1 Results

3.1.1 The Case Study of Dumfries

Dumfries is the regional capital of the Dumfries and Galloway council area (see Figure 2). It houses 34,040 residents (National Records of Scotland 2022). It concentrates most of the new developments and economic regeneration areas (Dumfries and Galloway Council 2019), it has the 2 largest employers and the most important healthcare facilities (Kirkpatrick 2021). Each year they receive around 6000 new students at the different educational institutions (Complete University Guide 2021; Rinaldi 2017; University of West Scotland no date).

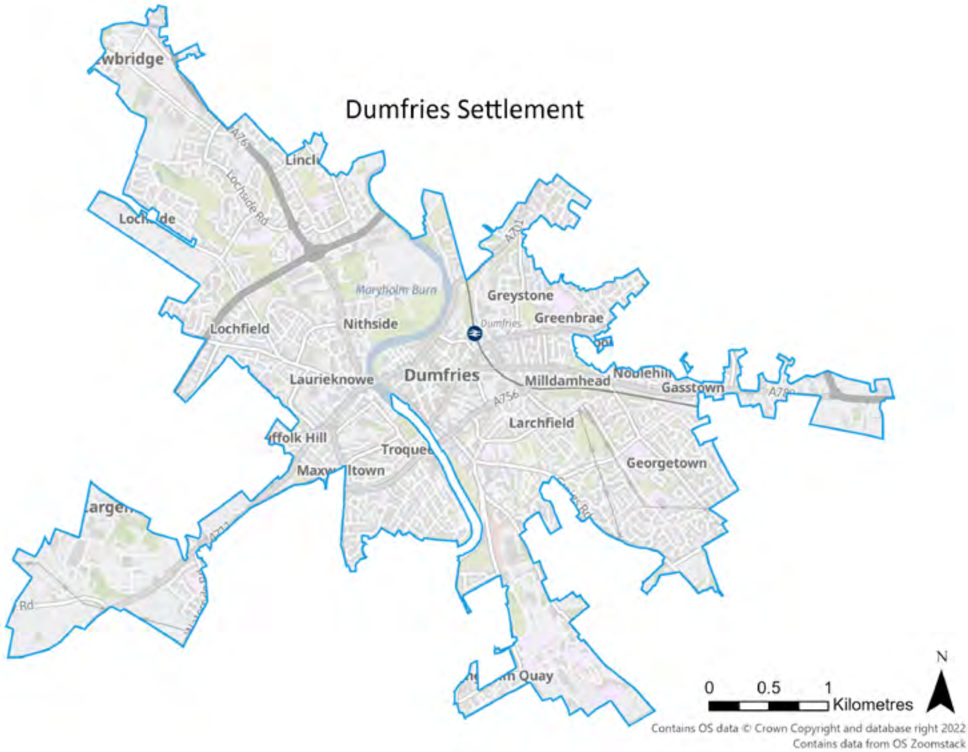

Figure 2. Dumfries Settlement, study area (Arrieta-Solís 2022)

3.1.2 About the Transport and Land Use Planning in Dumfries

Land Use and Transport Planning follow different streams in Dumfries. Transport Planning is represented through the current Regional Transport Strategy which was elaborated in 2008. Transport Planning is under the scope of SWestrans, which is the Regional Transport Partnership for the Southwest of Scotland (SWestrans 2008). This strategy is updated every 15 years. On the other hand, Land Use Planning is the Dumfries and Galloway Council responsibility, consolidated in the Local Development Plan, being its latest version from 2019 (Dumfries and Galloway Council 2019). This plan is updated every 5 years. Both planning processes are independent of each other, following different streams, focuses, and priorities.

3.1.3 Dumfries' MaaS readiness evaluation

Dumfries' preparedness to operate MaaS was evaluated using the Modified MaaS Readiness Index from Thanos (2018). This index contains 69 scoring factors. Each factor was scored using a scale from 1 to 4, where 1 implies significant limitation for MaaS, and 4 means total support to it. Scores were then averaged to obtain the MaaS readiness for Dumfries.

Based on that assessment, Dumfries' MaaS readiness score was 2.42. This means that considerations on current transport, ICT, demographics, and regulations, offer some usefulness to a MaaS implementation in Dumfries. However, they are below of what should be desirable to a fully supportive MaaS delivery.

A deeper look at this score shows how the lowest scores were those from the Demographic Considerations, Public Transport, and Attitudinal Aspects. On the other hand, the highest values were for Additional Services and Individual Motorised Transport (see Table 1).

Table 1. Dumfries MMRI results

Major Themes	Availability of Transport and ICT		Customer Demand		Government Support	
Evaluation Topics	Active Transport	2.29	**Demographical Considerations**	1.50	Political facilitation, investments, collaboration, data privacy	2.25
	Public Transport	1.88				
	Individual Motorised Transport	3.33				
	Flexible Vehicle Access	2.30	**Attitudinal Considerations**	2.00		
	Flexible Trip Access	2.23				
	Additional Services	4.00				
	ICT Services	2.40				
Total Average		**2.42**				

3.2 Results analysed

Findings about Demographic Aspects showed how employment in D&G has decreased significantly more than the national values. Only during the pandemic, employment dropped a 7.2%, while in Scotland that drop was of 1.2% (Skills Development Scotland 2022). Even more, weekly incomes in D&G have been among the lowest nationally (Dumfries and Galloway Council 2020). In terms of population, it was found that D&G has an ageing population. What is more, while Scotland's population is set to increase, D&G's is set to decrease (National Records of Scotland 2021; Skills Development Scotland 2022).

With a weak economy, Dumfries' residents have less opportunities to afford smartphones, technological devices, pay for internet usage, or subscribe mobility services. As to the population, according to researchers, older age groups tend to engage less in technology, and are less keen to give up their cars (Alyavina et al. 2020). Definitely, all major barriers to MaaS.

The PT is comprised of the bus network, the railway, and community transport. MaaS builds on robust PT (ITF 2021), and the weaknesses found in Dumfries' system are one of the major barriers. The transport system in Dumfries is fragile and fragmented, with lack of infrastructure linkages between modes, timetables are desynchronised, there is a reduced number of passengers, no tariff integration or app for booking or paying, there is a drivers' crisis, while bus routes have been terminated (SWestrans 2022; Stantec 2022; Temlett 2022; TP&E 2019). This has affected Dumfries economy and increased social issues. With an unreliable and inefficient public transport system, less people can access jobs, schools, healthcare, plus, this increases social isolation. This greatly impacts that share of the population who is highly dependent on the PT network, especially vulnerable people, and the elderly. This aggravates socioeconomic issues, and in many cases also pushes people to drive more.

As to attitudes, there are 2 sides. Though there is good disposition for active travel, and 64% of respondents to a survey from the council said they are willing to give up their private cars (Dumfries and Galloway Council 2022), Dumfries residents' reliance on their private vehicles is manifest, same as the low public transport uptake.
Car ownership and use in Dumfries and Galloway is higher than Scotland's average (Dumfries and Galloway Council 2019). A 55% of respondents to a survey from the D&G council said they use their private vehicle for daily journeys (Dumfries and Galloway Council 2022). In Scotland, 51% of journeys are made by car (Transport Scotland 2022). This reliance on private cars greatly impacts multimodality, however, this is just a reaction to an inefficient public transport, a lack of connections between modes, dispersed catchment areas, and undoubtedly, the rurality of the whole region.

The Additional Services in the area include food and groceries delivery like JustEat and Deliveroo, and services provided by Amazon or DPD.

In general, for a city or town to be ready for MaaS, there needs to be 3 different types of integration. Multimodal Physical Integration, Integrated Platforms, and Tariff Integration and Governance Models (Arthur D. Little 2018). None of them is present in Dumfries at the moment. This explains such low preparedness for MaaS.
Preparedness has not been assessed in many cities, so comparisons are difficult to make, plus, evaluated cities are densely populated urban areas. Despite this, experiences in other cities provide a benchmark to understand Dumfries readiness.
The index selected was used to evaluate San Luis de Potosí in Mexico, giving a score of 2.03 (Thanos 2018), while Dumfries had a 2.42. Dumfries is better prepared in terms of active travel and governance but they share dysfunctional public transport and a lack of bike hire schemes. London and West Midlands, although assessed with a different index, are evidently more prepared for MaaS, and the West Midlands even has a MaaS solution already operating. Japanese cities have not been assessed, but their rural cases offer learnings Dumfries could use given that they had to overcome a poor public transport, and work with an ageing population. In Scotland, though the trials are still under scrutiny, they are a way to see how partnerships were created, and how MaaS can be deployed in urban-rural settings.

3.3 Increasing Dumfries' preparedness to obtain sustainability benefits

In order to increase Dumfries' MaaS preparedness, it was suggested to look at a multi-modal transport master plan, trying to integrate land use and transport planning and place the citizens at the center of all designs and policies. The multi-modal transport master plan will build upon the Transformation Programme intended by SWestrans (Kirkpatrick 2021), and the 8 principles of sustainable urban mobility planning (SUMP) by Rupprecht Consult (2019). Its aim will be to upgrade the transport system through a redesign of its commercial offering (see Figure 3) and the cocreation of the future Local Development Plan. Because without effective integrated land use and transport planning and attractive PT services in place, MaaS by itself will be unable to reduce car dependency (ITF 2021).

Figure 3. Fusion of SUMP principles and commercial offering redesign for Dumfries (Adapted from Arthur D. Little 2018; Rupprecht Consult 2019)

Furthermore, 4 MaaS concepts were proposed for rollout in Dumfries, as small solutions to start building up a better transport system. Since MaaS is flexible and customisable, this allows solutions to be based on specific aspects. Designing these MaaS strategies requires a migration from socio-demographic customer segmentation to attitude-based mobility segmentation (Arthur D. Little 2018). This is, moving from transportation solutions to satisfaction of mobility needs, understanding why people move and fulfilling their mobility requirements. Accordingly, 4 proposals are presented in Figure 4. The first one aims to connect the around 6000 students to the town centre, the second one uses Demand Responsive Transport to provide first and last-leg trips in underserviced areas. The third proposal is about a working scheme, providing services to biggest employers in the area. The fourth one aims to create a bike hire scheme, promote active travel, and boost tourism in the region. These 4 concepts take on experiences from the current Scottish MaaS trials, and Japanese MaaS solutions.

	Aim	Service Coverage	Mobility Needs	Transport Modes	Interface	Similar Experience
Proposal 1	Creating conditions for students to improve their mobility, while connecting commerce, culture, and academia, while including rewards and incentives for sustainable behaviours.	Linkages between the Crichton State and Dumfries centre.	Studying Working Shopping Leisure	CT, DRT, bike hire schemes.	Mobile app	University of St. Andrews, or My D&A Travel from Tactran
Proposal 2	Providing first or last-leg options for underserviced areas.	Dumfries centre surroundings.	Studying Working Health Etc.	CT, DRT.	Phoneline, website, mobile app	GoSestran, Japan
Proposal 3	Creating a working scheme with affordable and attractive fees in different modes, partnering employers, commerce, and transport operators. Including gamification. Similar to cycle to work scheme or the NHS ridesharing.	Dumfries centre.	Working mostly, but could also include health needs, or shopping, and others.	CT, DRT, taxis, bus, bike hire, etc.	Website and mobile app	GoNHS Tayside in Dundee
Proposal 4	Creation of a bike hire from the DGC and transformation of the GoSmart initiative into a more dynamic interface, allowing to rent bikes, pay for DGC buses tickets, and enhance the AT experience.	D&G region.	Tourism and leisure mainly, also including shopping, exercising, etc.	Bike hire, AT, bus.	Website and mobile app	GoHi in the Highland & Islands, Japan MaaS solutions.

Figure 4. MaaS concept proposals for Dumfries

4 Conclusions and discussion

In conclusion, based on this evaluation, Dumfries' current transport and planning conditions pose significant barriers for MaaS and the digitalisation of mobility. Such situation reflects on Dumfries' urban-rural context, with an inefficient public transport provision, a high reliance on private vehicles, low employment rates, and low weekly incomes. When summed up, all these factors make mobility more difficult, as a result, a vicious cycle appears, where economy and society contract, posing even more complicated and enduring challenges. Therefore, Dumfries is yet to experience the benefits MaaS promises to deliver on sustainability and planning.

However, if Dumfries places MaaS essentials of car ownership reduction, transport integration, and people-oriented vision at the core of transport and land use planning, the earlier Dumfries will witness a more sustainable, accessible, climate-resilient, and MaaS-prepared town.

In the meantime, the council and SWestrans could think of joining MaaS Scotland and partner up with other Regional Transport Partnerships. Dumfries could implement small MaaS solution then scale up by adding other components. They can operationalize the Transformation Programme from SWestrans. Improve transport digitalization competences in the council and SWestrans, and discover new ideas for planning.

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EVENS, LUKE

Assessing the Micro-climatic Impacts of and Opportunities for Bicycle Infrastructure in Seville, Spain

For the transport sector, cycling is widely considered the most environmentally sustainable form of mobility and a key means for reducing emissions. Bicycle paths can provide safer, faster and more comfortable routes to encourage modal uptake. However, as heat stress becomes a growing urban concern, efforts must be taken to address heat risks for bicycle path users as well. This study took a three-part approach to looks at how microclimatic conditions change at different sections of a bicycle path network to understand how heat stress varies across inner Seville, Spain. For part one, microclimate data was collected at eight different sites. This was then analysed, compared and interpolated to identify sites under severe heat stress and assess opportunities for thermal comfort improvement. Part two applied ENVI-met to determine other climatic readings. The third part of the study determined that there was a severe lack of climate-sensitive planning in the city's Sustainable Urban Mobility Plan. Strategic alterations were made to improve the worst affected site, advocating for integrated, holistic climate-sensitive planning. This study opened a novel way of approaching transport and town planning and provides evidence for more integrated, compact planning to enhance thermal comfort for bicycle path users.

1 Introduction

The urban microclimate is the meteorological conditions that affect the environment we live in; they have a profound impact on our quality of life and comfort. Rising temperatures are compromising liveability and our relationship to the places around us. This is forcing us to rethink and reconfigure our cities and as a result climate-sensitive design is becoming more common; adapting infrastructure and spaces to handle worsening conditions in the face of climate change (Carter 2015).

One of Europe's hottest cities, Seville, Spain, is very much on the forefront of extreme heat in Europe. To protect its residents and raise awareness about the deadly impacts of extreme heat, the city will be naming and classifying heatwaves, a world first (Murphy 2022). Seville has been attempting to tackle environmental issues for some time, having linked their Strategic Plan 2030 to the UN Sustainable Development goals.

One such focus of the city is the promotion of cycling and non-motorised transport, with over 80km of segregated cycle track in the city already and over 2600 public bicycles available to rent. While only a simple means, cycling is associated with many benefits; air quality, congestion and transport emissions are key concerns that can be addressed by a modal shift to cycling (Banister 2008). But the task of fostering sustainable mobility habits is complex. Cities are rarely configured in a way that is conducive for cycling, with low levels of accessibility and safety for users. Dedicated infrastructure is important for encouraging users, but considerations must be made for the thermal comfort of users to ensure they are protected and supported.

This study will investigate this notion. It will develop a framework for assessing the microclimate implications for bicycling infrastructure and its users in Seville. It will do so through an evaluation of the existing urban morphologies surrounding Seville's bicycling infrastructure.

It is hoped that these findings can better inform bicycling infrastructure in other hot, dry, Mediterranean cities. It will do so through a mixed-methods study using traverse ground-based data collection, ENVI-met climate simulations, GIS analysis and thematic policy document analysis.

Ultimately, this research will answer these questions:
How do microclimatic conditions change on the bicycle path network depending on urban morphology and *how does this affect thermal comfort and heat stress for users?*

In what ways can bicycle infrastructure and planning policy be adapted to enhance thermal comfort and reduce heat stress for users?

The objectives of this research accordingly are to:

- Manually measure microclimate conditions (air temperature and relative humidity) of eight sites within the segregated bicycle infrastructure in Seville;
- Analyse and compare the microclimate data collection of eight sites in Seville;
- Simulate the eight sites to derive air temperature, relative humidity and mean radiant temperature readings for the sites over the course of one summer day;
- Demonstrate how thermal comfort can be improved for bicycle infrastructure users by simulating strategic alterations to sites;
- Assess the Seville Sustainable Mobility Plan for references to thermal comfort and climate-sensitive design. Make recommendations for improvement.

2 Background

In fact, Xu et al. (2020) estimate that by 2070, 19% of global land mass will become unliveable "hot zones". Thus, more climate-sensitive, human-centred approaches that prioritise access, needs and equities within society are vitally required. This means adapting our cities to be more climate-sensitive for all.

Given that around 30% of the world's population is currently exposed to deadly heat for at least 20 days a year (Mora et al. 2017), the vulnerability of outdoor urban and spatial design to extreme heat should be considered urgently to prepare, mitigate, and adapt as rapidly as possible.

The disproportionate heat found in cities compared to its surrounding suburban and rural areas, Urban Heat Island. It is affected by several factors (Oke 1978).

Firstly, the thermal properties of building and surface materials nowadays present a high absorptivity of solar radiation, in turn increasing surface and air temperatures. That stored heat is then released slowly back into the atmosphere through convection and radiation processes, with the latter known as albedo (Santamouris 2019).

Anthropogenic heat emissions caused by heating systems, air-conditioning units and combustion engines also proliferate UHI (Kolbe 2019). Combustion engines have a double effect on UHI because of the high concentration of atmospheric pollutants that reflect radiation and convection back onto surfaces too.

Urban form affects UHI as well – specific geometries can prevent radiation and convection from escaping into space, by a cycle of reflection and absorption, deepening UHI (Mohajerani et al. 2016).

Conversely, reducing solar exposure and the sky-view factor can mitigate the UHI effect. For example, shade structures and vegetations can reduce surface temperatures and reduce UHI (Lin et al. 2010). Furthermore, vegetation can also promote cooling through evapotranspiration.

Mitigation aside; heat stress is a serious issue facing urban populations. This is because UHI has a direct effect on outdoor thermal comfort by way of heat stress. Because of Seville's residents' propensity to cycle, and because cycling requires increased energy expenditure when compared to walking or motorised-based transport modes, it is important to consider the implications of heat stress on this mode specifically.

It was in 1992 that the term "sustainable mobility" was first introduced as a concept to address the unsustainability of current mobility systems, in a European Commission Paper on the impact of the transport on the environment (Commission of European Communities 1992). It found that transport is responsible for several environmental impacts.

Policy decisions about infrastructure play a vital role in helping to steer sustainable mobility behaviours for generations to come (Berger 2014). For example, landuse planning can provide an ideal opportunity to embed sustainable mobility patterns within urban lifestyles.

Banister argues that transport and landuses are the two major sectors that contribute most to CO2 emissions, and that any policy-making that is striving for sustainability should consider both simultaneously (2008). The compact city is one of the leading paradigms of sustainable urban development (Bibri et al. 2020) and aims to do just this; embedding sustainability by reducing the amount of travel needed to live comfortably in the city.

The 15-Minute City (Moreno et al. 2021) is another popular theory on how to achieve that. It builds on the notion that all residents in a city should be able to achieve their basic essential functions within a 15-minute walk or cycle from their home. The urban planning mechanisms to orchestrate this are prioritising density, proximity, diversity and digitisation (Holden et al. 2019). Achieving this requires a drastic alteration of transport planning paradigms, in which Banister's Sustainable Mobility Paradigm comes in handy is a fresh envisaging of slower, human-centred transport systems at the heart of city mobility networks. Understanding human behaviour is key in this regard, and that's why heat stress and thermal comfort should be vital considerations in infrastructure planning.

There are various tools that can be used to implement standards and influence processes to steer behaviour. Gehl claims that the quality of life in our cities is centrally signified by the improvement of the streetscape and the proliferation of compact, open spaces (2009). Local reconfigurations of the urban form can complement sustainable mobility behaviours, and then create new sustainable path dependencies. Ultimately, there is a need to reconceptualise urban mobility within a wider urban-social lens to address the grave environmental issues embedded within it. This can be achieved by integrating it into city and local-level masterplanning to ensure compact neighbourhoods and communities. As part of the compact city, cycling is one of the most straightforward ways for cities to improve mobility and address climate change (Bakker et al. 2018).

Bikeability is a term used to describe the social, environmental, political and legal environments that enable or disable urban cycling (Hardinghaus 2021). Notwithstanding, there is little consensus about how cities should measure and assess bikeability in practice.

There is little research on the relationship between environmental amenity and bikeability. What this means is, there is a gap in research on how environmental features can affect cycling behaviours.

The true benefits of adapting the environment to enhance thermal comfort and reduce heat stress and bicycle infrastructure has not been assessed systematically, exposing a critical research gap.

Hot weather affects human physical comfort, it can also affect the way that people access and experience active travel options, like walking and cycling. Evidently, this is to do with the direct exposure to the prevailing weather conditions, without the protection of a vehicle to act as a shield (Coutts 2001; Bocker 2018).

What this literature review found was there is a wide body of research on urban climate and similarly a wide body of research on cycling, but not enough on the infrastructure and urban morphological factors that connect the two. That is what this study seeks to bridge.

3 Methodology

The plan for research study is an experiment and case study. It aims to develop a new set of theories through the analysis of empirical data by investigating potential cause-and-effect relationships between the bicycle path infrastructural design and the microclimate, using a case study of two neighbourhoods in Seville, Spain (Csa: Hot-summer Mediterranean climate): Old Town (LCZ: 2) and Nervion (LZ: 5).

Meteorological data had to be collected first-hand, at two different times of the day (08.00 and 16.00), over the course of one week (21 June – 28 June 2022),
This method was chosen for its low organisational requirement and relatively low equipment cost, meaning replication would be accessible for future. Furthermore, the ground-based traverse method provides high temporal resolution during the measurement period (Rodriguez et al. 2020). It also helps to determine key local features to be able to attribute them to the bicycle path network (Rajkovich & Larsen 2016).
Two set of instruments were installed and deployed for the readings. Firstly, a solar-shielded reference or 'control' (referred to as "CRTL") station was set up on the

rooftop of the researcher's building to measure any natural variations in air temperature during the measurement times (Maharoof et al. 2020).

Secondly, the mobile instrument was mounted on a measurement platform to measure air temperature, relative humidity and wind velocity. It was carried on a 4.5km eight-location route that was followed uniformly on each reading journey (figure 1). After all multi-day readings were collected, they were cleaned using Microsoft Excel and then inputted into ArcMap 10.6 to be interpolated using the kriging method, through a Gaussian process governed by covariance. Heat maps were produced as a result.

Image 1. Map of cycling route (researchers's edit, **google.com**, 2022)

The kriging formula performed by GIS is as follows

$$Z(s_0) = \sum_{i=1}^{N} \lambda_i Z(S_i)$$

Where
$Z(s_i)$ = the measured value at the *i*th location
λ_i = an unknown weight for the measured value at the *i*th location
s_0 = the prediction location
N = the number of measured values (Burrough, 1986)

The next research stage saw the triangulation of findings using ENVI-met simulations to understand whether localised traverse readings could detect the same level of heat stress as the climate simulation model. ENVI-met simulates the temporal evolution of several thermodynamic parameters on a micro-scale range, creating a 3D, non-hydrostatic model of the interactions between building-atmosphere-vegetation (Ambrosini et al. 2014).

The meteorological data was sourced from Wunderground.com, from the nearest public meteorological station in the city (37.38 ºN, 5.99 ºW) on 20 June 2022, the first day of the traverse data collection. The model would run for 24 hours from 00.00 until 23.59.

The thematic document analysis strategy was finally used to determine the presence and extent of climate-sensitive design and heat stress planning within the Seville Sustainable Urban Mobility Plan.

The steps followed are:
(1) Collection of definition samples;
(2) Identification of analysis criteria.
(3) Creation of analysis framework;
(4) Code definitions;
(5) Record results in the analysis framework;
(6) Assess reliability and accuracy (intercoder agreement);
(7) Tabulate results. (p197).

3 Results

3.1 Traverse Study

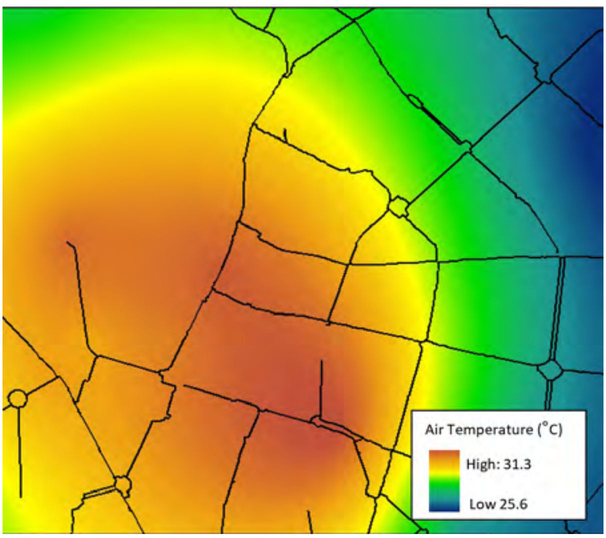

Image 2. PM air temperature heat map (Arcgis, 2022)

Figure 2 illustrates the air temperatures found across the bicycle path network from the traverse study. It shows how both air temperatures can vary spatially across different sections of city.

3.2 GIS Analysis: Detecting Severe Heat Stress

After layering and applying the kriging method to the heat maps, it was possible to rank heat stress to identify where there is severe vulnerability on the bicycle path network based on the air temperatures and relative humidities.

It was clear to see that in both calculations, the bicycle path surrounding site 5, the fountain site was under the most heat stress.

3.3 ENVI-met Simulation: Mean Radiant Temperature

ENVI-met was used to determine the mean radiant temperature at the sites to begin to properly understand the lived experience of each site, and the heating and cooling potential of each site.

3.4 Modifying the Fountain Site

Using the knowledge gained already, ENVI-met was utilised to realise alterations to the site to illustrate how the microclimate can be affected and heat stress reduced.
The Hispalis Fountain site was altered to include more greenery, directly adjacent to the bicycle path, creating compactness and reducing the wide canyon effect.
The result can be seen in figure 4.

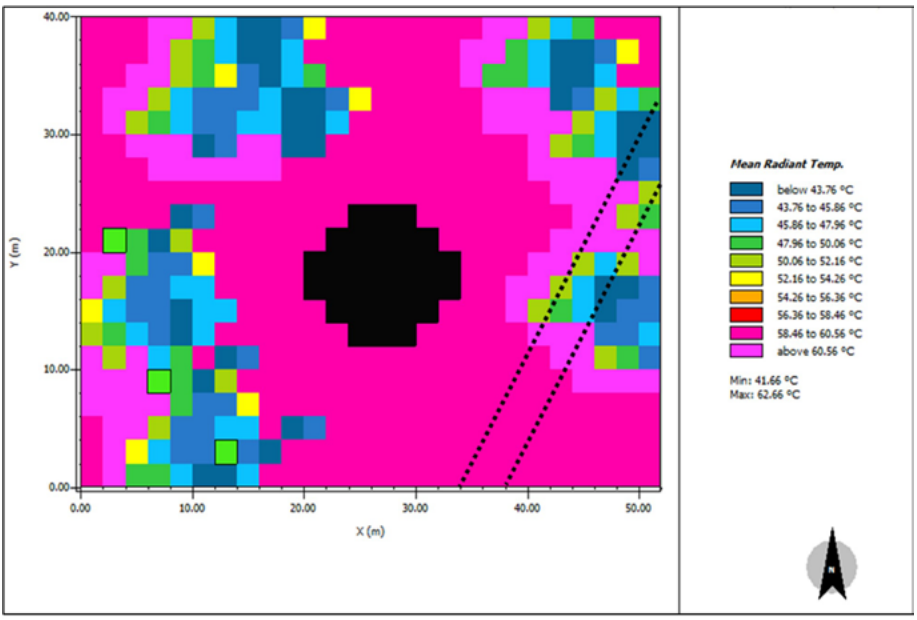

Image 3. Simulated Mean Radiant Temperatures over a 24hr period (20 June 2022)

4 Discussion

4.1 Traverse & Simulation Findings, Kriging Method

The results provided information about urban cooling island in addition to the UHI effect. Emmanuel (2005) describes the myriad counter-effects as: heat storage capacity of surfaces, imperviousness, lack of shading reduced solar radiation gain of urban surfaces, and the reduction in anthropogenic heat emissions from daily life, e.g., motorised transportation, human activity, heating/cooling engines and so forth.
The heat maps also showed that proximity to Seville's arterial roads played a significant role in increasing ambient temperatures. This is of concern for bicycle path users as the role of anthropogenic heat emissions will make cycling significantly less comfortable.

4.2 MRT Simulations

Figure 3 shows the MRT variations across the sites. One result that can be deduced is that the cooling benefits of vegetation and the impact that will have on MRT. That result provided ample justification for the further implementation of urban greening and next to the bicycle path network in particular.

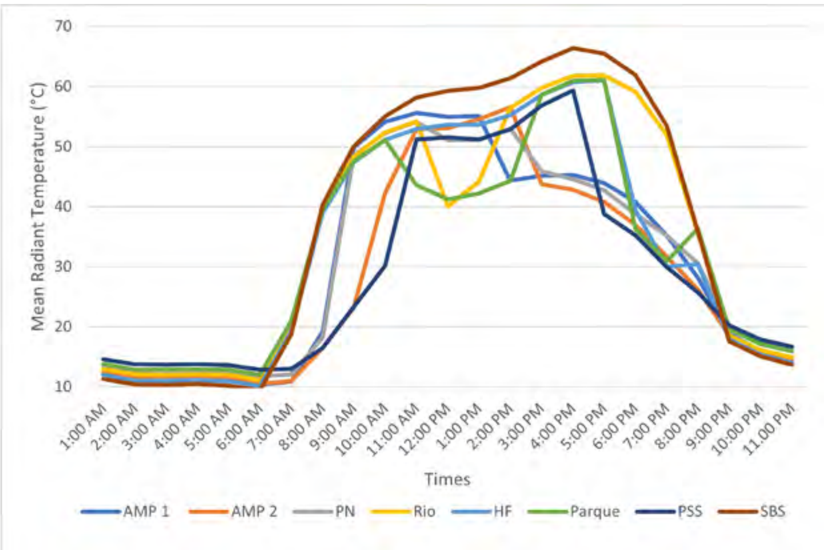

Figure 4. Simulated Mean Radiant Temperatures over a 24hr period (20 June 2022)

4.3 Site Alteration

Figure 4 shows the altered site, with the addition of mature vegetation, lining the bicycle path. By reducing the canyon and SVF, the surface temperatures would be reduced as well (Heisler 1986 according to Emmanuel 2012). Subsequently, urban comfort would be enhanced not actually by the air temperature changes but in fact to the radiation reduction (Robinette 1973; Barradas et al. 1999) again by reducing solar reflection.

4.4 Content Analysis, Seville SUMP

The policy document (AdS) analysis provoked several interesting avenues of understanding how the city plans sustainable mobility through a lens of environmental adaptation and heat stress prevention.

Only one reference is made to thermal comfort and not one single reference is made to UHI and how this could be mitigated though sustainable urban transport planning.

It can be deduced that there is a chronic lack of climate-sensitive planning in Seville's SUMP.

5 Conclusions

This methodology provided a novel framework for comparing the degrees of heat stress severity on the bicycle path network and was able to show how different urban morphologies contribute to differing degrees of heat stress.

Planners could benefit from this information; could bicycle path infrastructure be planned to match urban geometries, which could in turn potentially prevent severe heat stress for bicycle path users.

By promoting cycling in cities, transport emissions can be reduced as well as anthropogenic heat emissions. This means that mean radiant temperatures are reduced as well as heat stress.

That variation highlights the importance of compact, integrated planning and ensuring that there are sufficient local-specific interventions that create shade and reduce direct solar radiation that is going to intensify UHI. This could be achieved with vegetation, covered cycleways, arcades and awnings.

Vegetation has tremendous synergistic benefits that could be explored as part of an integrated, climate-sensitive transport planning approach. Lining bicycle paths with trees to provide canopy cover would be a fantastic approach in future for transport planners to consider, as begun to be demonstrated by the altered fountain site on ENVI-met.

The thematic content analysis exposed a systemic lack of climate-sensitive thinking in sustainable mobility planning in Seville. An integrated, interdisciplinary approach would help to bring heat stress issues to the fore, and address issues holistically.

While Seville has made impressive strides towards making the city more cycle friendly, it must do more to ensure holistic, climate-sensitive approach going forward. A starting point would be to update the SUMP to ensure that it addresses heat stress for cyclists.

There is still a wide research gap between urban transport studies and urban climate ones. This study sought to bridge that gap and identified key areas for future study. Firstly, the impact of anthropogenic heat emissions would be pertinent to look at. This would involve dissecting all sources of urban heat that exist on the bicycle path network to understand where the biggest sources lie and with that information solutions can be proposed. Alternatively, bicycle paths could be planned in such a way that they avoid severe sources of heat emissions, for example specific bicycle and pedestrian-only streets. Studies that investigate shading and irradiation reduction on those streets would also be of use, as would future studies that investigate the differences between the benefits of such measures on heat stress.

Table 1. Thematic content analysis: climate sensitivity

Criteria for Analysis (Working Hypothesis Derived From Pilot Study)	Searchable (s)	Observation (s)	Reference to Cycling? (Y/N) If Y, what?
Green Infrastructure: Vegetation, trees, evapotranspiration, greenspace	Infraestructura verde	0	
	Las vegetaciónes	5	
	los árboles/arbolado	18	
	evapotranspiración	0	
	las zonas verdes	3	
Anthropogenic Heat: combustion, metabolism, emissions	Calor antropogénico	0	
	combustión	10	
	metabolismo	0	
	las emisiones	0	
Urban Geometry: shade, canyon, skyview factor, solar load, radiation/rays	Geometría urbana	0	
	sombra	6	
	cañón	0	
	factor skyview	0	
	carga/rayos/ radiacion solares	3	
Heat: heat index, heat stress, UHI, temperature, condiciones climatológicas	Calor: estrés térmico, índice de calor, La isla de calor urbana, temperatura		
	estrés térmico	0	
	índice de calor	0	
	La isla de calor urbana	0	
	temperatura	7	
Blue Infrastructure: river, ponds, lakes, streams and storm water provision	Infraestructura azul	0	
	el Río	22	
	el estanque	0	
	el lago	5	
	el arroyo y el suministro de aguas pluviales	0	
Thermal Comfort: cooling, wind (speed/flow), breeze	Confort térmico	0	
	refrescante/la refigeración/end friamiento	0	
	el viento (velocidad/flujo)	2	
	la brisa	0	
Cycling: Bicycle, Bicycle Path, Non-Motorised Transport, Cyclists [References to Any of the other Criteria Assessed]	Movilidad Ciclista: Bicicleta, Carril bici, Transporte no motorizado, Ciclistas	22	

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ABHIJITH MATHIYATHU SEBASTIAN

Reclaiming the Right to the City

Towards Equitable Active Transport in Glasgow

A modal shift to active travel (AT) is increasingly being recognized as critical to reducing transport emissions and transitioning to net zero. The Scottish Government has allocated 10% of the transport budget to AT. Glasgow has successfully prioritized AT by integrating it with city-wide transformations. However, Glasgow's long-standing history of deprivation and legacy of planning mistakes calls into question the effectiveness of its strategies in addressing policy goals and delivering infrastructure equitably. This research critically evaluates Glasgow's AT policy and infrastructure using Henri Lefebvre's Right to the City. The concept of the right to the city has played a critical role in mobilizing social movements and academic interest to address and resist spatial inequities of neoliberal urban infrastructures. The research uses combined qualitative and quantitative methods to address the fundamental question of who is excluded from the right to mobility. Literature and policy review, semi-structured interviews, and macro-micro spatial analysis has been employed to understand the policy, planning, and delivery of AT infrastructure. Qualitative methods suggest a complex delivery process involving multiple stakeholders and highlight an inadequate consultation process that overlooks the strength of collective local decision-making. GIS-based spatial analysis indicates the inequitable distribution of AT infrastructure while neighbourhood-level walkability analysis reveals a mixed picture that calls for further research. This research contributes to knowledge in the field of AT by re-politicizing the dynamics of policy implementation towards advancing critical perspectives on transport equity.

1 Introduction

Concerns over climate change peaked in the early 1970s with the scientific community increasingly favouring the warming theory. This was also the time when governments across the world chose an extreme anti-regulatory approach to neoliberal globalization which set up the course for deepening climate change while widening inequality. What happened over the next few decades was the creation of a global economy and a period of rapid urbanization. This neoliberal course of urbanization strategically expanded geographical boundaries (of urban areas) and physical assets to gain economic benefits. A range of scholars in geography, urban studies, political economy, and elsewhere echo the fear that the growing power of capital and its pursuit of neoliberalization will increasingly disenfranchise the mass of people, excluding them from the decisions that determine the course of globalization, thus encouraging authoritarianism and undermining democracy (Purcell 2002). The resultant political and economic restructuring has a significant influence on urban policies that shape our cities.

A key element of neoliberal cities is their extensive highways that lead to suburbanization, a restructuring of the whole metropolitan region and has allowed the disproportionate use of private cars. The climate crisis that we face today quite starkly illustrates the failure of this neoliberal infrastructure. Transport accounted for 29.8% of carbon dioxide emissions in the UK in 2020 with private cars and taxis accounting for over 70% of transport emissions. Reclaiming road space from vehicles and reinstating active modes of mobility can be a great tool to reengineer our cities to be more sustainable and equitable. Walkable cities have shown a high correlation with improved air quality and narrow income disparity among various other benefits. Active travel being the most affordable form of mobility can be considered an equalizing mode. There has been global interest in the promotion of active travel recently, but much of this effort and associated investment is on creating infrastructure within commercial centres. In the UK, cities are pioneering efforts to improve active travel infrastructure. As with any neoliberal infrastructure, Active Travel faces the threat of extreme commercialization and failing to deliver access to the most vulnerable populations.

In this context, French Marxist philosopher, and sociologist Henri Lefebvre's idea of the 'right to the city' (RTTC) emerge as a tool to respond to neoliberal urbanism and empower urban inhabitants. Lefebvre's political and intellectual project, inspired by Marx, Hegel, Nietzsche, and Heidegger, offers a critique of existing society to pave way for another society, a possible world beyond capitalism, the state, and consumer society (Purcell 2014). Social movements and academics have adopted RTTC, both the concept and the slogan as a means of articulating and resisting spatial inequalities in the capitalist city. RTTC offers a lens to evaluate active travel both as a neoliberal infrastructure project and as a potential agent for urban change.

Glasgow has projected itself as one of the greenest cities in Europe, with its ambitious aims of achieving net neutrality by 2030 and is investing significantly in active travel infrastructure (ATI). Among its plans are to add 270 km of segregated cycle paths and transform the city centre into a pedestrian first zone. Thus, Glasgow as a case study offers immense potential to understand the ATI planning process (PP) and investigate the spatial equity of its delivery. Thus, this research aims to evaluate Glasgow's Active Travel policy, planning process (PP), and infrastructure delivery through Henri Lefebvre's Right to the City (RTTC) theory. The question of who is excluded from the right to active mobility, and thereby the right to the city becomes the crux of this research.

2 Background

2.1 Right To The City

The Right to the City is both an idea and slogan first proposed by Henri Lefebvre in his 1968 book Le Droit à la Ville (Gupta and Kavita 2020). Lefebvre proposes this as a radical way to collectively transform our cities against the extensive commodification of urban space. Lefebvre argues that when economic systems value urban space mainly for its exchange value, the true potential of urban life is suppressed (Alisdair 2014).

An effort to conceptualize the right to the city to promote social justice, sustainability, and inclusion in cities (as part of a broader human rights agenda) was led by UN-HABITAT and UNESCO. While in Brazil the concept has been codified into the national law, community organizations in the US have formed the Right to City Alliance (Purcell 2014). Urban Geographer David Harvey (Harvey 2018, 27) puts it as "The right to the city is far more than the individual liberty to access urban resources: it is a right to change ourselves by changing the city. It is, moreover, a common rather than an individual right since this transformation inevitably depends upon the exercise of a collective power to reshape the processes of urbanization. The freedom to make and remake our cities and ourselves is, I want to argue, one of the most precious yet most neglected of our human rights." The four concepts that are paramount to Lefebvre's idea can be distilled down to "participation", "appropriation", "autogestion" and "value"(Kuymulu 2014). Participation is the ability of inhabitants to contribute to the production of space while appropriation relates to the equal access to occupy and use urban space and infrastructure. Autogestion is the idea of self-management of urban environments by inhabitants.

2.2 Active Travel

Active travel occupies a critical role in almost all modern discourses of a sustainable city. The concept finds itself at the nexus of a series of multidisciplinary fields ranging from urban design and planning to broader issues of climate change, equity, public health, and social cohesion. In a sense the act of walking/biking is the most equitable form of transport and can hence have an equalizing effect on social life. Many ideas of a modern city, such as the '15-minute city' emphasises on the significance of active travel. A 2022 paper defines active travel as "travel in which the sustained physical exertion of the traveller directly contributes to their motion"(Cook et al. 2022, 155). Although used as an umbrella term, walking and biking are the two major modes of transportation that preoccupy the term 'active travel'.

The contemporary dialogue on active travel does not acknowledge the political and economic considerations that underpin its dissemination. In most cities Active Travel infrastructure is confined to the economic centre resulting in the creation of a network of pedestrianised routes connecting commercial establishments. The purpose of this AT network is limited to the flow of capital, often ignoring its inherent social value. "Attractivity" of pedestrianization projects become key components in commercial spatial appropriations. Deprived communities that are more likely to walk are often marginalized with low-income neighbourhoods having minimal walking infrastructure (Massingue and Oviedo 2021). Unequal access has contributed to creating disparities in terms of both health and social deprivation (Aldred et al. 2021). The progressive intentions of AT policy and infrastructure thus do not translate to inclusive and transformative practices. In the context of this neoliberal class politics, it is ever more critical to re-politicize active travel. This thesis proposes an approach to understanding AT through the lens of social justice, as a potential step towards the production of social values as opposed to just health-economic benefits.

2.3 Glasgow

The study area is Glasgow -Scotland's largest city with a population of around 635,000. Prior to its modernist urban experiments, cycling was one of the most popular modes of transport in Glasgow and many other European cities. It saw a significant setback with industrialization and the invention of the automobile. In the early 90's, Glasgow was also home to one of the largest tram networks in Europe with over 1000 trams and 160 kilometres of tram network. In the decades that followed, Glasgow's public transport was deprecated, the city was depopulated (a population of over 1 million in 1950s reduced to around 600,000 by 1980), and its communities disintegrated in an attempt to create a modernist city (Urban 2018). Many of Glasgow's current transport challenges are a result of this. Over the past decade cycling and walking has seen steady growth and is attributed to infrastructure change.

3 Methodology

Transport induced exclusion, inequality, and accessibility and related research plays an important role in informing this research. Inquiries are aimed at understanding the process of production of ATI and spatial distribution of infrastructure. The methodology framework identifies the concept of participation and appropriation as tangible elements of RTTC in understanding AT policy and infrastructure respectively. A mixed method with both quantitative and qualitative methods have been used. Within each method of analysis concepts of RTTC are further explored.

3.1 Interpreting Participation

The two qualitative methods used to understand participation are literature and policy review, and interviews.

3.1.1 Thematic literature review

The thematic literature review was aimed at identifying theories, themes, and associated studies that guided the formation of research question, approaches, and methods of analysis. A key aspect of this was synthesising RTTC through its various interpretations to identify its key concepts.

3.1.2 Policy Review

This helped develop an understanding of the policy landscape. Institutional reports, policy documents, strategy documents and academic papers were analysed. Policy review was complemented by interviews which helped bridge gaps in the understandings.

3.1.3 Semi-structured Interviews

Perspective of those implementing the policy (institutional) and those advocating for change (activists) needs to be captured. A semi structured interview of multiple stakeholders is proposed to develop this understanding. Sampling of interviewees were done to include policymakers, policy advocates, and users to give a holistic picture of the processes that leads to the production of ATI. A deductive approach to coding was used with the broad themes guided by RTTC.

3.2 Analysing Appropriation

Appropriation in this study is evaluated as the ability of inhabitants to access and use active travel infrastructure. Access to active travel represents an extension of the inhabitant's ability to appropriate urban spaces. This is analysed at two scales: (A) Macro-level, which influence the distribution of ATI and (B) Micro-level, which looks at spatial equity through human-scale planning outcomes that the inhabitants directly engage with.

3.2.1 Macro Spatial Analysis

The spatial distribution of AT infrastructure and its comparison to area deprivation forms the basis for the analysis. The parameters studied include the distribution of bicycle lanes, bicycle hirings station, bicycle storage facilities, walkability of rail stations and subway stations, and the level of public transport integration.

3.2.2 Micro-analysis: Neighbourhood Study

Spatial equity as a key element of human-scale placemaking as theorised by Jane Jacobs (1993), underpins the spatial analysis at micro-scale. The indicators of walkability are partly derived from Jacob's writings on the 'conditions for successful, diverse, and attractive neighbourhood'. This includes density, diversity (mixed uses), connectivity (indicating smaller blocks) and access to open spaces; indicators that are evidenced to contribute to walkability (Gunn et al. 2017).

Density

Population density was calculated as people per sq.km of floor space. The population obtained from the SIMD data zones were used for this calculation.

$$Population\ Desity = \frac{Pi}{Ai}\ (1)$$

Pi = Population of the neighbourhood and Ai = Total floor area of the neighbourhood

Green Space

Green Space was defined as the total area of parks and open public spaces. The percentage of green space was calculated as:

$$\%\ Green\ Space = \frac{PRi + Oi}{Ai}\ (2)$$

PR*i*= Area of Park; O*i*=Area of open public space; Ai=Area of the neighbourhood
Diversity of Building Use

Land use diversity is most commonly calculated using the entropy index (Boarnet 2011). Entropy index ranges from 0-1 where 0 means maximum homogeneity (specialization) and 1 means maximum heterogeneity (diversification). The entropy index based on building use instead of land use was calculated as it is more representative of the neighbourhood level functions. The following formula was used (Shannon 1948):

$$Entropy\ Index = -\sum_{i=1}^{N} Pi \times \frac{\ln(Pi)}{\ln(N)}\quad (3)$$

P*i* = proportion of land use category i within the selected study area boundary; And
N = number of land-use categories

Connectivity

ArcGIS Network Analyst Tool was used to produce nodes and edges for the network within each neighbourhood. Nodes were classified into cul-de-sacs, and three and four-leg intersections. The indices for measurement of connectivity is as follows (Tresidder 2005) :

$$\%\ of\ Cul-de-Sac = \left(\frac{Number\ of\ Cul-de-Sacs}{Number\ of\ Nodes}\right) \times 100\quad (4)$$

$$\%\ of\ 4-leg\ intersections = \left(\frac{Number\ of\ 4leg\ intersection}{Number\ of\ nodes}\right) \times 100\ (5)$$

$$Link\ Node\ Ratio = \left(\frac{Links\ per\ unit\ of\ Area}{Nodes\ per\ unif\ of\ area}\right) \times 100\quad (6)$$

$$Connected\ Road\ Ratio = \left(\frac{Actual\ Nodes}{Actual\ Nodes + Cul-de-Sacs}\right)\quad (7)$$

4 Results

4.1 Policy Review

Scotland's transport policies establish a strong rationale for promoting active travel. The delivery mechanism involves multiple players, primarily local authorities and third sector organizations who act as delivery partners. The Scottish Government also has a very limited role or control in the actual outcomes of ATI implementation. The implementation depends heavily on the priorities of LAs and their ability to seek funding through time bound submission of application. At the local level, multiple senior officials and directors of various departments are influential agents in determining the policy translation (Transport Scotland 2016). Smaller LAs could be disadvantaged in their ability to produce these applications due to overlapping priorities and limitations of human resource. Glasgow being one of the largest LAs in Scotland has a significant advantage in terms of available resources and scope of work. The initial review suggests that the city has successfully integrated AT as priority to achieving its wider goals of sustainability. However, there is a lack of clarity on how the projects are prioritized and rolled out. The strategy is also divorced from addressing challenges of car use which could deter any progress in active travel. Although there has been a significant increase in active travel budget, it is much less in comparison to that of motorways and highways.

4.1.1 Infrastructure Delivery

The interviews highlighted infrastructural deficit as the primary barrier to active travel. Trip generation was the primary parameter used to prioritize AT projects. This assumed that a particular group of people tend to cycle predominantly. It was also found that the proposals reflected ideas developed in contexts elsewhere and is susceptible to enforcing particular 'visions' of urban environment which Lefebvre argues against. Delivery partners who are part of the funding panel ensure that the policy is not diluted when it translates to infrastructure. Figure 1 on the next page visualizes the various stakeholders involved from policy formulation to infrastructure delivery.

4.1.2 Public consultation process

Public participation is an indicator of the centrality of importance given to the city's inhabitants. The preparation of Active Travel Strategy was based on the Glasgow City Council's extensive public consultation called 'connecting communities 2020'. The initial view of the document suggests a deeply participative process. The attempt to be inclusive of minority groups, genders and ethnicities is also commendable. However, direct citizen participation was limited (due to Covid-19) and the character of online surveys were inherently un-interactive. The method of engagement was found to be extremely prescriptive. Thus, the process of consultation paints the picture of a predominantly informative and consensus seeking process rather than participation. Nevertheless, the acknowledgement of public participation and an attempt to implement is a step that deserves appreciation.

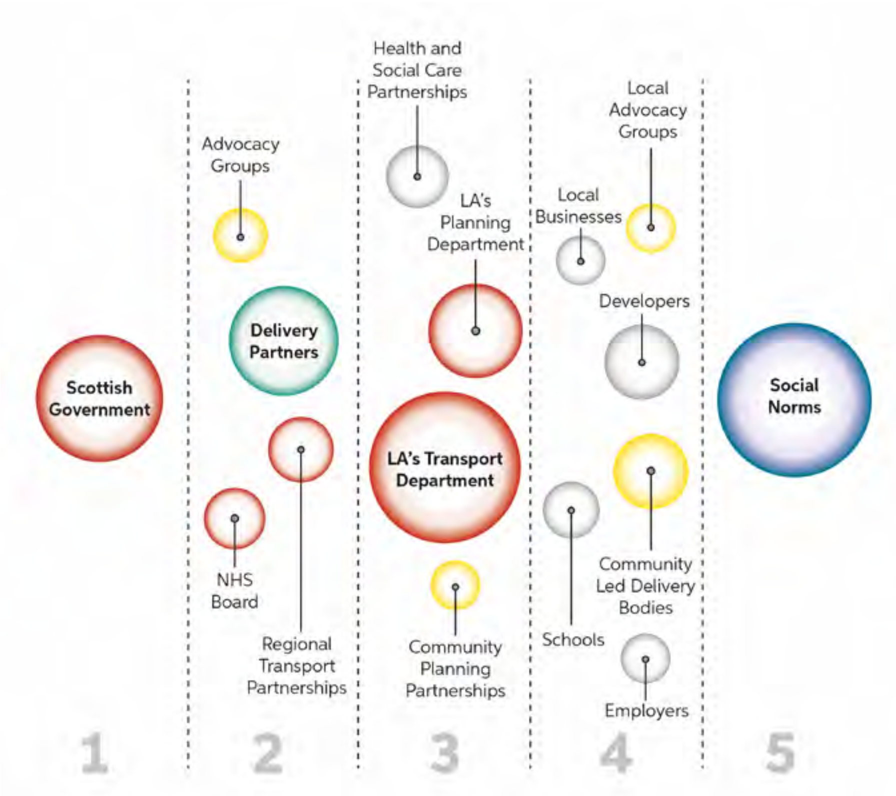


Figure 1. Stakeholders involved in the Scottish AT policy landscape based on AT Policy implementation review (Transport Scotland 2016)

The key findings of interviews are summarised in figure 2 on the next page. Both interviews and policy review complement each other in helping frame a nuanced understanding of the planning process. Both methods lead to an understanding the confirms Lefebvre's argument about the nominal role of citizens in decision making. The findings suggest a limited and partial public participation that allows residents and interested parties to object to planning applications and comment on the development of development plans, rather than actively take decisions. While institutional channels for participation directed through departmental mechanisms were inadequate, the Active Travel Form (comprising of citizen groups and activists) played a significant role in influencing the policy landscape and the City Council's approach to AT. Involvement of delivery partners also democratise decision making to a large extent. Policy interpretation was found to be dependent on several factors including the number of stakeholders, departments and officials involved. Leadership and alignment of goals plays a significant role in policy translation. The understanding also highlighted the need for self-management which Lefebvre conceptualised as autogestion.

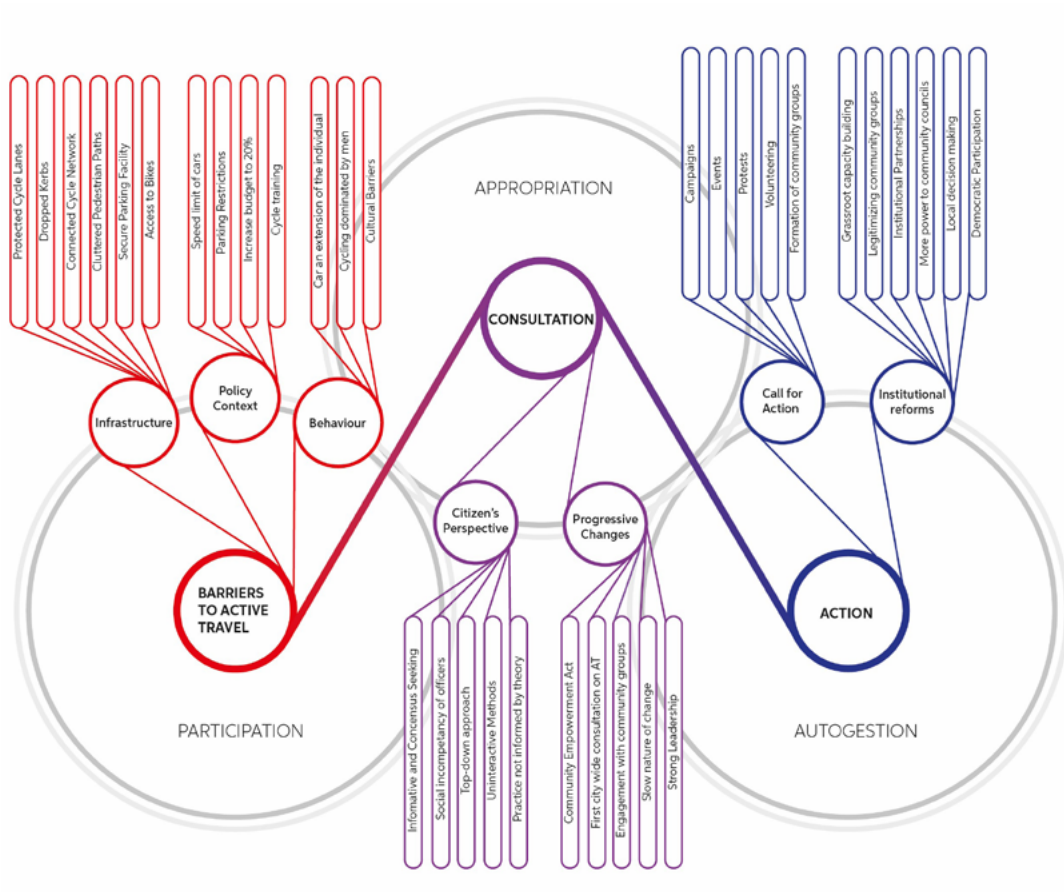


Figure 2. Figure showing the different codes and themes identified and their link to RTTC (Sebastian 2022)

4.2 Macro-spatial analysis

The spatial distribution of Bicycle infrastructures was compared to the Scottish Index for Multiple Deprivation to understand its equitable access. It was found that bike lanes were fairly equitable distribution with each SIMD quintile having roughly 20% of bike lanes. However, bike lanes were found to be disconnected with only 20% segregated lanes. Most automated bike hire stations and bicycle storage facilities were found to be in less deprived areas. Walkability to public transport facilities also revealed a similar picture. It was found that the catchment areas of rail stations predominantly served less deprived areas. Transport integration map also revealed that the most integrated transport hubs were in less deprived areas. Figure 3 on next page shows the spatial distribution of infrastructure and their quintile deprivation ranking by data zone (SIMD) in their location and service area.

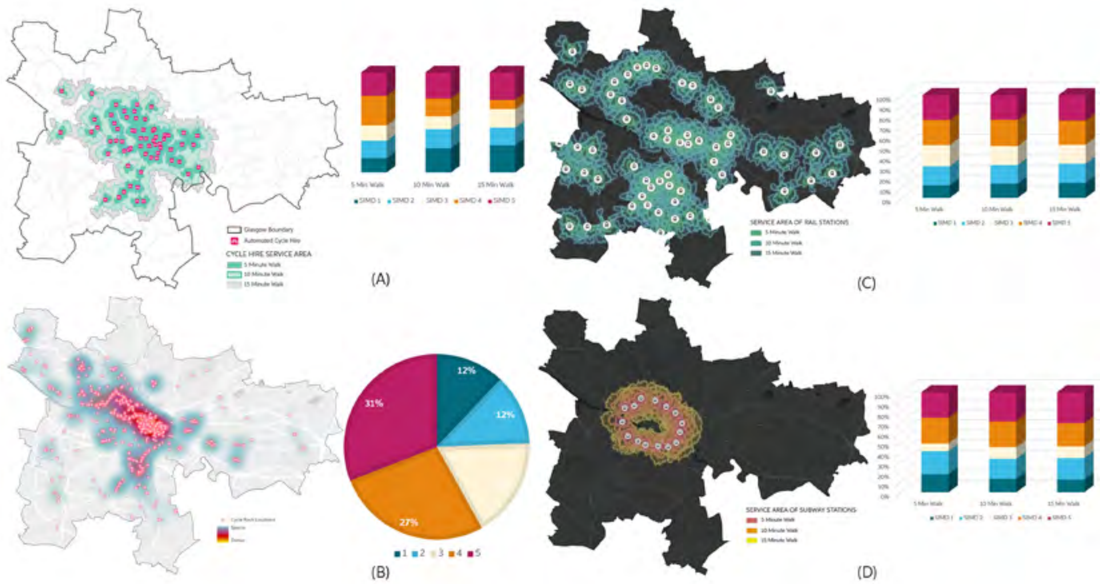


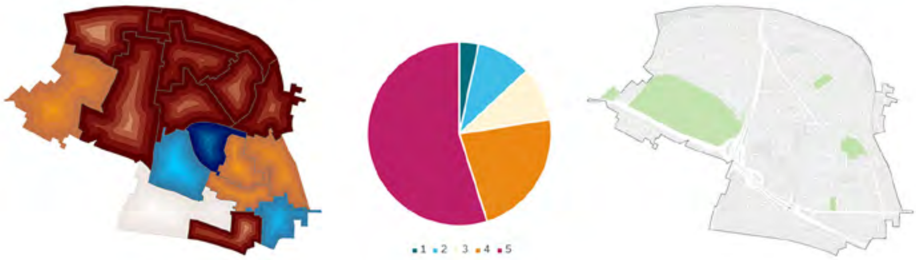
Figure 3. Spatial distribution of (A) Bike hire stations (B) Bicycle storage facilities (C) Rail station catchment area and (D) Subway station catchment area, according to SIMD (Sebastian 2022)

4.2 Micro-spatial analysis: Neighbourhood study

The walkability of three neighbourhoods were compared- site 1 (Partick and Broohmhill), site 2 (Govan and Ibrox), and site 3 (Govanhill). The comparison has been summarised in figure 4. Site 1 is least deprived and site 2 is the most deprived followed by site 2. It was found that site 3 had almost 6 times the cyclists count compared to site 1 and 2. The neighbourhood level study did not reveal a significant relation with walkability and deprivation levels. But the provision of ATI and public transport systems indicate marginalization of the most deprived areas. Spatial analysis could not reveal the reason for the disproportionately high cycling counts in Site 3. But a broader contextual view suggests how the Victoria Road is critical to connecting the city centre to the south side of Glasgow which is one of the least deprived areas of the city.

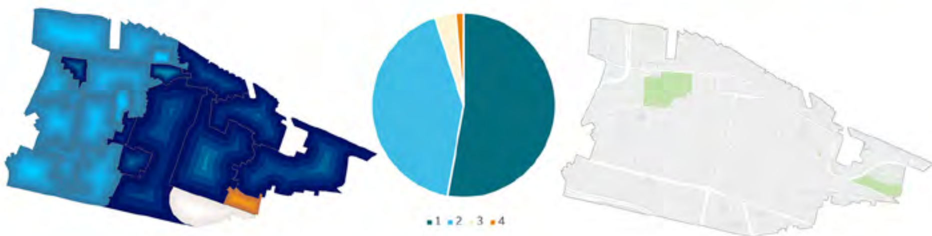
Site 1 Broomhill+Partick 2.1 sqkm

10.7 % Green Space



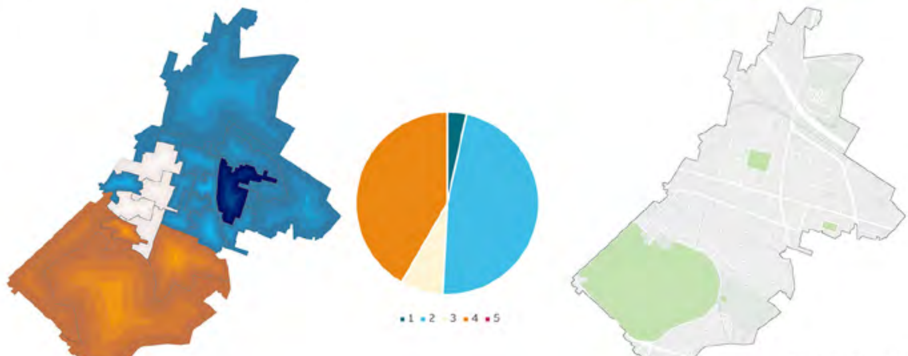
Site 2 Govan+Ibrox 4.2 sqkm

4.2 % Green Space



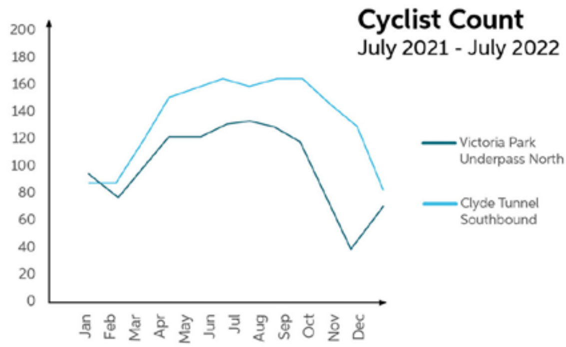
Site 3 Govanhill 2.4 sqkm

19.8% Green Space



*maps not to scale

Density	Population Density	7355.85
Diversity	Entropy	0.38
Connectivity	Link node ratio	1.41538
	Connected node ratio	0.8843
	% Cul-de-Sacs	13.07692
	% 4 leg intersections	12.3



Density	Population Density	3642.28
Diversity	Entropy	0.69
Connectivity	Link node ratio	1.35648
	Connected node ratio	0.8587
	% Cul-de-Sacs	16.45338
	% 4 leg intersections	6.398

Density	Population Density	6557.03
Diversity	Entropy	0.678
Connectivity	Link node ratio	1.5235
	Connected node ratio	0.9246
	% Cul-de-Sacs	8.15047
	% 4 leg intersections	16.3

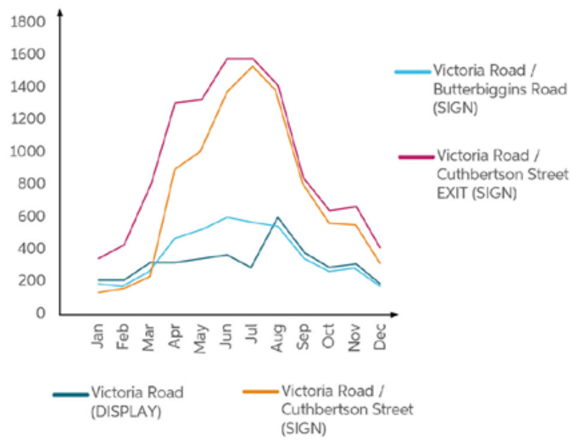


Figure 4. Comparison Of Walkability Indicators And Cyclist Counts Of All Three Areas (Sebastian 2022)

5 Discussions and Conclusions

Active Travel infrastructure is reshaping Glasgow's urban landscape, enabling its citizens new ways of mobility and access. This thesis fundamentally questions whether this mobility and access for some is attained at the cost of immobility and inequity for others. Lefebvre's vision of right to the city proves to be a powerful idea that reveal the dichotomy between AT policy and implementation towards answering this question. Equitable access to AT is not only paramount to achieving goals of emission reduction, but also fundamental to creating a sustainable and equitable urban environment. This research successfully integrates thematic debates on the production of urban infrastructure to foster a nuanced understanding of Glasgow's policy landscape and the complex socio-spatial contradictions of its delivery.

The result of this study suggests that institutional mechanisms translate policies for justice into unjust spatial practices. The user's ability to participate in the planning process was limited and existing provisions were found to be superficial. The consultation process was largely informative and consensus seeking reflecting a systemically top-down approach. The inadequate nature of consultation in Glasgow has been subject to previous studies (Muir 2020; Giupponi 2021) and was also highlighted in the interviews. Spatial enquiries draw attention to the uneven ways in which AT is configured in producing unjust mobility scenarios and poses the question of who holds the power over defining urban experiences. The result from spatial analysis indicates the inequitable distribution of several active travel infrastructures, particularly evident in the distribution of bike hire stations and cycle storage facilities. However, bike routes themselves were found to be equitably distributed. Inequitable spatial distribution of cycle storage facilities was complemented with the already high demand for such facilities. Equity in bike sharing has been the subject of various research approaches in different places. One study in Glasgow corroborated the results confirming the inequitable location of bike hire stations (Beairsto et al. 2022). Nevertheless, spatial inequity was found to be much less compared to cities like Barcelona (Anaya-Boig et al. 2022), although Barcelona has a much larger fleet of cycles. The distribution was also found to be relatively balanced compared to bike-share systems in North American cities (Beairsto et al. 2022). A study of 35 bike share systems in the United States revealed that only 5% of stations were located in census block groups in the highest economic hardship quintile (Smith et al. 2015). A 2014 paper suggests that "deprived areas face the 'double jeopardy' of high deprivation and environments that are unsupportive of walking" (Shortt et al. 2014, 1485). The neighbourhood level analysis confirmed these theoretical assumptions regarding the role of built environment in promoting neighbourhood walkability. Areas with higher values of walkability indicators had better ATI implementation and showed a higher footfall of cyclists. Although the number of sites compared is insufficient to indicate a correlation between walkability and deprivation, the findings corroborated previous studies (Kenyon and Pearce 2019) that found no wider evidence that deprivation levels are related to poorer walkability potential. While there were inconsistencies in the results of spatial analysis, this was attributed to the approach to site selection and quality of trip data.

Within this complex landscape of multiple institutional agents and inadequate planning processes, progressive change was brought by virtue of a prolonged political struggle. 10% budget allocation for active travel became a reality as a result of the power sharing agreement between the SNP and the Greens. Proportional representation created a fundamental shift the Glasgow City Council's approach to planning. Active travel forum pushed the city to reprioritising its transport policy. Delivery partners strengthen the decision-making process regulate infrastructure delivery. What we see is progressive change fostered through collective decision making, and the dissolution of power leading to democratisation of the process. This legitimises Lefebvre's theorization and argument for participative appropriation of the city.

What this research succeeds is in politicising the Active Travel by integrating thematic debates and revealing the contradictions in planning and practice. The possibilities for strengthening grassroot level decision making and engaging community actors add a healthy dose of optimism to this debate. It emphasises the need to break the imperialistic structure of decision making to instigate new forms of collaborative practices that transcend institutional boundaries towards a redefinition of how public infrastructure is conceived, constructed, occupied, and used. Changing the current processes of urbanism can only come through the mobilization of the masses. The contradictions of neoliberal urbanism and its periodic failure offer the opportunity to collectively reimagine the processes of production of space towards the creation of a new urban; one where social value triumphs over exchange value. As Lefebvre writes "A revolution that does not produce a new space has not realized its full potential".

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Creating Sustainable and Equitable Communities in a Post-Covid Context

Development of the Scottish 20-minute Neighbourhood Concept

This article aims to contextualise the 20-minute neighbourhood in Scotland as a place-based approach to a post-pandemic green recovery; to understand how the concept is being received and understood by stakeholders, including residents, planners, and policy makers; and to gain insight into the opportunities and barriers to implementation and success.

A mixed-methods qualitative approach utilising a wide a range of primary and secondary sources was taken to identify key themes. Emergent themes of Liveability, Community, Resilience, Changing Behaviour, and Barriers & Constraints were identified from stakeholder interviews. The Place Standard tool was used to structure participant explorations of their experience of use of, and movement around, their neighbourhoods as well as their experiences of place during the pandemic. Mapping was used to understand how the neighbourhoods were performing as 20-minute neighbourhoods, and to identify significant barriers to access and connectivity. Physical and mental barriers included accessibility, safety, topography, and a lack of infrastructure. Neighbourhoods with greater access to amenities, greenspace, and community support were more resilient to the negative impacts of Covid-19 restrictions.

1 Introduction

In response to the climate crisis, and in line with the Paris Climate Agreement, Scotland committed in 2019 to stringent and ambitious net zero targets for emissions of all greenhouse gases by 2045. The aim of this target is to keep the average global temperature rise below 2oC. Following COP26 it is clear that current plans are not doing enough to achieve this target, and our planet is on course for a minimum global temperature rise of 3, if not 4oC. (Climate Change Committee 2021).

Adapting and adjusting our physical and mental spaces will be vital in fostering resilience within our communities, and in mitigating the worst impacts of climate change while ensuring that we are equipped to deal with the economic, social, and environmental shocks. Essential changes to achieve these goals include reducing car-dependency and improving active travel networks.

The global Covid-19 pandemic has had a devastating economic and social impact worldwide. It has accelerated the need for, and pace of change in, our economy and tested the resilience of communities. It has brought into focus the limits and opportunities of place, and highlighted vast inequalities of resilience and experience of individuals and communities in the types of access and quality of space and services (strongly influenced by quality of amenities, travel networks, and public green spaces).

The pandemic has affected the way that many governments (Scotland included) action their emission reduction targets to ensure that priority is given to wellbeing of citizens through supporting the economy. In some cases, this has resulted in downgrading and reducing climate targets to bolster economic recovery. In Scotland the focus is on a "Green Recovery" as a solution to the "tough balancing act to meet our economic, environmental and social needs in order to overcome Covid-19 and the climate crisis so we can build a stronger, fairer, more sustainable world." (Zero Waste Scotland 2020.)

The 20-minute neighbourhood concept, (also known as the 15-minute city; these concepts are largely interchangeable (Moreno et al. 2021)) is one of many solutions currently being explored by politicians, planners, and citizens globally, as a framework to help cities decarbonise. It aims to do this by reducing car dependency and promoting active and green travel, while keeping social wellbeing of its citizens at the forefront of plans (C40 Knowledge Hub 2020; O'Gorman & Dillon-Robinson 2021), by ensuring citizens can access all daily needs within a 15-20-minute walk (or "wheel", i.e. active travel) from their home. Broadly speaking this includes opportunities for work, recreation, education, and access to goods and services including healthcare, groceries, transport infrastructure and greenspaces.

1.1 Aim

The aim of this study was to contextualise the 20-minute neighbourhood as a place-based approach to a green recovery in a Scottish urban context, and to gain insight into the opportunities and barriers to successful implementation through an exploration of stakeholder and citizen experiences over the COVID-19 pandemic.

2 Background

2.1 The 15- and 20-minute Cities in a post-Pandemic context

The related concepts of the 15-minute city & 20-minute neighbourhood describe urban environments where citizens should be able to access all their everyday needs, including essential services, jobs, culture, and leisure activities, within a 15 or 20-minute walk or cycle from their homes. Several similar proximity and place based urban planning concepts have emerged in recent years. Variations exist in the criteria, definitions, outcomes and aims, but there is shared recognition of the relationship between sustainability, health, and wellbeing. (Nieuwenhuijsen 2021).

The 20-minute neighbourhood concept focusses attention on a recovery from the pandemic based on the human experience of city. The concept supports and shares many aspects of the Circular Economy, such as promoting local investment; business use; connectivity and connections; social enterprise and sharing resources (Ellen Macarthur Foundation 2017). Several cities globally have adopted the concept; each has developed its own local approach to implementation. Notable examples include Portland (Portland Plan: Complete Neighbourhoods 2012), Melbourne (Plan Melbourne 2017 – 2050: 20-minute Neighbourhoods 2017) and Paris (Ville Du Quart D'Heure 2021).

The Paris 15-minute city model (Moreno 2020) proposes that residents will be able to enjoy a higher quality of life when they are able to effectively fulfil six essential urban social functions. These include (a) living, (b) working, (c) commerce, (d) healthcare, (e) education and (f) entertainment.(Moreno et al. 2021)

In the context of the COVID-19 pandemic,(Moreno et al. 2021) propose a modified "15-minute city" framework to support urban recovery from Covid-19 argues that cities would be better placed to deal with the effects of the pandemic on city dwellers if they had prioritized the following 4 dimensions; Density, Proximity (to food and services), Diversity (mixed-use neighbourhoods) and Digitalisation (sharing technologies, infrastructure for home working, online shopping). (Moreno et al. 2021.)

2.2 Impact of the Pandemic on Urban Living

The global pandemic caused by Covid-19 has changed the way we live, work, and interact with our local communities, accelerating changes that are already occurring in the context of the digital economy and globalisation. The pandemic highlighted the deep-rooted inequalities in terms of health, wealth, physical space, safety, and comfort that impacted people's experiences. (Bambra, Riordan, Ford & Matthews 2020.)

2.3 Diversity

Diversity in the context of the 20-minute neighbourhood is multifaceted. Fundamentally it refers to the diversity of services and amenities required for the "complete" mixed-use neighbourhood with "a healthy mix of residential, commercial and entertainment components" to meet the needs of the people who inhabit it (Moreno et al. 2021). Most importantly however, it refers to the recognition that not everyone's needs, or experiences are the same. "This diversity of experience, or "experiential equity," needs to be accounted for in urban design decisions." (Cappasso Da Silva, King & Lemar 2019)

2.4 Density

The specific density required for a successful 20-minute neighbourhood is difficult to quantify as each country, city or neighbourhood is different and has different topographical, economic, and historic character, presenting various issues and opportunities. Mathematical modelling of the Melbourne Plan concluded that the optimum density for "A city of 20-minute neighbourhoods" in Greater Melbourne, Australia was approximately 92 persons per hectare or 36 households (Shatu & Kamruzzaman 2021).

The competing priorities of ensuring a diversity of land use, ensuring the critical mass of people to support these services and providing adequate open green space for the population mean that the optimum density for a 20-minute neighbourhood needs to be carefully considered (Moreno et al. 2021; Shatu & Kamruzzaman 2021).

2.5 Health

20-minute neighbourhoods have the potential to improve health inequalities by improving access to primary health services. If these services are within walkable distances, they are more accessible and can benefit a larger and more diverse range of users. Walkable neighbourhoods can also have a positive impact upon health and wellbeing and have been found to reduce obesity and diabetes related illnesses by encouraging walking and exercise (Howell et al. 2019; Weng et al. 2019).

2.6 Transport inequality

Studies of new & recent housing developments in England found that most orientated around & encouraged car use (Transport for New Homes 2018). This increases inequality and has negative economic and social impacts on communities; individuals who do not own cars are excluded from accessing jobs and services, and are at higher risk of becoming isolated or trapped in cycles of deprivation and poverty (Architecture and Design Scotland 2018). Increasing options and opportunity for active travel gives people choices, but also addresses some of these inequalities. (Just Transition Commission 2022; O'Gorman & Dillon-Robinson 2021).

2.7 Scottish Policy & Context

The Scottish government is "committed to delivering a place-based approach to support Scotland's Green Recovery" (O'Gorman & Dillon-Robinson 2021), with a consensus between government and industry partners to work towards a 20-minute neighbourhood concept (Brice & Sustrans 2019; O'Gorman & Dillon-Robinson 2021). The Scottish Government has defined radius of the 20-minute city at 800m. (Director-General Communities & The Scottish Government 2021). This distance is based upon Melbourne's 20-minute neighbourhood model (Gunn et al. 2017; Victoria State Government 2019). The Melbourne plan has developed a framework which identifies several elements central to a 20-minute neighbourhood. These elements are grouped into 6 categories (see fig.1)

Figure 1. Features of a 20-Minute Neighbourhood, Melbourne Model (Victoria State Government 2021)

In Scotland, National Planning Framework 4 (NPF4) is the long-term spatial plan setting out proposed development and infrastructure, national planning policies and a decision-making framework to support sustainable and inclusive growth for Scotland to 2050 (Director-General Communities & The Scottish Government 2021). The plan (currently out for consultation) recognises and prioritises climate change action as the driver for its vision and plans. The Plan for Scotland 2050 includes a plan for net-zero emissions, resilient communities, a well-being economy, and better greener places (Director-General Communities & The Scottish Government 2021). All these plans and outcomes draw on the 20-minute city concept for successful implementation.

2.8 The Scottish Urban Context: Dundee as a Case Study

Dundee is Scotland's 4th largest city; with the second highest population density in Scotland, due in part to tight city boundaries and rapid industrial development in the 19th century. The city has been chosen as the base for this study because it exemplifies a typical Scottish city, being a post-industrial city. The housing stock and nature of urban expansion reflects national construction and planning policies and trends, and a similar pattern of growth can be found in most Scottish towns and cities. It suffers from a range of social and economic issues related to industrial decline, unemployment, poverty, and ill health. Demographic issues include an ageing and declining population (National Register of Scotland 2021).

3 Methodology

3.1 Approach

A mixed-methods qualitative approach was taken, to allow analysis of diverse data from a range of primary and secondary sources. A pragmatic approach was taken regarding collection of primary data (interviews, workshops, and public comments on websites). The pandemic and associated restrictions presented opportunities to gain insight into public experiences and feeling of place. It also presented limitations; interviews were necessarily mostly conducted via videoconferencing software, and number of residents able to participate in the workshop was limited by restrictions on households meeting.

Four phases of study and analysis were conducted to collect, review, and critically analyse various sources of primary and secondary data.

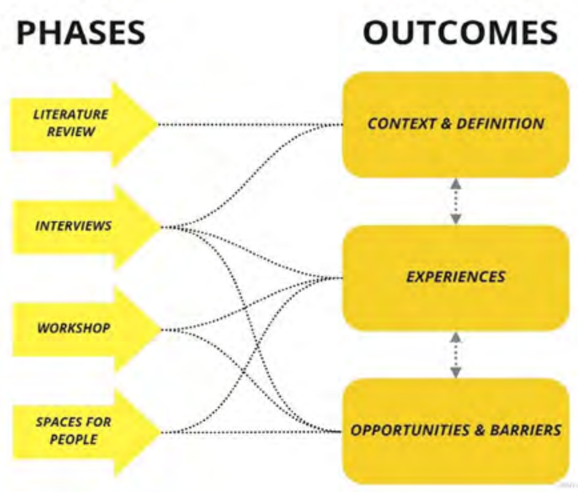

Figure 2. Illustrated Methodology - phases of study and related outcome (Mackenzie 2022)

3.2 Phase 1- Literature Review

A qualitative narrative review of the literature was conducted to define the concept of the 20-minute neighbourhood and its implementation.

A structured systematic Boolean search of the literature was performed through Glasgow Caledonia University's library system, with secondary searches of Google Scholar and related databases. Hand-searching of references and a snowball/reverse snowball approach identified further relevant resources. A grey literature search was carried out of websites of relevant organisations and government bodies.

Using a modified PRISMA guideline approach, results were filtered. Included papers were assessed for relevance at abstract and full-paper levels. Included literature was coded and qualitatively synthesised into a structured narrative review to provide context and understanding of the definition of a 20-minute neighbourhood.

3.3 Phase 2- Interviews

Semi-structured interviews with relevant stakeholders were carried out (both in-person and via teleconferencing software). Four interviews were carried out with five stakeholders in October and November 2021.

Stakeholders were defined as people or organisations working or involved in research, decision making, or project delivery within urbanism, policy, and planning in Dundee & the Tay region, and across Scotland. Stakeholders interviewed included urban planners, politicians, decisions-makers, and academics.

A semi-structured interview process was utilised to enable wider discussion of themes and ideas, and gain insight into individual (subjective) opinions and experiences. Questions were tailored to individual depending on background, role, and experience.

Interviews were recorded and transcribed. A process of thematic analysis was performed using qualitative analysis software (NVivo 12 Pro) to code data and identify emergent themes. An editing and immersive approach was used in a process of data familiarisation, coding, and reviewing to define the themes and generate findings (Bloomberg & Volpe 2015).

3.4 Workshops

A workshop was organised with local residents. Residents were all mothers with young children and lived in a diverse range of neighbourhoods across the city. Due to Covid-19 restrictions, the number of participants was limited; 5 workshop participants volunteered to participate. Due to restrictions in place only 2 participants were able to attend the workshop on the day. The workshop was facilitated by the author and conducted using the Place Standard Tool (The Scottish Government et al. 2017) and a mapping exercise as a framework for discussion.

The mapping exercise asked participants to locate services and amenities they use on a map and identify physical limits and perceptions of their neighbourhood area. Participants also indicated typical walking or travel routes they use and identified barriers or missing services (physical, social, perceived), as well as suggestions for positive intervention or opportunities for improvement. Workshop participants were specifically asked about their experiences during the pandemic; questions focused on how the experience affected them and their families, and whether it changed how they felt about or interacted with their home and local area.

3.5 Spaces for People

Analysis was carried out on qualitative secondary data in the form of public comments on the Spaces for People project website (Dundee City Council 2021). The Spaces for People project was a public consultation process allowing the public to comment on conditions and highlight locations where interventions or improvements could be made to support active travel during the Covid-19 Pandemic. The data provided a contemporary record of public views and opinions, which gave a unique insight into the impact of the pandemic on how people use, perceive, and move about the city.

Analysis was performed by measuring incidence of key phrases relating to two questions: "What is the problem?" and "How could we make it better". Participants could answer these questions by selecting from a list of pre-defined phrases/comments. Comments were all geotagged, allowing identification of areas performing well or poorly.

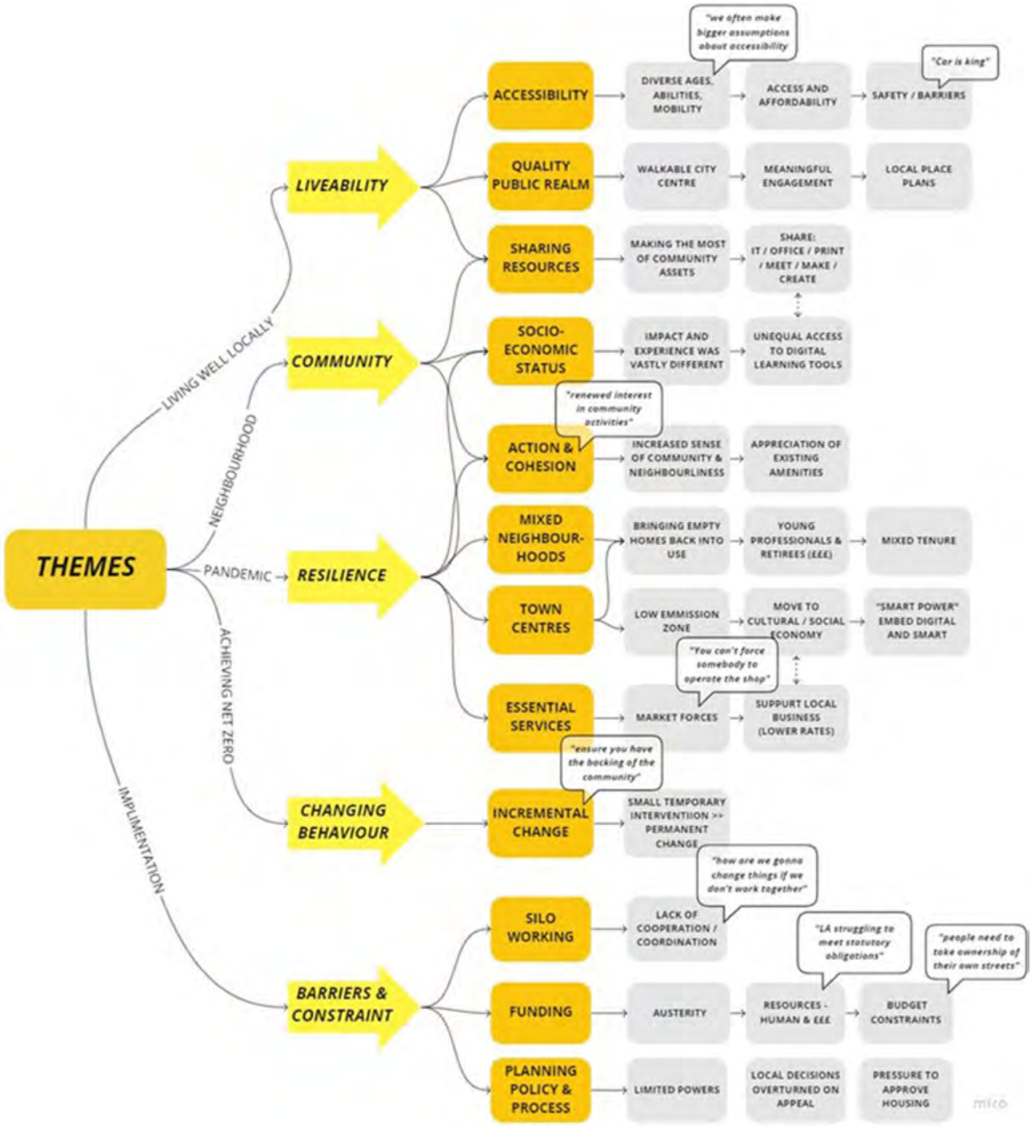

Figure 3. Emergent themes, subthemes, and key quotes. (Mackenzie 2022)

4 Results

4.1 Interviews

Interviews identified emergent themes (Liveability, Community, Resilience, Changing Behaviour, Barriers & Constraints) as illustrated in figure 4 below. Interlinked with these were overarching themes of climate change, carbon reduction, and placemaking.

4.2 Workshops

Included participants lived in two different and distinct neighbourhoods of the city; the first located in a recent new-build developer led housing development on a greenfield site to the west of the city, and the second living adjacent to 'the Hilltown', a historic neighbourhood to the north of the city centre which has suffered economic decline. Physical barriers to accessing services, amenities and active were quickly identified. Both participants indicated that they were willing to walk to some local services; however, accessibility, safety, and topography (the Hilltown being on a steep hill) were all identified as barriers. Participants indicated they would be willing to walk over 20 minutes in single direction to access services.

4.3 Place Standard Tool Assessments

The results of the Place Standard Tool assessments were graphically presented on a compass graph (Fig 6, below). The new-build development performed well in aspects of feeling safe in well looked after streets and spaces, with good access to greenery, but performed poorly in aspects of public transport, facilities, and amenities, and moving around. The historic urban neighbourhood performs well with good access to natural space, play and recreation, facilities, and amenities due to proximity to a park and the city centre, but performs poorly in terms of public transport, sense of influence and control and identity and belonging.

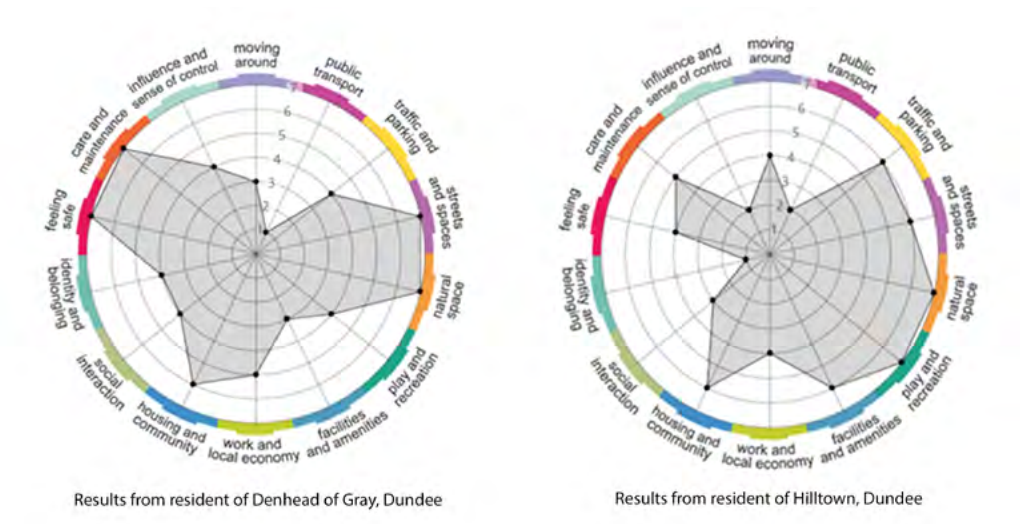

Figure 4. Results from Space Standard Tool assessments (Mackenzie 2022)

4.4 Spaces for People

The Dundee Spaces for People interactive map tool was open for comments from January to July 2021, with most comments being made between January and March. There were over 239 comments made over the period, with the public invited to support comments they agreed with. Of the 239 comments, the majority of respondents (234) supported changes being made permanent. Comments related equally to 4 themes, District Centres, Connecting Schools and Communities, Pop-Up Cycle Lanes, and the Green Circular, with slightly high proportion not attributed to a theme (none of the above. Amongst responses (fig 9,10) safety was the most cited problem, with no safe space for cycling mentioned 87 times. Other concerns include the speed and volume of traffic and poor driving dominating remarks. Accessibility was a common problem, with complaints about crossings and pavement clutter. Not enough space for physical distancing was cited, though as a pandemic specific issue may not be as relevant as restrictions ease.

In terms of suggestions for improvement, equal weight was given to strategies to improve safety and accessibility. Reducing the speed of traffic was the most cited suggestion for improvement. Safe junctions and crossings that priorities pedestrians were popular suggestions, as was keeping pavements clear of parked cars and clutter, so paths could be effectively and safely used by a variety of users. Other suggestions relate to the maintenance and improvement of existing infrastructure.

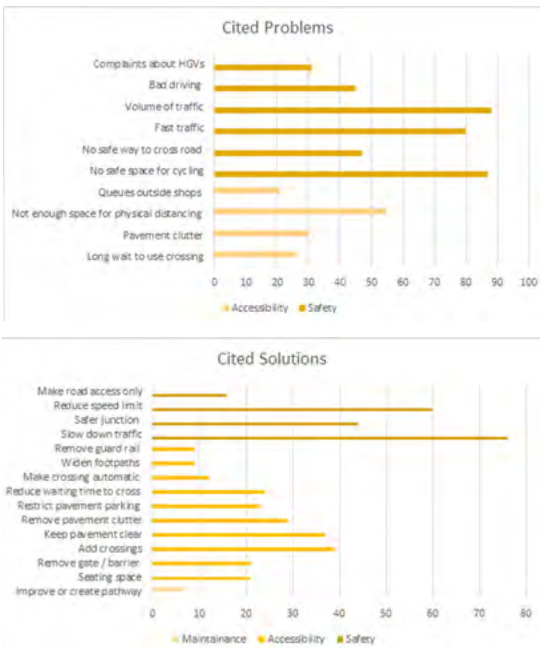

Figure 5. Cited Responses - Frequency of responses to question "What's the problem?" and "How could we make it better?" (Anon. Spaces for People Dundee 2021)

5 Conclusions and discussion

The aim of this study was to investigate the development of the 20-minute neighbourhood concept as a tool for a green and just recovery from the Covid-19 pandemic and address urgent climate issues. This research gained insight into how the concept is being received and understood by planners, policy makers and urban professionals in a Scottish context, it allowed exploration of the lived experience of those inhabiting affected communities and helps us begin to understand how the experience of the Covid-19 pandemic will shape our neighbourhoods as we adapt to the climate crisis.

5.1 Defining the 20-minute city in a Scottish planning context

The Scottish definition of the 20-minute neighbourhood concept is still evolving, but some key themes and elements have emerged from this study. The concept can fundamentally be expressed through the phrase "Living Well Locally", i.e., meeting your daily needs in your local area, without relying on a car. As a place-based concept, it is easily understood by the public and well received by urban professionals. The concept is about giving residents the opportunity to live, work, support and enhance their local neighbourhoods.

It is widely accepted that everyone has a different understanding of what those 'needs' are. The consensus of literature, policy documents, and stakeholders is that services and amenities fall into 6 broad categories: Commerce (equitable access to affordable, healthy food choices as a priority); Healthcare, (primary healthcare, dentists, mental health support services, or pharmacies); Education (at least primary and secondary, but also further and lifetime learning opportunities); Greenspace (high quality greenspace that provides health and leisure opportunities); Cultural and Recreation (including community and sports facilities); and Connectivity (Active Travel & Public Transport).

The Scottish policy context gives a clear definition in terms of proposed time, distance, and mode of travel (800 metres, 10 minutes, Walking), however, this study found that this does not reflect the diversity of abilities, health, and opportunities of citizens. The concept should be adaptable and localised with recognition that especially place-based solutions are needed that are unique to each community or area. The key to understanding the various and diverse needs of a community in the context of a 20-minute neighbourhood is to ensure that community consultations are as inclusive as possible. Meaningful and high-quality engagement is required with a cross-section of residents, users, and community groups to give a true reflection of diverse experiences and evaluate proposed interventions. Community input can identify opportunities to improve and localise existing services and make the most of existing community assets.

Active travel and reliable and affordable public transport can unlock opportunities for employment, recreation, participation, civic life, and shared resources. Sharing resources or amenities (cultural, leisure, healthcare, digital, or support services) between different areas or neighbourhoods, will be an essential part of realising the concept in the current economic climate.

Achieving these aims requires improved connectivity and permeability with integrated and well supported transport infrastructure. Working towards providing equitable, safe, and accessible active travel networks will promote connectivity and improve health and wellbeing outcomes and reduce carbon emissions.

5.2 Exploring experiences of the 20-minute city

The pandemic revealed widespread inequalities in terms experience with, 20-minute neighbourhoods would improve resilience by improving access to amenities, greens-pace, and community support. In general neighbourhoods came together and became strong communities during the pandemic, a surge in community spirit. Residents have rediscovered their local environments and amenities, promoting localism and activism. 20-minute neighbourhoods can build on this momentum. Quality urban green spaces with opportunities for recreation and exercise improve physical and mental health and became critically important to residents during restrictions on travel and exercise during the Covid-19 pandemic. The volume and speed of traffic, and safety concerns had a negative effect on resident's physical experience of the city during the pandemic. Tack-ling speed limits, congestion, improving pedestrian access, and the safety of road cross-ings, improves equitable access by removing physical, mental and economic barriers to accessing services.

5.3 Identifying barriers to implementation of the concept

Small and temporary interventions or events can enhance diversity, richness and contrib-ute to positive experience of a place by building awareness, and testing ideas in place. Successful interventions implemented during the pandemic, such as closing Union Street in Dundee to traffic, have illustrated the positive impact of prioritising liveability. Pocket Parks are being proposed and developed to improve the urban realm and introduce urban green space into neighbourhoods. Increased urban greening will help to tackle urban heat island effects, flooding, and urban drainage, and improve public health and wellbeing.

Funding issues will be one of the biggest barriers to successful implementation of the concept. City Centre Recovery plans will aim to promote social, night, and cultural econ-omies. Densifying town centres with high quality mixed-use developments with a mix of house types and tenures will help to support and sustain local businesses and essential services, and promote diverse, vibrant, and lifetime neighbourhoods.
New-build, developer homes are being built missing critical infrastructure, leaving them vulnerable, isolated, and unsustainable.

Planning policy and powers need to be more adaptable, flexible, and coordinated. Local needs and priorities need to be aligned with actions to achieve national and global climate targets, while building a stronger, fairer, more economically, socially, and en-vironmentally sustainable urban communities. What emerges from this study is the importance of connectivity; supporting active travel networks and public transport infra-structure to connect people and communities with thriving, liveable, healthy, safe, and accessible neighbourhoods, while reducing car-dependency and emissions. 20-minute neighbourhoods are an easily understood concept, which if adopted into overarching strategy, can empower communities, coordinating efforts and actions towards a timely solution to the critical climate problem.

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