November 2nd, 2020

BUILDING RESILIENCE IN A HOTTER EUROPE

MASTER'S THESIS

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SUMMARY

Europe is getting hotter, but cities in more temperate climates are often not well adapted for heat. They are also expanding and ageing, exposing more and more people to the negative impacts of a threat that is only just coming on to the urban planning and climate adaptation agenda. Its causes are complicated, and its impacts are cut across sectors such as health, the built environment, transport, and energy. Such a complex issue warrants a complex solution. Resilience is being increasingly adopted in cities across the world for such problems, however analysis of what constitutes a city resilient to the threat of extreme heat is limited. This research seeks to address this knowledge gap through evaluating and analysing resilience capacities (the capacity to prepare, absorb, recover, and adapt) in a case study of two European cities – London and Rotterdam. This research is informed by a preliminary study performed under supervision of an internship with the consultancy company Sweco, a societal actor keen to raise awareness of the problem of heat in cities. London and Rotterdam are found to each have different resilience emphases. London has focused on heat for longer as it has been more negatively impacted in the past, with the threat incorporated into the city's risk management infrastructure. The city thus focuses on preparing and recovering from extreme heat events. Rotterdam's emphasis is less distinguishable as heat is a very new issue for the city, so its emphasis on absorbing and adapting to the threat through innovative strategy is not as strong as might be expected. A variety of factors are identified that contribute negatively to the resilience emphases of each city: factors specific to the issue area of heat; limited organisational structure and capacity to deal with cross-cutting problems; and path dependency as a result of institutionalised reflexes and technical lock-in. The presence of networks and partnerships was found to be a factor that contributes positively to resilience. External shocks like the on-going Covid-19 pandemic represent an interesting event that may have the potential to alter our perceptions of societal care for the most vulnerable. Such perceptions prove to be a key factor when considering governance strategies to enhance resilience that actually work. Such governance strategies are discussed within the wider societal and scientific context, particularly in terms of the intersections between public health and care for vulnerable and marginalised groups, and in terms of what the results of this thesis research suggest for urban governance in the face of complex threats like heat.

ACKNOWLEDGEMENTS

I would like to acknowledge and thank all the interviewees who took the time to participate in the research for both this thesis and the Urban Insight report written for my internship. Writing the report for Sweco was a great opportunity, and I would like to thank Enrico Moens for providing me that opportunity and for supervising the process of writing and my time interning with the consultancy. I would also like to finally thank Dries Hegger for being a very helpful and patient supervisor during this time – I very much appreciate all the support that he has given me.

CONTENTS

1. INTRODUCTION

1.1 Societal Problem: Heat in Cities

Europe is getting hotter: anthropogenic climate change has increased the frequency and duration of heatwaves and the intensity of daily temperature extremes and is likely to continue doing so in the future (IPCC, 2014). Extreme heat and its impacts are most commonly framed as a public health issue. In Europe, heatwaves are more deadly than all other natural disasters combined, including floods, waves of extreme cold, earthquakes, or drought (EEA, 2019). In 2003 Europe experienced this most keenly, with a historic heatwave causing fatalities exceeding 70,000 (Robine, et al., 2008). As well as fatalities, extreme heat heightens the incidence of certain diseases including cardiovascular, respiratory, and cerebrovascular problems (EASAC, 2019). Extreme heat events also frequently occur alongside periods of drought, humidity, and high pollution, further exacerbating the health impacts (EASAC, 2019).

Urban areas are particularly impacted by extreme heat due to a multitude of factors. Firstly, the urban heat island (UHI) effect exacerbates and is exacerbated by hot weather conditions, with the increased frequency of hot days and warm spells in the future enhancing this (Revi, et al., 2014). The UHI effect results in cities being much warmer than their surrounding areas, particularly at night, when much of the heat stored in structures throughout the day is released (Memon, Leung, & Chunho, 2008). The key reasons for this are covered in Box 1. Secondly, many urban environments are maladapted to the threat of heat: many European cities in the more northern latitudes have been built with insulation and heat sources to handle the cold and wet of winter months, and commonly lack air conditioning.

Finally, urban environments are home to large concentrations of people, and these concentrations are on the rise. In 2018, 74% of Europe's population lived in urban areas, and by 2050 this is projected to increase to 85% (UN DESA, 2019). Specific groups in society are more physically susceptible to extreme heat: the very young, the very old, those with existing health conditions, and those in a hospital or bedridden (EASAC, 2019). These groups are more vulnerable as they have a greater propensity or predisposition to be adversely affected (IPCC, 2014). Furthermore, the proportion of many of these vulnerable groups in cities is likely to increase as populations increase – older people for example are projected to make up more than 25% of the European population by 2030, and this ageing will occur faster in urban areas than rural (UN DESA, 2015). Further vulnerabilities to heat that result from the intersection of socioeconomic factors are discussed in Box 2.

Box 1: Factors contributing to the urban heat island effect.

The UHI is complex, and is generally a result of the following factors (Rovers, 2016): urban areas have a lower albedo, reflecting a greater proportion of solar energy into their surroundings; they are great sources of anthropogenic heat – from people, air conditioners, vehicles, and the multitude of other fuel-burning activities that occur in a city; they often lack vegetation, reducing latent heat and evapotranspiration; the 'rough' surface texture of urban areas reduces the level of convective heat exchange with surroundings, as air is trapped between buildings: cooler air from surrounding areas is prevented from entering the city, and hot air is prevented from leaving; and finally: they are often highly polluted, absorbing and re-radiating heat. (Figure: Fuladlu, Riza, & Ilkan, 2018).

Despite the above, awareness of the threat of extreme heat, its impacts on urban environments, and efforts to address it are lacking. In the Netherlands for example, there is a lack of perception of extreme heat as an urgent problem (Runhaar, Mees, Wardekker, van der Sluijs, & Driessen, 2012; Mees, Driessen, & Runhaar, 2015), despite the fact that the most intense warming scenarios project a doubling in the duration of extreme heat events in the future (Molenaar, Heusinkveld, & Steeneveld, 2016). Public and infrastructural ability to cope are therefore low. Recent hot summers have contributed to an increase in awareness generally, with societal actors stepping in to fill the knowledge gap. The research for this thesis was conducted through an internship with Sweco, a leading European engineering, environmental and architectural consultancy. They are addressing the problem of a lack of awareness through including heat and its impacts on cities in their 'Urban Insight'[1] initiative – a series of reports that aim to contribute insights on topics related to urban climate action. Part of the research for this thesis will contribute to one of these reports.

1.2 Scientific Problem: Resilience as a Solution?

Tackling the threat of extreme heat represents a specific governance challenge. Heat can be framed as a 'wicked problem': it is a complex, systemic issue, hard to define and conceptualise due to the complex actor networks that perceive its scope and impacts differently. As a result, heat cannot be understood or solved within a singular domain (Rittel & Webber, 1973; Kuznetsov & Tomitsch, 2018). Evidence of the difficulties resulting from this have arisen in the literature – for example of whether it is a private or public responsibility to protect vulnerable citizens against urban heat (Mees et al., 2015), or the reduced effectiveness of measures due to an institutionalisation of urban heat management into top-down health risk management, removing other sectors and levels from the conversation (Zaidi & Pelling, 2015).

'Wicked', complex problems like heat require complex solutions. Resilience is being increasingly adopted at a societal level by cities all over the world for this purpose: a holistic policy goal that helps them plan for an uncertain future in the face of multiple threats and stressors, including climate change. 100 Resilient Cities, pioneered by the Rockefeller Foundation from 2013-2019 (100 Resilient Cities, 2020), is an example

Box 2: The intersection of vulnerabilities in those most impacted by extreme heat.

For some groups, additional social factors contribute to their vulnerability in hot weather conditions. Some studies show that among the elderly, being female is a greater predictor of being impacted by extreme heat, due to physiological differences and social isolation of elderly women living alone (D'Ippoliti, et al., 2010; Åström, Forsberg, & Rocklöv, 2011). In older age groups, a greater proportion of the elderly are female, exacerbating the gender differences (although this gender imbalance will decrease in the future; UN DESA, 2015). Social isolation is an important vulnerability factor, as is pre-existing health conditions including mental health (Stafoggia, et al., 2006). The elderly often do not see themselves as vulnerable or perceive extreme heat as a particular risk – preventative private behavioural measures are thus limited (Wolf, Lorenzoni, Few, Abrahamson, & Raine, 2009; Wolf, Adger, & Lorenzoni, 2010). Further socioeconomic factors include being a member of a minority or marginalised population and being of a lower socio-economic status – these factors affect the quality of housing one can access, whether private mitigation measures like air conditioning are affordable, and whether communities have green spaces that reduce the urban heat island effect (Reid, et al., 2009; Trigo, et al., 2009; Mayrhuber, et al., 2018).

[1] More information on Sweco's Urban Insight initiative: https://www.swecourbaninsight.com/

of a network that tuned in to the growing trend of cities catalysing change at a local level and enabled many cities across the world to develop their own strategies and actions for resilience.

However, whilst resilience is being adopted societally it remains a debated topic within the scientific literature, consistently being assessed and re-defined. There is also a knowledge gap in terms of analysis of its application to the threat of extreme heat, with a lack of empirical study on what constitues resilience to extreme heat and how urban resilience can be enhanced with regard to this threat. Furthermore, consideration of vulnerable citizens is frequently lacking in urban policy (Bulkeley, et al., 2013; Mees et al., 2015), with literature on enhancing urban resilience to extreme heat that pays particular attention to vulnerable groups also lacking.

The scientific and societal problem that this research would therefore address is the lack of empirical knowledge on the application of resilience to the ill-defined and increasing threat of extreme heat in cities with particular regard to vulnerable groups. Systematic insights into an operationalisation of urban resilience for this threat, and the various mechanisms that contribute to enhancing it are required.

1.3 Research Objective and Questions

The objective of this thesis research is to contribute insights on urban resilience when considering the threat of extreme heat in two European cities (London and Rotterdam), and insights on governance strategies that can enhance this resilience that take into account the complexity of heat as a problem. This objective is achieved by conducting an evaluation of resilience operationalised for the threat of heat in two European cities, followed by an evaluation of the factors and mechanisms that impact upon the strength or weakness of these capacities. Tangible insights on and recommendations for enhancing resilience are then inductively derived.

A secondary objective of this thesis research is to contribute to the knowledge gap on extreme heat through a broad study of the urban heat resilience and climate adaptation landscape in Europe, used to form the basis of an Urban Insight report for Sweco, the consultancy within which this research is facilitated. This report aims to raise awareness and put the problem of extreme heat in Europe on the map. This is achieved through a combination of facts, figures, and storytelling to communicate the social aspects of the problem and some solutions, achieved through the lens of resilience, to a wide audience in an accessible, engaging manner.

The central question for this thesis is as follows: **how resilient are two European cities to extreme heat, and what governance strategies can enhance resilience, with particular regard to vulnerable groups like the elderly?**

Answering this central question will be directed by the following research questions:

- RQ1: What conceptualisation of urban resilience capacities can be derived from the relevant literature?
- RQ2: How can this conceptualisation of urban resilience capacities be specified and operationalised for the threat of extreme heat using broad insights from an overview of urban heat resilience and climate adaptation in six European cities?

- RQ3: What is the extent to which resilience capacities are observed in London and Rotterdam when considering the threat of extreme heat?
- RQ4: What factors or mechanisms can be inductively derived from the findings that affect the extent to which these capacities are expressed?
- RQ5: What insights can be inductively derived from the findings regarding suitable governance strategies to enhance resilience capacities?

RQs 1 and 2 help to specify an operationalisation of urban resilience for the threat of heat, which helps frame more in-depth research indicated by RQs 3, 4 and 5.

1.4 Social and Scientific Relevance

Heat has had increasingly significant impacts across Europe, particularly in urban environments that are adapted to more temperate climates. In such places populations are expanding and ageing in maladapted environments that will face increasingly hotter days and heatwaves in the future. Resilience is being adopted in cities as a policy goal to address the complex challenges of climate change, but its application to that of extreme heat is limited. This thesis research thus contributes to the broader scientific effort to learn how to enhance resilience to climate impacts like extreme heat, an increasing social problem. By exploring the mechanisms and factors that impact upon the extent to which resilience capacities are expressed in two different cities, prescriptive lessons for governance can be provided that are socially relevant for urban resilience policy – addressing the "implementation gap […] [that] remains between resilience as ambitious objective and the 'demonstrated capacity to govern resilience in practice' at the urban level" (Coaffee, et al., 2018, p.403).

1.5 Research Framework

A simplified framework for achieving the answers to the research questions is presented in Figure 1 (a more detailed version is presented in 3.1). A literature review on resilience theory (a; Chapter 2) will yield a conceptualisation of urban resilience capacities (b; Chapter 2). This will help frame a preliminary study of urban resilience and extreme heat in cities across Europe for use in Sweco's Urban Insight publication. This study will help specify and operationalise the urban resilience capacities for the threat of extreme heat (c; Chapter 4). This framework will then be used to evaluate urban resilience in two European cities, London and Rotterdam (d; Chapters 6 and 7), with cities expected to differ on the extent to which each capacity is expressed. Underlying factors and mechanisms for the level of urban resilience will then be analysed (e; Chapter 8). A reflective discussion on these findings will result in insights for governance strategies to steer towards enhancing urban resilience for the threat of extreme heat (f; Chapter 9).

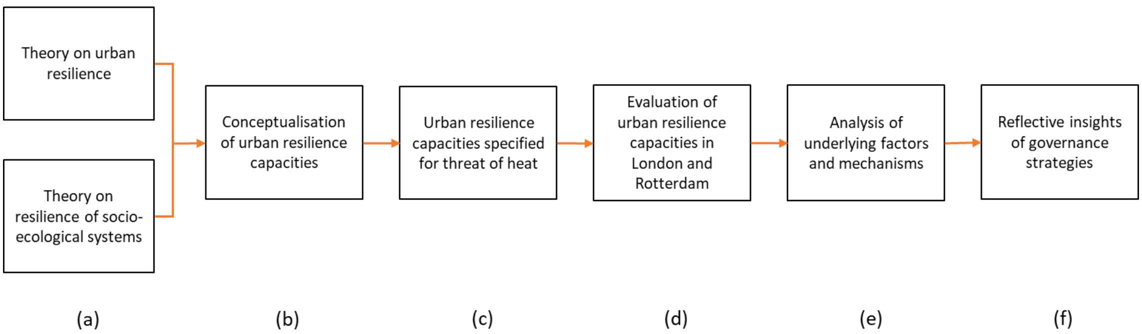

Figure 1: Simplified research framework.

2. CONCEPTUAL AND ANALYTICAL FRAMEWORK

This chapter sets the conceptual boundaries for this thesis research, defining the concept of resilience in 2.1 and what ‘heat’ means in 2.3, as well as conceptualising urban resilience ‘capacities’ into an analytical framework in 2.2, thus providing an answer to RQ1.

2.1 Defining Units of Analysis

Originating in the study of equilibrium in ecological systems (Holling, 1973), the concept of resilience is now used across a broad array of disciplines. The concept is nuanced and abstract and is thus variously and inconsistently defined both practically and in the literature. This can lead to conceptual tensions and uncritical practical application. In the fields of engineering and disaster management, resilience is focused on the absorption of stress and quick recovery (e.g. Pimm, 1984); in the fields of ecology and ecosystems, on the persistence of function when shocks occur (e.g. Holling, 1996). In these cases, resilience is perceived as a flipside to vulnerability in a static system, usually uncritically applied to maintaining business as usual (Pelling, 2011). Whilst definitions are debated in the scientific literature societal action for resilience is growing in popularity. However, due to the abstraction of the concept these applications are often, again, uncritical and static, focusing on the importance of ‘bouncing back’ to the prior system (White & O'Hare, 2014; Coaffee, et al., 2018; Hommels, 2018). Such a focus places implicit emphasis on a return to the status quo, thus continuing the unsustainable practices that led to the stress or shock in the first place as well as avoiding issues of social injustice and power that lead to specific vulnerabilities among certain populations.

In a broader socio-ecological context, resilience is conceptualised within systems thinking as a capacity to absorb disturbances and stress whilst being able to learn, develop, and reorganise (Carpenter, Walker, Anderies, & Abel, 2001; Folke, 2006). In this more critical conception resilience is not a product of a static system; it is instead an intrinsic or emergent property of a complex one, the dynamic product of institutions (Folke, 2006) – it is “only manifest through exposure to stress or shocks, and in the subsequent recovery or reorganization period, but its latent character exists within a system independent of that exposure” (Tyler & Moench, 2012, p.318). This conception thus places greater emphasis on transforming system components and institutions.

As a result, utilising resilience can be inherently political, with normative choices being made in what system or system components are being made resilient, to what, and for whom (Carpenter et al., 2001; Meerow & Newell, 2016; Wardekker, et al., 2020). It is therefore necessary to be explicit in the choices made (Wardekker, et al., 2020). This thesis research focuses on the latter socio-ecological systems conception of resilience, applied to an urban system (as defined below) to the threat of heat (as defined in 2.3). It has a focus on actions originating at the level of local governance and their partners (as opposed to originating with communities), and a focus on the impact of heat on more vulnerable groups.

Meerow, Newell, and Stults (2016), in their meta-analysis of urban resilience definitions, define an urban system as complex and adaptive, composed of interconnected socio-ecological and social-technical networks across spatial and temporal scales: governance networks; networked material and energy flows; urban infrastructure and form; and socio-economic dynamics. This can be understood schematically in

Figure 2, taken from Meerow et al. (2016). Using the systems thinking perspective, influencing the resilience of the whole urban system is done by enhancing the resilience of individual components and networks. However, it is not feasible to study an entire urban system in all its complexity, and not all aspects of an urban system can indeed be influenced. This is due to, for example, different institutional set-ups, embedded political structures, and pre-existing infrastructure. It is therefore useful to take the approach of building resilience *capacities.* Focusing on building capacities breaks down the urban system into parts that can be influenced and is thus useful as an analytical tool. This complexity is also why this research has focused on formalised action originating in local governance as opposed to e.g. bottom-up community action.

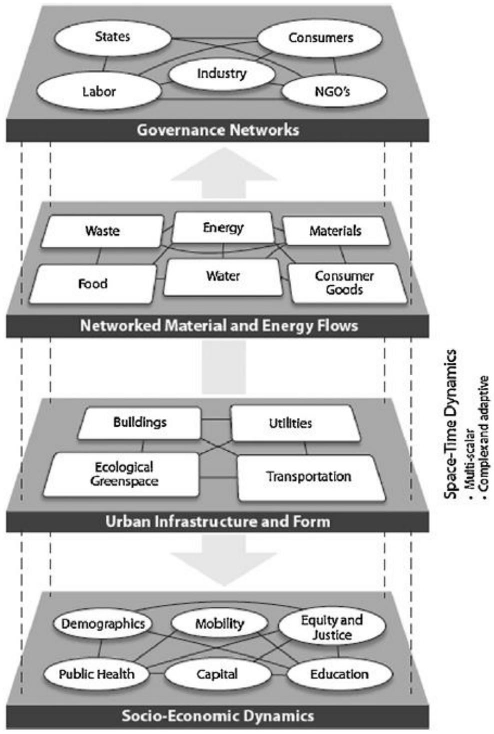

Figure 2: A simplified conceptual schematic of an urban system, taken from Meerow et al. (2016).

2.2 Conceptualising Urban Resilience Capacities

RQ1 seeks to conceptualise urban resilience capacities using relevant scientific literature. The conceptualisation used in this thesis is by Wardekker et al. (2020). This conceptualisation is based on an extensive synthesis of the wide array of socio-ecological systems and urban resilience literature, and has been conceptualised alongside policymakers with the purpose of creating a useable diagnostic tool that makes the abstract concept of resilience more tangible and the choices made in its application more transparent.

Following Wardekker et al. (2020), urban resilience is split into four capacities to be built in urban systems. These mirror key elements of resilience found in the scientific literature: the capacity to prepare; the capacity to absorb; the capacity to recover; and the capacity to adapt. These capacities can alternatively be viewed as four 'pathways' to be taken by distinct urban systems towards resilience-building: "proactive, reactive, recuperative, adaptive […] [which can] leave room for different priorities and approaches" (Wardekker et al., 2020, p.3) that may be specific to the local context and help take account of that within an urban system which cannot be, or is difficult to influence.

Each resilience capacity consists of various 'principles'. These are "specific mechanisms and behaviours [within and across the networks of an urban system as defined in 2.1] that make a city resilient or that help policies and practices improve resilience" (Wardekker, 2018, p.1). Based on the operationalisation of resilience principles in Wardekker et al. (2020, p.6) and further definitions in Wardekker et al.'s (2020) supplementary material, a simplified analytical framework of urban resilience capacities is presented in Table 1. Wardekker et al. (2020) operationalise each principle based on the scientific literature, and here these operationalisations are termed 'generic' as this thesis aims to specify them further for the specific threat of extreme heat. This framework thus answers RQ1 and forms the basis of the analytical framework to be further specified in Chapter 4 (RQ2), which is then used to assess the level of resilience in London and Rotterdam in Chapters 6 and 7 (RQ3)

Table 1: Simplified analytical framework of resilience capacities and principles based on Wardekker et al. (2020).

Capacities for resilience	Definition	Principles	Generic Operationalisation
Capacity to **PREPARE**	The capacity to **identify threats, assess their consequences, and plan ahead** before the threat occurs.	Anticipation & Foresight	- Relevant climate-related knowledge is available and accessible for a wide range of actors - Trends ('slow variables') that enhance vulnerability are monitored - Active learning occurs
		Preparedness & Planning	- Emergency response and management plans are in place - Risks and vulnerabilities are communicated to the public and businesses, who are aware of their responsibility
		Homeostasis (i.e. strategic management of feedbacks)	- Climate adaptation is integrated into other policy areas - Responsibilities of actors are integrated into law - Integrative policy processes ensure equitable and inclusive benefits - Communication channels are in place and functioning - Regulating ecosystem services are well maintained
Capacity to **ABSORB**	The capacity to **dynamically cope** with threats when they occur, whilst maintaining desired functioning.	Robustness & Buffering	- Climate impacts can be withstood or lessened due to policy, spatial, and infrastructural measures that focus on impact and risk reduction
		Diversity	- Diversification of governing authorities, resources, management strategies, means, institutions, and stakeholders, resulting in diversification of response - Functional diversity (multiple ways to fulfil a need, i.e. a function, exist) - High biodiversity
		Redundancy (i.e. spare system capacity)	- Functions of public services and resources overlap - Governance roles overlap - Vital city functions and resources have backups and alternative sources
Capacity to **RECOVER**	The capacity to **rapidly recover** from threats when they occur, whilst maintaining desired functioning.	Flatness	- Non-hierarchical, decentralised governance allowing competent, authoritative, and autonomous local action - Broad, active, and inclusive participation in decision-making (including the vulnerable and marginalised)
		High-Flux	- Quick movement of resources through a system, allowing quick mobilisation in response to threat - Widespread access to information and financial and human resources, connectivity between sectors - Decision-makers are resourceful and flexible in responses and strategies
Capacity to **ADAPT**	The capacity to **quickly modify and transform**, co-evolving with the threat.	Learning	- Reflective, participatory learning from experiences - Room for experimentation, innovation, and 'learning-by-doing' - Active application and implementation of new knowledge
		Flexibility	- Institutional flexibility: flexible decision-making and cooperation arrangements - Flexibility in spatial planning: 'structural elbowroom' for future modification, extension, or retrofitting in spatial planning - Flexibility in measures: adaptation measures now do not limit range of possible future measures, and are preferably reversible

2.3 Conceptualising Extreme Heat

The IPCC defines an extreme heat event, or a heatwave, as a period of abnormally and uncomfortably hot weather (IPCC, 2014). This is what is meant throughout this thesis when an ‘extreme heat event’ or ‘extreme heat’ is referred to. However, it is important to note that what is classed as ‘abnormal’ and ‘uncomfortable’ is variable – how people perceive heat and its impacts is subjective and context-specific, dependent on a complex interaction of many factors. These include: (Lafortezza, Carrus, Sanesi, & Davies, 2009; Montero, Miron, Criado, Linares, & Díaz, 2013; Royé, Codesido, Tobías, & Taracido, 2020):

- Physiology: as well as heightened vulnerability depending on age or health as discussed above, previous periods of hot weather can result in physical acclimatisation, reducing the negative impact of heat on the body.
- Geographic position: physiological acclimatisation also means that more northern latitudes experience extreme heat at lower temperatures, and vice versa with more southern latitudes.
- Local climate and built environment: humidity, air temperature, shading, windchill, greenery, and material and albedo of surrounding buildings all impact on how people experience heat.
- Socio-economic factors: the threshold above which temperatures are experienced as ‘extreme’ depends on socio-economic standing with different groups experiencing heat differently, as discussed in Box 2.
- Psychological factors: just spending time in urban greenery improves perceived well-being, which has been found to alleviate the perception of thermal discomfort.

In analysing resilience to the threat of heat in urban environments, it is thus important to keep in mind the multitude of factors that influence on what would be perceived a ‘threat’ level, and what this complexity means for mitigation and adaptation.

3. METHODOLOGY

This chapter outlines the strategy of this thesis, as well as the methods of data collection and analysis.

3.1 Research Strategy

The research strategy used in this thesis is a qualitative case study approach, with an in-depth study of two cities informed by broader insights from a preliminary study of six cities. This strategy enables the research to meet its two deliverables: the basis of a report for Sweco and this thesis for Utrecht University. This thesis research is designed accordingly to negotiate the different demands of these two deliverables and ensure time and opportunities are maximised. An overview of this research strategy is presented in the research framework in Figure 3 and outlined in further detail in the sections below.

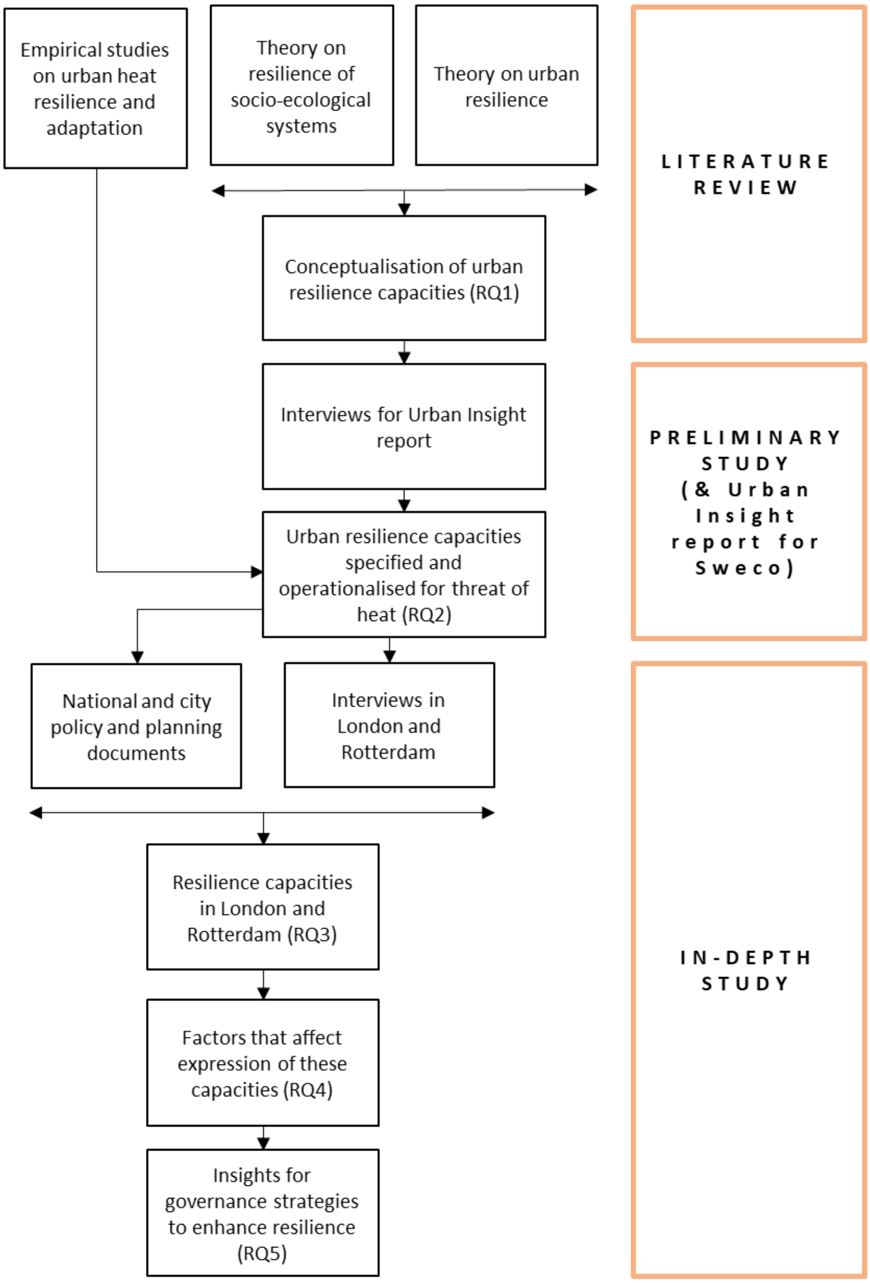

Figure 3: Detailed research framework.

3.1.1 Preliminary Study

The resources and contacts available at Sweco, as well as Sweco's aims for the Urban Insight report, provide an opportunity to undertake a broader overview of how the threat of urban heat is dealt with in cities across Europe. This assessment is incorporated in this thesis by acting as a preliminary study to help specify and operationalise Wardekker et al.'s (2020) urban resilience framework (as outlined in Chapter 2) for the threat of heat, thus answering RQ2. This preliminary study also provides background knowledge and identification of key focus areas to help frame the interviews with stakeholders in the in-depth study.

Six European cities were selected for study as part of the work for Sweco's Urban Insight report: Athens, Greece; Barcelona, Spain; London, UK; Rotterdam, the Netherlands; Stockholm, Sweden; and Warsaw, Poland. This selection was made as a result of direction from Sweco, for the following reasons: their membership of C40, a global network of cities committed to climate action (C40 Cities, 2017) – resilience and adaptation are thus already a part of the cities' lexicon and action; to gain a broad geographic coverage of cities facing different levels of climate threat; Sweco has an office or contacts in four of the six cities, making it easier to find relevant interviewees; and Athens and Barcelona do not contain Sweco offices, but are Southern European cities, likely to face the largest increases in hot weather days and severe health impacts (Fischer & Schär, 2010; Guerreiro, Dawson, Kilsby, Lewis, & Ford, 2018), making them useful and relevant to include in a broad overview. These cities are not indicative of Europe but are simply a subset of the variety of European cities, with the breadth of insights gained thus contributing validity to the analytical framework.

Chapter 4 contains a brief summary of how this work specifies the analytical framework of urban resilience for the threat of extreme heat.

3.1.2 In-Depth Study

The rest of this research focuses on two cases, the cities of London and Rotterdam. This method of deeper analysis of two cities is chosen for the depth and specificity it can contribute (Verschuren & Doorewaard, 2010), relevant to the aims of this stage. These cities are both members of the 100 Resilient Cities network, and thus have both actively directed attention to work on resilience and creating a formalised Resilience Strategy. Both cities are in western Europe – they thus have similar climates and relatively similar institutional set-ups, with extreme heat only very recently higher on the agenda. As a result, these cities can be viewed as 'frontrunners' in efforts towards resilience, but new to tackling heat specifically. The validity of their selection thus lies in the lessons that can be learnt for other cities in temperate climates that are increasingly facing extreme heat as an issue, and how resilience to this threat can be incorporated into burgeoning efforts towards city resilience generally. Practically, London and Rotterdam represent easily accessible cases due to accessibility of contacts and availability of documents in English.

Document reviews and interviews contribute to this stage of research. Chapter 5 contains a description of each case using information collected from desk research and supplemented where necessary with information from policy and planning document reviews and interviews. Chapters 6 and 7 contain an evaluation of the resilience capacities in London and Rotterdam, answering RQ3.

Following this, it is logical to look at *why* cities express different capacities, and to different extents. Therefore, to answer RQ4 a deeper level of analysis on the factors or mechanisms that contribute to the differential expression of these capacities will be performed, the results of which are presented in Chapter 8.

This evaluation and analysis will act as a basis for reflection on relevant insights on governance strategies for enhancing resilience which will form part of the discussion in Chapter 9, thus answering RQ5. This will be the result of logical reasoning from the findings, with support from the wider literature where necessary.

3.2 Data Collection

This section presents an overview of the data considerations, their sources, and their methods of collection and analysis for each stage of the research.

3.2.1 Literature Review

A literature review, an overview of which is detailed in 2.1, is undertaken to contextualise Wardekker et al.'s (2020) conceptualisation of urban resilience in wider literature and thus answer RQ1. This contextualisation is brief and reviews key papers in the areas of urban resilience and resilience of socio-ecological systems.

Empirical studies on urban heat resilience and adaptation will also be reviewed to help inform the research for the Urban Insight report and the operationalisation of urban resilience for the threat of extreme heat in Chapter 4.

3.2.2 Preliminary Study

A study of urban heat resilience and adaptation across Europe was performed as part of an internship with Sweco. The prior literature review and conceptualisation of urban resilience capacities helped to frame the initial interviews undertaken for this stage. Sweco and non-Sweco contacts were utilised to gain broad insights from a diverse selection of actors. Time and resource constraints meant that only a few interviews were conducted per city, and no interviews were conducted for Athens due to a lack of response to interview requests. These interviews were semi-structured. An overview of the interviewees is presented in Appendix A, and the broad insights gained to write the Urban Insight report were supported by further reviews of the literature, the sources of which are available in the report itself.

This stage of research was not intended to be sufficiently valid in an academic sense to contribute to the in-depth study, but instead to contextualise the in-depth study and further specify and operationalise the urban resilience capacities, thus helping to answer RQ2. Therefore, no analysis is undertaken at this stage, but some qualitative contextual and supporting data from interviews was taken forward to contribute to the in-depth study.

As a result of the COVID-19 pandemic, interviews with the elderly and healthcare workers were not easy to access, and so the initial broader interviewee emphasis was altered to focus on local government, consultants, and academics.

3.2.3 In-Depth Study

The type of data collected at this stage is also qualitative. Document analysis consisted of grey literature, collected in the following forms: city-level climate adaptation plans, city-level resilience strategies (published as a result of membership of the 100 Resilient Cities network), city-level heat plans, and national-level heat plans. Source titles, date of publication, and their citations (as they will be referenced throughout the rest of this thesis) are presented in Table 2. For the climate adaptation plans, the two most recent were analysed to ensure a more accurate impression over time of the extent to which measures in the earlier plan were continued and/or built upon in the later plan. Chapters obviously irrelevant to extreme heat were ignored (e.g. chapters on waste, ambient noise, hazards other than heat). The data collected from these documents includes current and past policies and practices aimed at enhancing resilience to extreme heat. All documents were available in English except for the Dutch national heat plan. Translation software was used for this document.

Table 2: Data sources for document review.

Data Source Type	Source	
	London	Rotterdam
City climate adaptation plans (two most recent)	Managing Risks and Increasing Resilience: the Mayor's Climate Change and Adaptation Strategy, 2011 (GLA, 2011); London Environment Strategy, 2018 (GLA, 2018)	Rotterdam Climate Change Adaptation Strategy, 2013 (City of Rotterdam, 2013); Rotterdam Weatherwise, 2019 (City of Rotterdam, 2019)
City resilience strategy	London City Resilience Strategy, 2020 (GLA, 2020a)	Rotterdam Resilience Strategy, 2016 (City of Rotterdam, 2016)
City heat plan	Severe Weather and Natural Hazards Response Framework, 2017 (London Resilience Partnership, 2017)	N/A (in writing at time of thesis research)
National heat plan	Heatwave Plan for England, 2019 (PHE, 2018)	National Heat Plan, 2015 (RIVM, 2015)

Five semi-structured interviews were conducted per city. An overview of these interviewees is presented in Appendix A. Interviews covered the following key actor groups:

- Built environment sector professionals (i.e. consultancies)
- Municipal workers/local policymakers
- Academic experts
- Relevant networks

As a result of the COVID-19 pandemic interviews were performed over video calling software. The interview format and questions were informed by the contextualisation and specification of the topic gained from the preliminary study. This involved sending interviewees the analytical framework specified for heat prior to the interview. This was because the previous work that Wardekker et al.'s (2020) framework was based on (Wilk, 2016) observed difficulties with research participants coming up with immediate associations and responses for all ten principles in an interview format, especially because the principles are not always intuitive. Time to reflect and develop ideas based on the principles in advance of an interview was recommended (Wilk, 2016, p.158). Furthermore, in the interviews for the preliminary study where no framework was given in advance it was difficult to properly cover all principles in the short time frame of a video call, and importantly, to cover them within the conceptual boundaries of the analytical framework. It therefore made sense to provide details of the resilience principles and their specification for the threat of extreme heat as gained from the preliminary study beforehand, and then base the interview upon a shared understanding of urban resilience. The semi-structured format then allowed discussion with reference to the defined principles.

All interviewees, for both the preliminary study and the more in-depth study, were given information on the aims of this research and what would happen to their contribution – informed consent was received from all interviewees regarding their participation. All interviewees have been anonymised.

3.3 Data Analysis

The documents and transcribed interviews from the in-depth study were firstly coded, the results of which were used for evaluation of each city using a scoring system and further inductive analysis. The coding system and scoring system method of evaluation are outlined below.

3.3.1 Coding System for Evaluation and Analysis

Coding was performed using NVIVO software to help describe the case, evaluate the strength of the resilience principles in each city, and to inform the analysis of relevant factors and mechanisms that contributed to the different strengths and weaknesses. Coding was performed inductively and deductively according to the following categories:

- Phenomenon: direct and indirect (where their manifestation can be deduced) mention of the resilience capacities and principles, as well as concrete examples
- Context: the background societal, institutional, political and historical context that may indicate the importance/relevance of certain principles in the city, including specific vulnerabilities and key threats
- Causal and intervening conditions: factors that act to weaken or strengthen a principle or the strategies towards its achievement
- Strategies: goal-oriented governance approaches and activities that result in the principle, including key measures, initiatives, plans, and actors
- Consequences: opportunities or challenges created from focus on a principle.

3.3.2 Scoring System to Evaluate Resilience Capacities

RQ3 involves evaluating which principles of resilience are emphasised in each city, and thus the capacity or capacities focused on (i.e. the resilience 'pathway' taken by the city). This evaluation is achieved by scoring each city for each principle based on the system in Table 3, which is adapted from Wardekker et al. (2020, p.8). Wardekker et al. (2020) discuss firstly engaging in a 'baseline diagnosis' of the current emphasis of resilience, and secondly an 'intervention diagnosis' of the impact of plans and proposals on the resilience principles. This thesis research follows this, with the scoring system distinguishing between both the current situation, and the future situation according to the policies and interventions detailed in the various plans assessed as part of the document review, and where mentioned by interviewees. Each principle in each city is scored against the various aspects of the operationalisation of urban resilience for the threat of heat as detailed in Chapter 4.

It is important to note that the language of 'weak/negative' and 'strong/positive' in this scoring system is used for ease of understanding, and does not indicate that there is a 'better' or 'worse' mode of action for enhancing resilience to the threat of heat. The resilience pathway or pathways undertaken (purposely or not) by a city is the result of a multitude of factors, and an advantage of the resilience approach is that this differentiation can be accounted for by pursing different pathways. Assessing the extent to which the resilience principles are observed in each city allows an exploration of the *emphasis* of the current and future approaches and not how 'good' or 'bad' they are. The following can be understood by 'weak/negative' and 'strong/positive':

- Weak/negative: constraining factors exist; there are gaps, vulnerabilities, and challenges that reduce the emphasis on this principle.
- Strong/positive: enabling factors exist; there are opportunities and capabilities that enhance the emphasis on this principle.

Furthermore, the scores are not intended to be comparable across principles: if a city scores ++ for its plans in one principle and + for another, this does not mean the latter principle is necessarily less strong in the future in comparison to the first principle. It instead refers only to the anticipated magnitude of impact of plans and proposals on that principle, as shown in the explanation in Table 3.

Chapter 4 will provide a brief overview of how the preliminary study (the Urban Insight report for Sweco) specified and operationalised the analytical framework, before the results of this thesis are presented.

Table 3: Scoring system to evaluate resilience capacities in London and Rotterdam, adapted from Wardekker et al. (2020) in order to answer RQ3.

Current Situation					
Score	--	-	0	+	++
Description	Current situation is very weak regarding principle.	Current situation is weak regarding principle.	Current situation is neutral regarding principle.	Current situation is strong regarding principle.	Current situation is very strong regarding principle.
Explanation	There are key weaknesses on most aspects, no strengths. Opportunities may be missed.	Either overall weak or mix of weaknesses and strengths that is still largely unfavourable.	Mix of strengths and weaknesses, with overall neutral or unclear effect.	Either overall strong or mix of weaknesses and strengths that is still largely favourable.	There are key strengths on most aspects, no weaknesses. Possibly valuable opportunities.
Plans					
Score	--	-	0	+	++
Description	Adaptation and resilience plans have a strongly negative effect on this principle.	Adaptation and resilience plans have a negative effect on this principle.	Adaptation and resilience plans have a neutral effect on this principle.	Adaptation and resilience plans have a positive effect on this principle.	Adaptation and resilience plans have a strongly positive effect on this principle.
Explanation	Plans have a negative effect on most aspects, no positive effects.	Either an overall negative effect, or negative on some aspects, while neutral or marginally positive effect on others. Total effect clearly negative.	Plans have positive and negative effects, e.g. positive on some aspects, negative on others. Total effect is unclear.	Either an overall positive effect, or positive on some aspects while neutral or marginally negative effect on others. Total effect clearly positive.	Plans have a positive effect on most aspects, no negative effects.

4. PRELIMINARY STUDY

This Chapter relays the results of the study performed for Sweco insofar as they help to specify and operationalise the urban resilience capacities for the threat of heat, answering RQ2. The full Urban Insight report written for Sweco, with its associated references and information sources, can be found here[2].

Table 4 contains the analytical framework of urban resilience capacities from Table 1 further specified and operationalised for the threat of heat. The following key establishes the alterations to the initial framework following the preliminary study:

- Blue: further specification of Wardekker et al.'s (2020) generic operationalisation, informed by interviewees and logical inference
- Green: additional points raised by interviewees not covered in Wardekker et al.'s (2020) framework
- Grey: points not raised by interviewee, possibly due to being too vague or not relevant for threat of heat. Will potentially be removed following confirmation from in-depth study

The rest of this Chapter briefly outlines these key alterations to the analytical framework, in advance of the in-depth study results that form the rest of this thesis, and which covers many of these issues in greater depth.

4.1 Capacity to Prepare

Much of the capacity to prepare has been further specified for heat and the vulnerabilities it presents rather than referring to generic climate threats. Active learning at this point was not raised as a factor – the focus instead is on creating information through data availability and maps. Businesses did not come up as an important actor for the threat of heat in the preliminary study – the main focus among interviewees and surrounding literature was instead the importance of the preparedness of healthcare workers and individuals: awareness and preparation at these levels is considered to have the greatest impact on how people are impacted in an extreme heat event. Furthermore, integration of actor responsibilities into law was not raised – rather there was a much greater focus on the importance of integration of heat into, and coordination across, other policy areas and sectors. Key sectors were identified, and include public health, urban planning, and climate adaptation, with a focus on the importance of vertical coordination particularly in the health sector and horizontal coordination between health and urban planning. Socio-economic and environmental factors were also identified as key trends or 'slow variables' that are important to monitor when preparing for an extreme heat event.

4.2 Capacity to Absorb

The capacity to absorb was most concretely specified, with a diverse range of measures raised by interviewees and surrounding literature that contribute to both robustness and redundancy. An overview of the most common measures can be found in Appendix B. Private measures were additionally identified as key to enhancing the capacity to absorb at an individual level, and so these have been added.

[2] https://www.swecourbaninsight.com/climate-action/building-resilience--being-young-and-getting-old-in-a-hotter-europe/

4.3 Capacity to Recover

The capacity to recover was difficult to further specify as it is relatively abstract and consists of institutional qualities rather than concrete measures. Context-specific, participatory design of buildings and urban spaces was raised as important when considering the vulnerable groups most impacted from heat – for example in terms of accessibility, or in considering the particular behaviours and routines of the elderly and their caregivers. Cross-sectoral networks and partnerships were added as a key mode through which high-flux appears to be enhanced for the threat of heat. Such networks include, for example, 100 Resilient Cities, the C40 Cool Cities network, the London Climate Change Partnership, and knowledge institutions that work closely with multiple stakeholders.

4.4 Capacity to Adapt

The capacity to adapt has been further specified for heat, focusing on the importance of learning across sectors and levels from extreme heat events – for example, relevant institutions like care homes and hospitals need to ensure they formally monitor their performance in times of hot weather and subsequently make active changes to policies and routines. Furthermore, institutional flexibility, spatial flexibility, and flexibility in measures all remain key points, but flexibility in measures for the threat of heat can be summed up as the prioritisation of 'no-regret' measures that are relevant for multiple threats (e.g. flooding and heat) and a range of possible futures.

Table 4: Urban resilience capacities specified and operationalised for the threat of extreme heat.

Capacities for resilience	Principles	Specified operationalisation for heat
Capacity to PREPARE	Anticipation & Foresight	- Relevant heat-related data and mapping is available and accessible for a wide range of actors - Mapping and data include socio-economic and environmental variables - Socio-economic and environmental trends ('slow variables') that enhance vulnerability are monitored e.g. elderly population, pollution levels - Active learning occurs
	Preparedness & Planning	- Localised extreme heat event response and management plans are in place - Risks and vulnerabilities are communicated to the public and businesses and healthcare workers, who are aware of their responsibility
	Homeostasis (i.e. strategic management of feedbacks)	- Heat is integrated into other sectoral programs and policies like public health, urban planning, and climate adaptation - Responsibilities of actors are integrated into law - Integrative policy processes ensure equitable and inclusive benefits, including consideration of those most impacted by heat - Communication channels are in place and functioning horizontally across sectors and vertically across levels - Green and blue infrastructure is well maintained
Capacity to ABSORB	Robustness & Buffering	- Climate impacts can be withstood or lessened due to policy, spatial, private and infrastructural measures that focus on impact and risk reduction (see Appendix B for examples of measures that enhance robustness)
	Diversity	- Diversification of governing authorities, resources, management strategies, means, institutions, and stakeholders, resulting in diversification of response - Functional diversity (multiple ways to fulfil a need, i.e. a function, exist; see Appendix B for a diversity for measures that enhance capacity to absorb) - High biodiversity
	Redundancy (i.e. spare system capacity)	- Shared functions and governance responsibilities across scales and sectors for heat preparation and response - Vital city functions and resources have backups and alternative sources
Capacity to RECOVER	Flatness	- Non-hierarchical, decentralised governance allowing competent, authoritative, and autonomous local action - Broad, active, and inclusive participation in decision-making (including the vulnerable and marginalised) - Participatory and context-specific design of buildings and urban spaces
	High-Flux	- Quick movement of resources through a system, allowing quick mobilisation in response to threat - Cross-sector networks and partnerships facilitate widespread access to information and financial and human resources and enhance connectivity between sectors - Decision-makers are resourceful and flexible in responses and strategies
Capacity to ADAPT	Learning	- Reflective, participatory learning across sectors and levels from previous extreme heat events - Room for experimentation, innovation, and 'learning-by-doing' - Active application and implementation of new knowledge
	Flexibility	- Institutional flexibility: flexible decision-making and cooperation arrangements - Flexibility in spatial planning: 'structural elbowroom' for future modification, extension, or retrofitting in spatial planning - Flexibility in measures: prioritisation of 'no-regret' measures

5. CASE DESCRIPTION

This section provides a description of the two case cities in this research, with a general overview of each city, its vulnerability to heat, and a brief timeline of the city's climate adaptation and resilience actions studied for this work. Finally, the main actions from these plans and strategies geared towards extreme heat are presented. Evaluation of these actions in terms the resilience principles they weaken or strengthen is then addressed in Chapters 6 and 7.

5.1 Rotterdam

Rotterdam is the second largest city in the Netherlands, one of four major cities that make up the Dutch urban agglomeration of the *Randstad*. The municipality covers an area of 325.8 km^2, and is home to a population of around 651,000 (Centraal Bureau voor de Statistiek, 2020) constituted of 170 different nationalities (City of Rotterdam, 2016). It is an economically open, global city: a delta city, home to the largest port in Europe (which makes up 1/3 of the city's total land area; City of Rotterdam, 2013), Rotterdam has made a name for itself internationally for its experience pioneering innovative delta technologies and maritime professional services (City of Rotterdam, 2013). As a result, it has identified itself as exposed to numerous challenges and future transitions (City of Rotterdam, 2016). Much of the city was bombed during the Second World War, so unlike the historic centres of other cities throughout the Netherlands, it is more modern in infrastructure due to post-war rebuilding efforts. The city's level of unemployment (highest among immigrant groups), low educational attainment, and social segregation within its diverse population are key challenges facing the city (City of Rotterdam, 2016; Joseph Rowntree Foundation, 2017).

5.1.1 Rotterdam and Heat

The Netherlands has been subject to multiple heatwaves in recent years: hot weather in summer 2006 caused 1000 excess deaths across the country (van den Hazel & Weterings, 2019) and the summer of 2018 was the hottest in at least three centuries (Ruimtelijk Adaptatie, 2020a). Although not a significant threat in the past, Rotterdam's awareness of heat risk in the city is growing, with the city subject to seven heatwaves between 2000 and 2020 (2003, 2006, 2013, 2018, twice in 2019, and 2020). Half the heatwaves that have occurred in the city since records began in 1956 have happened in the last 20 years (Weerstatistieken KNMI, 2020).

The average summer-time high temperature in Rotterdam is 22.2°C (KNMI, 2020). A 'heatwave' has occurred if there were 5 consecutive days of 25°C or higher, of which at least 3 can be classed as 'tropical' (30°C or higher; RIVM, 2015). The Dutch national heat plan is activated if there is an expectation of maximum temperatures above 27°C for four or more days (RIVM, 2015) – various systems of alert then dictate the action required, see Table 5 for details. The urban heat island (UHI) effect results in the city being up to 8°C warmer than surrounding rural areas in hot weather (City of Rotterdam, 2019), and is visualised as a summer-time average in Figure 4. Rising temperatures have important consequences for the Netherlands' primary climate-related problem, flooding: the Dutch meteorological institute, KNMI has calculated that for every degree rise in temperature, rainfall intensity will increase by 14% (City of Rotterdam, 2013).

Under an RCP4.5 scenario, by 2050 the city is likely to experience an increase in the maximum temperature of its warmest month of 3.5°C, making its overall climate likely to be more similar to that of Paris today (Bastin et al., 2019). For the period 2051-2100, a medium impact scenario of the supposed 'worst-case' climate projection, RCP8.5, demonstrates a 19.7% increase in the number of heatwave days, and a 6.8°C increase in the maximum daily temperature of such days (Guerreriro et al., 2018).

Heat in Rotterdam is identified as impacting quality of life in general, particularly for more vulnerable people like the elderly. Health impacts, as well as higher death rates among vulnerable groups are identified, as is reduced labour productivity and reduced thermal comfort (City of Rotterdam, 2019). As well as the direct impacts of higher temperatures Rotterdam has identified the following additional impacts: an increased energy demand for cooling; increased demand for fresh water; decreased water quality; potential increases in allergies and infections; loss of biodiversity; increased harmful organisms such as blue-green algae in the city's waterways; and reduced accessibility to the city due to issues with opening and closing bridges (City of Rotterdam, 2019) – all of which impact city liveability.

Some areas of the city are more vulnerable to the threat of heat. 30% of Rotterdam residents have no cooling in their own homes and immediate surroundings, and there are neighbourhoods that have a higher proportion of paved public spaces, little shade, and little greenery (City of Rotterdam, 2019). For example, whilst Rotterdam's city centre is more spacious than that of other Dutch cities due to its more recent post-war re-construction, it is highly paved with a lot of traffic, adding to the UHI effect as well as enhanced flood risk (City of Rotterdam, 2013).

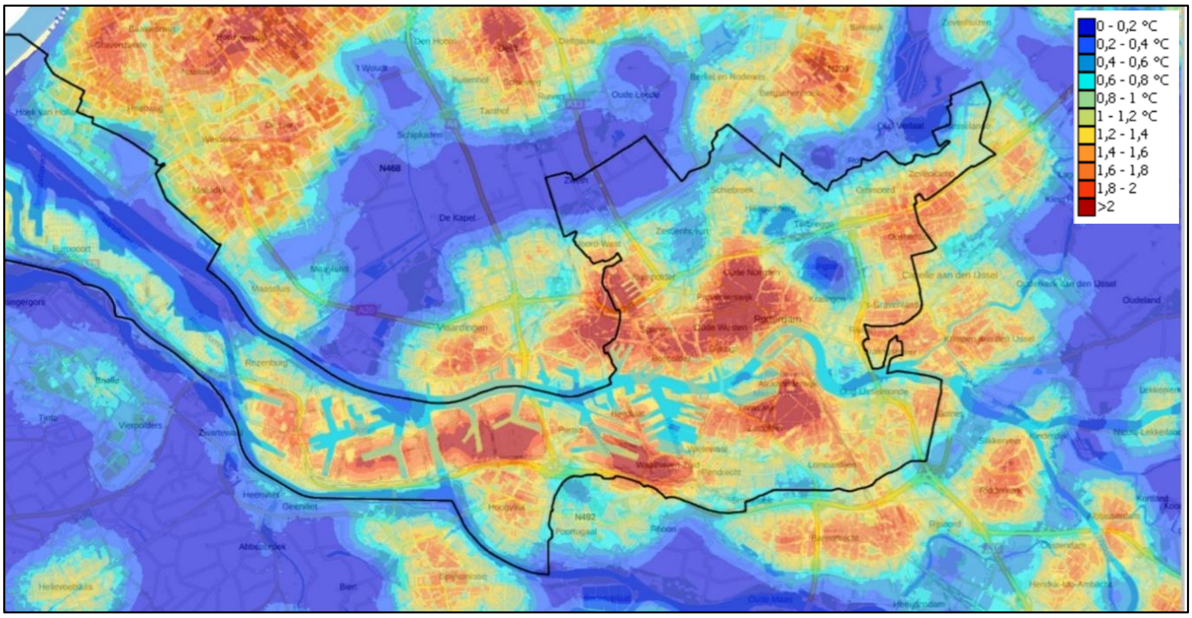

Figure 4: A model of the UHI effect in Rotterdam, showing the annual average air temperature difference in °C between the city and surrounding rural areas. On average annually, the temperature difference is up to 3°C, with this difference increasing on hot summer days and especially at night. The model simulates the UHI effect based on population density, wind speed, green and blue infrastructure and surfaces (i.e. greenery and waterways) and is extracted from the interactive national Dutch Climate Impact Atlas (Klimaat Effect Atlas, 2020).

5.1.2 Climate Adaptation and Resilience Action

The Netherlands is governed as a decentralised unitary state with three levels: national, provincial, and municipal. City governance is run at the municipal level by the Municipal Executive Committee (the executive body) and the City Council (the legislative body). Beyond this, the city is split into 14 districts, that make up a total of 71 neighbourhoods (City of Rotterdam, 2020).

National climate action is led by (Ruimtelijke Adaptatie, 2020b):

- The 2016 *National Climate Adaptation Strategy* (NAS), updated from the first Dutch climate action strategy in 2007, which details the main climate risks and sets the course for addressing them. This is the result of a requirement by the European Commission for all EU countries to draw up a NAS by 2017. Action planning is led by the *NAS Implementation Programme*.
- The 2018 *National Delta Plan on Spatial Adaptation*, a joint spatial adaptation plan drawn up collectively by municipalities, provinces, central government, and district water boards as part of the Delta Program. Much of the Netherlands is low-lying, and this combined with the impacts of a catastrophic flood in 1953 has resulted in a huge governmental focus on protecting against future flood-related threats. The Delta Program is now released every year, focusing on flood protection, ensuring fresh water supplies, and climate-proofing (Government of the Netherlands, 2020).

The collective aim of these two plans is to embed spatial adaptation in policy and implementation at all government levels by 2020, and for the Netherlands to be water-resilient and climate-proof by 2050 (Ruimtelijke Adaptatie, 2020b). The responsibility for local implementations of national plans lay with the municipalities (Mees & Driessen, 2011).

Work on policies and projects related to climate action has been active in Rotterdam since 2007 (Spaans & Waterhout, 2017), with the main focus being flooding. Rotterdam sits on the mouth of the Nieuwe Maas, a channel leading to a delta formed of a confluence of three rivers, the Rhine, the Meuse, and the Scheldt. 90% of the city is below sea level (Kimmelman, 2017), and as such Rotterdam has a strong narrative of continual adaptation to the "ever-changing delta for centuries" (City of Rotterdam, 2013, p.11). This has resulted in a focus on robust flood infrastructure in the city in the form of sewers, pumping stations, dikes, and canals. Scope was widened to include other issues related to climate change and sustainability from 2010 as a result of the Rotterdam Programme on Sustainability and Climate Change ('*Programma Duurzaam*'), which ran from 2010 to 2014 and saw the approval of the city's first climate adaptation strategy in 2013 (Spaans & Waterhout, 2017). As this project came to an end, Rotterdam sought to continue its work in this area by applying to the 100 Resilience Cities (100RC) programme.

The city's 2016 *Resilience Strategy* was developed as part of the city's membership of the 100RC network. It was one of the earliest cities to apply and join, and received (along with all other member cities) support in the following ways (City of Rotterdam, 2016):

- Financial and logistical support for the position of a Chief Resilience Officer (CRO)
- Access to technical expertise to guiding the process to develop a resilience strategy through 'strategy partners'

- Access to solutions, service providers and public and private partners and NGOs through the 100RC platform
- Membership of a network of world cities for knowledge exchange and learning

The *Resilience Strategy* integrates the challenges and goals of Rotterdam with 100RC's resilience framework to produce a vision for a 'resilient Rotterdam' by 2030. The definition of urban resilience used by 100RC is "the capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow no matter what kinds of chronic stresses and acute shocks they experience", with a focus on seven resilience goals: reflective; resourceful; robust; redundant; flexible; inclusive; and integrated. These goals are integrated in the *Resilience Strategy* alongside six Rotterdam-specific focus areas: social cohesion and education; energy transition; climate adaptation; cyber use and security; critical infrastructure; and changing urban governance. The core of the *Resilience Strategy* is to maintain the pre-existing robustness of the city, but also to think more holistically, enhancing flexibility and inclusiveness in order to deal with a wider range of current and future risks (City of Rotterdam, 2016).

Rotterdam's resilience department was instigated as a result of work with 100RC. The department's aim is to work with ambassadors in other departments to ensure the Resilience Strategy is implemented, putting resilience and the identified challenges on the agenda for the experts elsewhere to work on (Interview R3).

In 2019, Rotterdam released its most recent *Climate Adaptation Strategy*, *Weatherwise,* which following the 100RC programme's end in 2019 and in alignment with the national focus continues with the goal of climate resilience. The focus of *Weatherwise* is to scale up and finetune the work of the first *Climate Adaptation Strategy* from 2013 and to accelerate and intensify the national plans – the aim is for Rotterdam to be water-robust and climate resilient by 2025 (City of Rotterdam, 2019).

5.1.3 Action for Heat

In terms of climate threats, the focus area of both the 2013 *Climate Adaptation Strategy* and 2016 *Resilience Strategy* are primarily flooding and rainfall, with heat seemingly a secondary issue area mentioned in the former and not mentioned at all in the latter. Heat is more heavily addressed in the 2019 *Climate Adaptation Strategy*, *Weatherwise* – alongside drought, groundwater, and land subsidence, all of which are problems that are gaining increasing traction.

Since its inception in 2007 the Dutch *National Heat Plan* has been activated almost annually (RIVM, 2015). The purpose of the plan is to communicate warnings of impending periods of prolonged warm weather, specifically to more vulnerable groups as well as the municipal public health services (called *GGDs*), other health organisations, and the Dutch Red Cross. More details of this plan can be found in Table 5. The local implementation of this plan has not yet been released.

The vast majority of Rotterdam's strategy for dealing with the threat of heat lies with enhancing urban greening measures, already in large-scale implementation due to their importance as a flood risk mitigation measure. An overview of measures detailed in the different strategies and plans assessed for this research is detailed in Table 5.

Table 5: An overview of measures detailed in the documents assessed for this research.

Document	Heat-related key points and measures
2013 Climate Adaptation Strategy (first climate adaptation strategy) (City of Rotterdam, 2013)	• Paving removal and increase green and blue infrastructure, particularly in densely-built areas, with the primary aim of reducing flood risk and increasing liveability • Encourage investment in heat-resistant measures for existing buildings • All new construction to incorporate heat-proof measures • Improve knowledge base • No details on measures to be taken specifically for vulnerable groups
2016 Resilience Strategy (City of Rotterdam, 2016)	• Very little mention of heat, with none of the 68 actions directly geared towards it • Measures mentioned for other threats (e.g. climate-resilient infrastructure, climate-proof neighbourhoods, green roofing) applicable to heat despite no explicit link made
2016 National Heat Plan (RIVM, 2015)	• Communication chain of advance warnings and information, allowing relevant organisations (e.g. healthcare institutions (*GGDs*), sector organisations, Dutch Red Cross) to prepare or initiate certain actions and communications to professionals and the general public • Aimed at triggering short-term behaviour changes in individuals, and for individuals to look after those around them • 3 phases of communications: vigilance phase (summer preparedness planning); pre-warning phase (there is the chance of a heatwave); and warning phase (high probability of heatwave, usually in next 24 hours) • Monitoring and evaluation phase post heat event • Allows for differentiated communications to different sectors and vulnerable groups
2019 Rotterdam Weatherwise (most recent climate adaptation strategy) (City of Rotterdam, 2019)	• Greater focus on heat than in previous resilience and climate adaptation plans • Continued focus on green and blue infrastructure, particularly in vulnerable areas • Requirement of inclusion of heat-resistant construction in building and public space design • Work with green space managers, urban infrastructure specialists, and health specialists to define preventative procedures • Development of a local heat plan • Improve knowledge base and communications • Incentive scheme to encourage private construction of cooling measures
To be released: Rotterdam Local Heat Plan (Details from van den Hazel & Weterings, 2019; Interview R1; Interview R4)	• Practical implementation of *National Heat Plan* at local level, to be drawn up with local partners • Building of local networks, and identification of responsibilities of various actors and local partners, measures to be taken at different levels in a heat event, what individuals can do in a heat event, and where they can find relevant information • Focuses on more vulnerable groups, sectors, and urban areas, and how to communicate effectively to vulnerable groups

5.2 London

London is Europe's third largest city, with a population of 8.96 million people in 2019 (Office for National Statistics, 2020) – almost 14 times as many people as in Rotterdam. It covers 1,572 km^2, which is about half the size of the entire Dutch *Randstand* region, and is very diverse, with 38% of Londoners born abroad (GLA, 2020a). London has an open economy and is a global centre for commerce and finance, which like Rotterdam exposes it to continual change and transition on a local to global scale. It is one of the most-visited cities in the world, as well as being a commuter city with over 900,000 coming in to work daily (GLA, 2020a). London is growing, with its population set to reach 10 million with the next 10 years (GLA, 2020a). Income inequality is stark, with high levels of poverty, socio-economic inequities, and lack of affordable housing characterising the city. Additionally, many buildings are old, with Victorian infrastructural systems not designed for a large population or new climatic stresses.

5.2.1 London and Heat

Like the Netherlands, periods of extreme heat in the UK have been increasing, with the country's 10 warmest years on record all occurring since 2002 (Kendon, et al., 2020). Heatwaves in London have occurred in 2003, 2006, 2009, 2013 (Arup, 2014), and every year since 2015 (Met Office, 2020a). The deadly 2003 pan-European heatwave resulted in 600 excess deaths in London alone, mostly among the elderly (GLA, 2020b) – deaths among those aged over 75 rose by 60% (London Resilience Partnership, 2017). Summer 2020 in London saw temperatures reaching over 34°C for 6 days in a row – a first since records began in 1961 (Campbell & Parveen, 2020).

The average summer-time high temperature in London is 23.4°C (Met Office, 2020b). Heatwave classifications in the UK are locally defined (unlike the national definition in the Netherlands), with alerts in London triggered if forecasts indicate day-time temperatures will reach or exceed 32°C and night-time temperatures will reach or exceed 18°C for more than 2 consecutive days (London Resilience Partnership, 2017). Further threshold temperatures have been defined for other sectors which activate specific actions – for example, specific measures are activated on the London Underground when temperatures exceed even 24°C (London Resilience Partnership, 2017). The urban heat island (UHI) effect results in the centre of the city being up to 10°C warmer than surrounding rural areas in hot weather (GLA, 2018), and is visualised as an annual average in Figure 5.

Under an RCP4.5 scenario, by 2050 the city is likely to experience an increase in the maximum temperature of its warmest month of 5.9°C, making its overall climate likely to be more similar to that of Barcelona today (Bastin et al., 2019). As stated in London's 2020 *Resilience Strategy*, what is currently thought of as a heatwave is likely to occur most summers by 2050. For the period 2051-2100, a medium impact scenario of the supposed 'worst-case' climate projection, RCP8.5, demonstrates a 19.1% increase in the number of heatwave days, and a 7.6°C increase in the maximum daily temperature of such days (Guerreiro et al., 2018).

Rising temperatures in London were identified as a key risk from climate change back in 2002 (alongside flooding and water scarcity), with a range of knock-on effects including impacts on biodiversity, air quality, and increased pathogens and pests (GLA, 2018). Since then, risks and impacts from heat directly and indirectly on different sectors have been assessed by the London Resilience Partnership. At even small temperature rises, impacts on citizens and services are felt, for example on the transport and health sector (GLA, 2018), and on electrical and telecommunications infrastructure (GLA, 2020a). As a large economic centre, the disruptions to business operations as well as daily life as a result of this can be significant. The links between heat and air quality is also a particular problem in London – low air quality due to high levels of pollution is already a serious issue. Hot weather exacerbates this and creates breathing difficulties for those with respiratory issues (Future Climate Info, 2020).

The significant inequalities already extant in London will be exacerbated by the climate risks it faces. Already marginalised groups have a reduced capacity to cope in the face of shocks (of which heat is currently) and stresses (of which heat will be in the future).The city has identified in its 2018 *Climate Adaptation Strategy* the groups particularly at risk from rising temperatures and heatwaves: the elderly, young children, socially isolated people, rough sleepers, and seriously ill people (GLA, 2018). Furthermore, London has a large amount of high-rise buildings, and those living in these with little access to green space also are at higher risk. London's 2020 *Resilience Strategy* additionally identifies the years of austerity measures which have impacted heavily upon the city's public services, further reducing the ability of those most vulnerable to seek help and resources.

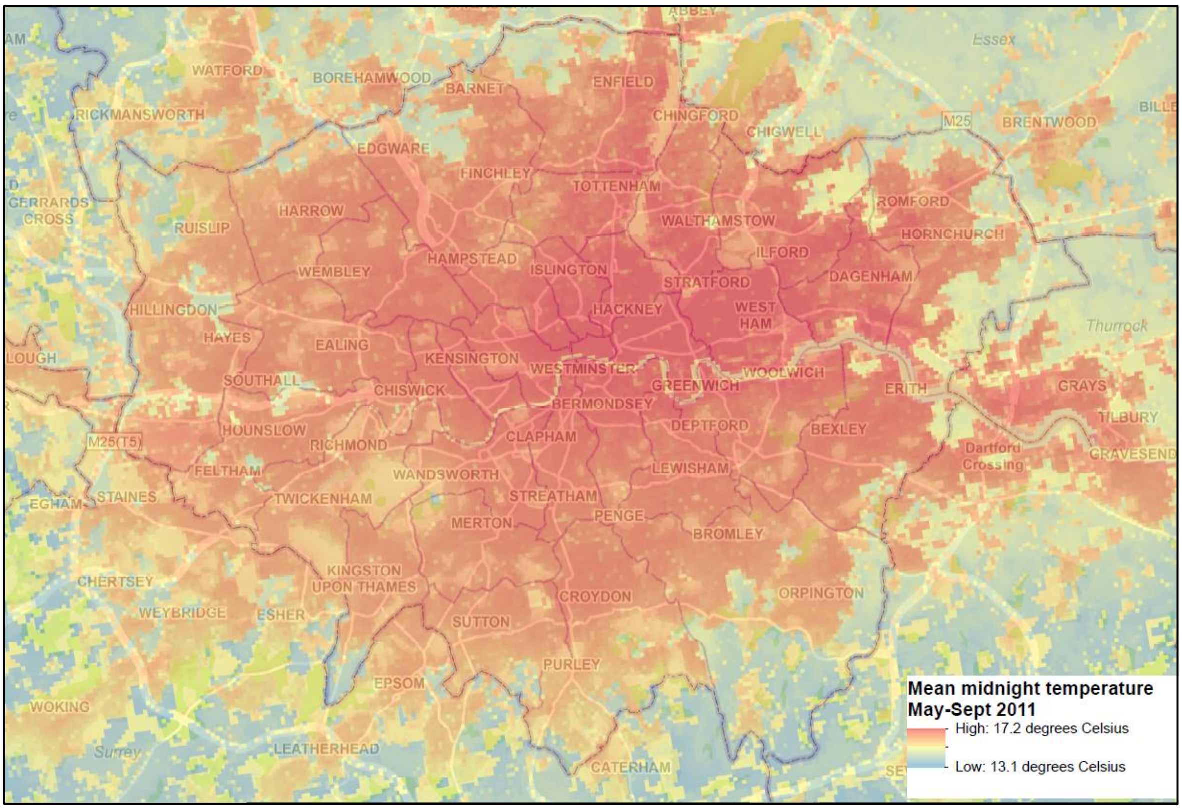

Figure 5: A model of the UHI effect in London, showing the average temperature in °C at midnight over the summer of 2011 (May to September). The night-time temperature is on average approximately 4°C higher in the city centre than in surrounding rural areas, with even larger effects observed on hot nights. The model simulates the UHI effect based on weather conditions and the impact of urban development on parameters like humidity and temperature, and is available from the GLA's Datastore (VITO, 2016).

5.2.2 Climate Adaptation and Resilience Action

The UK is governed as a centralised unitary state with three levels: national, regional, and local (with devolved administrations in Scotland, Wales and Northern Ireland). London has greater devolved governing power than other regions in England, with this level run by the Greater London Authority (GLA). The GLA is a strategic authority made up of the Mayor of London, who plays an executive role and sets the overall vision for London through the 'London Plan' (a strategic plan setting out frameworks for social, environmental, economic, and transport development), and the London Assembly, who hold the Mayor and mayoral policy to account. Local services are then overseen by the 33 borough councils, who govern themselves (London Councils, 2020).

National climate adaptation strategy, as required by the EU, was adopted in 2008 through the UK Climate Change Act, with action planning led by the National Adaptation Programme. This plan works in five-year cycles, with the broad aim of "a society which makes timely, far-sighted and well-informed decisions to address the risks and opportunities posed by a changing climate" (DEFRA, 2018, p.ii). The most recent iteration sets out an updated and post-Brexit version (DEFRA, 2018). London boroughs implement the national plans on a local level (with many boroughs for example independently declaring climate emergencies and setting goals and targets), with the GLA setting plans for London as a whole.

Climate action has been a priority in London for some time, with key focus areas including air quality, heat, and transport. The topic was placed higher on the agenda with the release of the city's first draft adaptation strategy in 2008 (Mees & Driessen, 2011). The first full strategy was published in 2011 with a comprehensive coverage of a range of climate risks, including heat (GLA, 2011).

Resilience was included as an aim in the 2011 *Climate Adaptation Strategy*, however the conceptualisation used is more in the realm of risk management. The city has a long history with this conception of resilience due to its embeddedness within emergency preparation and response infrastructure. This conception of however narrower than that of urban resilience utilised in this thesis (as discussed in 2.1). London's Resilience Team was formally established in 2002, moved to jurisdiction of the GLA in 2010, and was merged with the Fire Brigade Emergency Planning Team in 2016 (GLA, 2020c). It is now made up of various structures including the multi-agency London Resilience Partnership, made up of over 200 organisations with responsibilities for preparing for, responding to, and recovering from emergencies (GLA, 2020a). The Partnership also releases a register of the key risks that London faces and its planning for these risks, within which heatwaves are included.

In 2018 the most recent climate adaptation strategy was released – the *London Environment Strategy* – with a similarly comprehensive strategy and policies for a zero-carbon city by 2050. The range of focus areas includes air quality, waste, ambient noise, mitigation and adaptation, green infrastructure, and a low-carbon circular economy.

London is also a member of the 100 Resilient Cities (100RC) network and released its *Resilience Strategy* in collaboration with 100RC in 2020. It follows the 100RC definition of urban resilience, focuses on the same seven resilience goals, and receives support from 100RC in the same way as Rotterdam – as do all other member cities. London's *Resilience Strategy* focuses on a developing a 'resilient London' by 2050, a later goal than Rotterdam. It defines multiple shocks and stresses, including climate change, environmental degradation, terror threats, cyber-attacks, economic instability, inequality, social tensions, and Brexit (GLA, 2020a). It is important to note that the *Resilience Strategy* is not a product of the London Resilience Team infrastructure, but instead a collaborative product of multiple organisations. Going forwards, the *Resilience Strategy* implementation is to be undertaken by the GLA Fire and Resilience Team and the various associated structures.

5.2.3 Action for Heat

London has a much longer history of action for urban heat than Rotterdam. The London Climate Change Partnership released a report on London's main climate risks, including heat, called 'London's Warming' back in 2002 (GLA, 2018), and from the late-2000s projects began to start modelling the city's urban heat island and other factors related to heat risk (Interview L2). Managing heat risk forms a significant part of the 2011 *Climate Adaptation Strategy*, is integrated within other dimensions such as adaptation and green infrastructure in the 2018 *Climate Adaptation Strategy*, and a key action of the 2020 *Resilience Strategy.*

The national heat plan, the *Heatwave Plan for England*, was published for the first time in 2004 as a response to the impacts of the 2003 pan-European heatwave. Similar to the Dutch plan, its purpose is to communicate various levels of alert to different organisations, including the NHS, public health and social care organisations, and community and voluntary organisations that support people vulnerable to heat (i.e. those with health, housing, or economic vulnerabilities), as well as raising public awareness. More details on this plan can be found in Table 6.

At a local level for London, this alert system is incorporated into London Resilience Partnership's *Severe Weather and Natural Hazards Response Framework* (more details on this framework can be found in Table 6). Heat risk and London's response to it is thus embedded within this emergency planning infrastructure, and heat is therefore considered within a broader risk framework. The alert system within this framework mirrors that of the national level risk preparation and response in the *UK Heatwave Plan for England*.

The main strategies in London for dealing with extreme heat are in the realms data creation, alert systems, and green infrastructure. An overview of measures detailed in the different strategies and plans assessed for this research is detailed in Table 6.

Table 6: An overview of measures detailed in the documents assessed for this research.

Document	Heat-related key points and measures
2011 Managing Risks and Increasing Resilience (first climate adaptation strategy) (GLA, 2011)	• Focus on data creation and mapping • Main adaptation measures include enhancing greenery and reducing overheating risk and demand for mechanical cooling in infrastructure through retrofitting and regulations in new developments • Focus on creating a 'robust' local heat plan • Focus of knowledge creation for and adaptation efforts on worst affected areas and most vulnerable groups • Includes detailed discussion of cross-cutting nature of climate impacts across different sectors
2017 Severe Weather and Natural Hazards Response Framework (includes local heat plan) (London Resilience Partnership, 2017)	• Alert system for heat risk consisting of 5 levels (aligned with 2019 *Heatwave Plan for England)* incorporated into a London-level plan for a range of natural hazards. • London-specific thresholds for activation • Follows 2019 *Heatwave Plan for England* alert system and intended recipients, but with extra actions to be coordinated across the London Resilience Partnership. Further roles and responsibilities across actors are defined • Includes specific information main drivers of vulnerability in London: age (75+, very young); environmental factors (lack of green space, housing quality, building height); social/institutional factors (income, inequality, strength of social networks, nursing home care regimes) • Includes specific information on impact on other sectors, particularly air quality and transport
2018 London Environment Strategy (most recent climate adaptation strategy) (GLA, 2018)	• Various mitigation measures including green infrastructure and reflective paints • Focus on problem definition: data collection and monitoring in an integrated, cross-sectoral way, with partner collaboration based on this data • Development of a communications plan for alerts • Focus on sectoral interdependencies, including minimising heat risk in buildings and during transportation (on streets and on the Underground)
2019 Heatwave Plan for England (PHE, 2018)	• Alert system to helps trigger actions to prepare for and prevent major avoidable health impacts • 5 alert levels: 0 – long-term multi-agency strategic planning; 1 - summer preparedness planning; 2 – heatwave is forecast (forecast 60% risk of heatwave in next 2 or 3 days); 3 – heatwave action (thresholds for heatwave reached); 4 – severe/prolonged heatwave occurring (affecting multiple sectors, emergency response activated) • Steps for risk reduction for a variety of actors (health and social care institutions, local communities, individuals), with specific action for at-risk groups and sectors in levels 3 & 4 • Provision of 'real-time' info on excess mortality and morbidity due to heatwaves • Defines responsibilities and lead agencies at national and local level • Threshold temperatures on a regional basis • Monitoring and evaluation incorporated in plan
2020 *London Resilience Strategy* (GLA, 2020a)	• Establishment of a network of 'cool spots' accessible for all Londoners, with spaces to rest, cool down, and access water • Improvement of data on extreme weather

6. CASE EVALUATION: ROTTERDAM

Chapters 6 and 7 seek to answer RQ3 – the extent to which the resilience capacities are expressed in Rotterdam (Chapter 6) and London (Chapter 7) regarding the threat of heat. Each principle is scored according to the scale in Table 3, and thus the emphasis of each city on each principle is assessed in terms of current practices, and future practices as indicated by the adaptation and resilience plans assessed. An overview of each capacity is presented first, followed by a more in-depth presentation of the results per principle. The results of this assessment for Rotterdam is illustrated in Table 11.

6.1 Capacity to Prepare

Awareness of the threat of heat is low in Rotterdam, so the capacity to *prepare* for this threat is weak across all principles. This is likely to improve as Rotterdam seeks to address this knowledge gap.

Table 7 provides an overview of the assessment of each principle, scored against the operationalisation of urban resilience for the threat of heat detailed in Table 4. The following sections expand on this in further detail.

Table 7: The score per principle for both current practices and future practices as indicated by adaptation and resilience plans.

Principle	Current practices	Why?	Plans	Why?
Anticipation & Foresight	-	Heat risk and impacts only recently being properly assessed. Understanding of risk on vulnerable groups and across sectors lacking.	+	A stronger focus on heat and knowledge generation is in process, with an increasing availability of quantitative information enabling this.
Preparedness & Planning	--	Low public awareness of risk and thus low large-scale preparedness, low effectiveness of emergency planning.	++	Strong focus on enhancing communication and awareness, local emergency plan in development.
Homeostasis	-	Integration of heat risk into other policy and sectors is low.	+	This gap is identified, and measures to address it are present in plans.

6.1.1 Anticipation and Foresight

Scoring

Until recently, whilst knowledge on other climate risks has been well developed, data and mapping on the risk of heat, its impacts, and related socio-economic vulnerabilities has been limited and is thus relatively <u>weak</u>. However national climate stress tests, standardised methodologies for measuring heat, and defined commitments to improving specific types of knowledge at the city-level indicates that plans will have a <u>positive</u> influence on this principle.

Elaboration

Climate stress tests are an obligatory part of the National Delta Plan on Spatial Adaptation (Ruimtelijke Adaptatie, 2020c). All municipalities had to carry out a stress test for each of the four nationally-identified climate themes in the plan (heat, drought, flooding due to rainfall, and flooding from the sea, rivers etc.) by 2019, in order to gain a standardised inventory of local impacts and vulnerabilities as a result of each theme.

As of early 2020, the interactive national Climate Impact Atlas (*Klimaat Effect Atlas*) used by municipalities to assess these themes was updated to include a standardised methodology for mapping heat – the Physiological Equivalent Temperature (PET; Koopmans, Heusinkveld, & Steeneveld, 2020). PET methodology takes into better account the multiple factors that impact upon the experience of heat, including physiological processes; meteorological parameters like radiation, air temperature, and windchill; and geographical factors like building height and street configuration, which impact upon shading and exposure to sunlight (Koopmans et al., 2020). Prior to this, assessments of urban heat were produced by different agencies for the municipalities, using different methods and metrics (e.g. air temperature, surface temperature, or number of 'tropical' nights of temperatures above 20°C; Koopmans et al., 2020). Usage of the PET methodology was patchy and depended on the accessibility of various organisations to the knowledge and data (Sweco, 2020, personal communication). Its standardisation now allows for more accurate, higher-resolution assessments of vulnerability, and enables more effective local adaptation planning – for example by allowing optimal placement of greenery due to maps showing heat hotspots at a street level (Sweco, 2020, personal communication). Due to its recent introduction, Rotterdam's climate stress tests and its most recent 2019 *Climate Adaptation Strategy, Weatherwise,* do not include the PET methodology. However, the municipality aims to utilise it in future plans and projects (Interview R1).

Layered mapping is also used in Rotterdam, showing vulnerable areas where multiple climate themes overlap, and where other vulnerabilities come into play due to high populations of older people, a lack of greenery, or particularly vulnerable infrastructure. This information is being used to develop Rotterdam's local heat plan (Interview R4) and enables linkage between water management approaches and heat (which promotes *diversity* and *redundancy* through an increased variety of measures). The city plans to use data created on heat hotspots and more vulnerable groups in this way to change local regulation and planning documents (like the '*Rotterdamse Stijle'*, the municipality's public space guidance document on design principles for different areas of the city): the aim is to perform priority area mapping, alter regulations on buildings design, and alter guidance on street design (Interview R1).

Despite the above, all interviewees alluded to the lack of focus on knowledge generation for heat until recently. As most of the planning, climate adaptation, and resilience documents were released prior to much of this knowledge being available, this impacts upon the municipality's funding cycles, which impacts on the action they are able to take: "*municipalities have a plan for future years, but they made the plan in 2017 or 2018 when heat wasn't such an issue yet, so they don't have it in their governance documents, so they don't have money for it, they don't have a reservation for it*" (Interview R4). In its most recent *Climate Adaptation Strategy* the city has a defined objective to continue to develop its knowledge on the effects of heat on people, infrastructure, and public space, as well as on the most effective measures to be taken. It is also explicit in the potential to update actions in the future as a result of the new knowledge developed. There remains however a lack of evidence for knowledge on impacts across different sectors, like transport.

Knowledge on climate adaptation generally is collected from a variety of sources – from universities, other cities around the world, and from locals. Most interviewees mentioned that in projects, the municipality aims to enhance their information and data with context-specific knowledge by incorporating local insights through 'risk dialogues', a method of public participation that are an additional part of the obligatory climate stress tests. This supporting knowledge is important: "*the stress test results in spatial insight into* *vulnerabilities, without any value judgment. Whether the vulnerabilities are actually a problem becomes clear during the risk dialogue. This is a discussion between the parties involved about climate adaptation, in which it is determined whether the potential vulnerabilities resulting from the stress test are a problem and should be acted upon*" (Ruimtelijke Adaptatie, 2020c; quote translated to English). However, evidence of both qualitative and quantitative knowledge of the impacts of heat across sectors and levels is lacking.

6.1.2 Preparedness and Planning

Scoring

Rotterdam scores very weakly for this principle, as although an emergency response and management plan for the risk of heat is in place, it is only at a national level. Whilst targeted risk communication exists, the public are not fully aware of their responsibility: awareness of heat risk is low, as is engagement in climate adaptation efforts generally. However, improving communications is a strong focus of plans, a local emergency response and management plan is in development, and it is possible that risk dialogues will improve awareness further. Plans therefore indicate a strongly positive effect on this principle.

Elaboration

The chain of communication structure of the 2016 *National Heat Plan* allows different institutions to pass down warnings and information to relevant actors – including to health institutions and subsequently those who work with vulnerable groups, including both caregivers and volunteers. There is however no obligation in the *National Heat Plan* for institutions to implement specific heat protocols. However, despite the activation of this plan almost annually since its inception, Dutch citizens' awareness of the threat of heat remains low (Mees et al., 2015).

A localised heat plan is still in writing, but the aim is to focus on behaviour change and targeted communications to vulnerable groups (Interviews R4, R1). For example, part of the preparation communications will involve television adverts, as this is a form of media used mostly by the elderly (Interview R4). There is also an awareness that the local heat plan needs to function on an operational level, by being locally relevant. To ensure this, information is being gathered on a neighbourhood scale: as stated by interviewee R4 who is working on the plan: "*you don't want to have a plan that's mostly in government. It's not going to work. You want to ensure your actions are delivered to vulnerable people*".

Other communications exist beyond the *National Heat Plan* and the imminent local iteration. Rotterdam, along with other cities like Paris and Athens, has offered a public app since 2018 called Extrema, that shows personalised heat risk on the basis of current weather conditions, age, gender and state of health, as well as enabling preparation by showing cool spots and drinking water points in the city and advising on measures to take (City of Rotterdam, 2019). No evidence was found on the effectiveness of this app, potentially due to its only recent implementation.

Although involvement in collaborative 'risk dialogues' does enhance *preparedness and planning* across stakeholders (Interview R5), the level of public awareness of extreme heat is currently very low, as mentioned by multiple interviewees. The 2019 *Climate Adaptation Strategy* refers to this problem and the significant need to improve it, as well as improve public interest and involvement in climate adaptation generally. A key reason highlighted for this need is the fact that 60% of Rotterdam is privately owned (City of Rotterdam, 2019) – the 2013 *Climate Adaptation Strategy* states that private residents need to understand their responsibility, and *Weatherwise* builds on this (key actions as a result would involve, for example, a greater proportion of greenery in private gardens in place of paving). Increased public awareness and involvement is also linked to other resilience principles including *diversity*, *flatness*, and *high-flux*, and thus has significant consequences for reducing vulnerability.

Other important recipients of effective communications beyond the general public are visitors and businesses: "*initiating and maintaining a dialogue with all these different groups and collecting their views, ideas, insights and stories requires differentiated communication*" (City of Rotterdam, 2019, p.15). Rotterdam therefore plans to create a targeted communications and marketing strategy for climate adaptation that engages all these groups. A focus is on communicating enjoyment of being involved in actions, to make participation more appealing and inspiring.

6.1.3 Homeostasis

Scoring

The integration of heat into other sectoral programs and policies is <u>weak</u>, in part due to lack of understanding of sectoral interdependencies and cascading impacts. However, there is an awareness at the municipal level of the need to account for this, with enhancing communication channels and increased use of risk dialogues likely to improve this. The impact of plans in the future is therefore likely to have a <u>positive</u> effect on this principle.

Elaboration

This principle is less clearly deduced and refers to the strategic management of feedbacking variables. This is operationalised as effective integration of climate adaptation into other policy areas and sectors (ensuring cross-sectoral understanding of risk and impact and implementation of measures to account for this); integrative policy processes to ensure equitable and inclusive benefits (thus reducing negative feedbacks down the line); and maintenance of ecosystem services (the original manager of feedbacking variables).

The main aspect regarding *homeostasis* that Rotterdam focuses on is integrating the issue of heat (as well as other climate adaptation themes) into other sectoral programs and policies, for example in urban development, management and maintenance of public areas, and private area development and construction. The 2019 *Climate Adaptation Strategy* commits to including regulations for heat-resistant construction in the designs for area development and public space, and to invest in cooling measures in public space planning as standard. These regulations are also set to be included in the city's public space design guidance document, 'Rotterdam Style'. Furthermore, the 'risk dialogues' that must be pursued with a variety of stakeholders are an important way which equity and inclusiveness is integrated into policy and design processes.

However, integration between sectors and city departments is also one of Rotterdam's biggest challenges. There is much less focus on cross-sectoral impacts in Rotterdam than London and thus little evidence for a quantitative understanding of the impacts of heat on other sectors, which would encourage further integration. There is an agreement among most of the interviewees that for the issue of heat, a social focus is required as well as technical – the two main sectors focused on for the issue of heat are usually health and urban development, and it has been found that often these two sectors do not interact, resulting in deficiencies (Interviews R2, R4, R5). They cite the need for people within departments to have the know-how to put the issue on the agenda, but they also agree that such cooperation and awareness is currently low for the issue of heat, which limits this. The 2019 *Climate Adaptation Strategy* advocates for better integration internally within the municipality and for good communication channels to permit this: "*climate-adapting action and resilience must be in the DNA of everyone who champions the city's public space and adaptability. We will therefore actively inform colleagues about Rotterdam Weatherwise and particularly about their role within it*" (p.51).

Ecosystem services that regulate heat are important, especially in urban areas. Well maintained, biodiverse green and blue infrastructure help to absorb heat and reduce cascading impacts like worsened air quality, drought or flooding (i.e. due to impervious surfaces like heated, hard-packed earth). Rotterdam already has a strong focus on maintaining such ecosystem services due to their importance for mitigating flood risk, and this benefit passes on to mitigating extreme heat.

6.2 Capacity to Absorb

Rotterdam's key focus within the capacity to *absorb* is that of enhancing *robustness*, primarily through the existence of green and blue infrastructure aimed at flood risk management, which has the co-benefit of also addressing extreme heat. *Diversity* across means, institutions, stakeholders is identified as something that is needed, but it is unclear how this will be addressed. *Redundancy* is low.

Table 8 provides an overview of the assessment of each principle, scored against the operationalisation of urban resilience for the threat of heat detailed in Table 4. The following sections expand on this in further detail.

Table 8: The score per principle for both current practices and future practices as indicated by adaptation and resilience plans.

Principle	Current practices	Why?	Plans	Why?
Robustness & Buffering	+	Maintaining robust infrastructure key element of climate adaptation efforts, resulting in a significant focus on green and blue infrastructure.	+	Focus on green and blue infrastructure to continue in future.
Diversity	0	Better than in the past due to increasing awareness of the threat, but barriers still exist.	0	Unclear whether this will be addressed effectively by plans.
Redundancy	--	Redundancy for the threat of heat barely addressed.	0	Unclear whether this will be addressed effectively by plans.

6.2.1 Robustness and Buffering

Scoring

Robustness and buffering is currently strong in Rotterdam, due it being to the historical focus of the city's climate action and adaptation policies directed at water management for flood risk. As a result, green and blue infrastructure is already a significant measure, to which heat has been attached. Future planning seeks to expand on this infrastructure thus having a positive effect on this principle. Other policy, spatial, and infrastructural measures are less often referred to.

Elaboration

Spatial and infrastructural measures, primarily green and blue infrastructure, is a significant measure in Rotterdam. Rotterdam has a strong tradition of robustness, as a result of the primary focus on water management as its main climate mitigation and adaptation issue. In the various climate adaptation strategies, maintaining this robustness forms the heart of the strategy. For heat, this means that buffering capacity is enhanced through linking heat to the pre-existing green and blue infrastructural measures that tackle flood risk. The aim of enhancing this infrastructure was embedded in the 2013 *Climate Adaptation Strategy* and has been further committed to in the most recent strategy from 2019.

Heat is explicitly linked to these measures in the strategies and by the interviewees and involves incorporating more greenery particularly in more vulnerable areas (i.e. in more paved and densely built areas, and in areas with a larger presence of vulnerable groups). The municipality aims to add 20 hectares of green space by 2022 compared to 2018 (City of Rotterdam, 2019). This also relies on the communication link with communities and individuals, who are encouraged to make the changes to their own properties through subsidies and incentives – primarily through removing paving and installing green roofs. In public areas, increasing green and blue infrastructure is linked to replacing standard paving with permeable paving, enhancing green spaces in the city (parks e.g. the *Dak Park*, cycling and walking routes, street greenery, green roofing and facades on public buildings) and incorporating more water features (water squares, fountains, the *Blauwe Verbinding* – Blue Corridor) – all with the additional aim of enhancing city attractiveness and liveability. There is additionally a recent focus on climate-resilient schools and sports pitches. The 2019 *Weatherwise* strategy aims to create a plan that helps schools financially and practically with modifications to their mostly paved schoolyards.

Beyond greening, other spatial and infrastructural measures that enhance robustness to heat are more vaguely referred to. There is a continual commitment in the plans to incorporating heat-proof measures in all new construction and design, with the 2013 *Climate Adaptation Strategy* listing white as well as green roofs, easy-to-open windows, sun blinds, insect screens, improving building insulation, and ensuring that bedrooms are situated on the lower floors and on the north sides of buildings as examples of measures beyond green and blue infrastructure. *Weatherwise* further details that there must be "*sufficient cooling available in homes, businesses and the public space during heat waves*" (p.31). However, the interviewees focused much more on green and blue infrastructure with very little discussion of these other elements. Despite this it was noted that such measures are more prevalent in the Netherlands than the UK – "*this is* *something I found fascinating – you don't see awnings on buildings in the UK, whereas here [the Netherlands] they're everywhere*" (Interview P6).

6.2.2 Diversity

Scoring

For the threat of heat, the current situation is <u>neutral</u> – whilst diversification of resources, means, institutions, and stakeholders is growing, there are still significant barriers to this principle. There is a sense that in the future this will improve due to increasing awareness of the threat, but it remains unclear as to whether this will enhance this principle – plans thus have a <u>neutral</u> effect.

Elaboration

There is not a great cross-departmental awareness of the threat of heat within the municipality (Interviews R1, R3, R4), resulting in a lowered diversity of departments coming together to tackle the problem, and thus a lower diversity of resources and knowledge. There is however a sense among all interviewees that this is improving. For example, interviewee R1's position, whilst relatively new, is in the physical domain, focusing on climate adaptation within the municipality for the threats of heat and drought, and interviewee R4's position is in the social domain within the municipal health services, and has expanded to include a greater focus on heat. They work together, with the provincial level of *Zuid-Holland*, and with other relevant actors.

Rotterdam aims to work with a greater diversity of stakeholders for the threat of heat: urban planners, city and social development departments, water boards, health professionals, district councils and committees, social housing corporations, citizens, and community organisations. The aim of this, for example through the risk dialogues, is to "*select together with stakeholders what to do*" (Interview R5): to better understand local context, local needs, and a range of relevant perspectives to create a holistic view of the problem. As stated by interviewee R4, "*you want to work on issues with people from all kinds of backgrounds – not only physical or only social but put it together. Otherwise it's only half a plan. It's a shame it's not working like this already, because it has to be more integral*."

The community connection, whilst identified as important across interviewees and plans assessed, is lacking. This lack of diversity in stakeholders is a result of communication mismatches, which impacts upon not only on the diversity of response measures but also on justice-related aspects of who actually benefits from them. As stated by interviewee R2: "*when I was speaking to them [the municipality] they were saying yeah we're trying to speak to communities, but we don't know how, and there's all these cultural issues, different expectations, different interests, just mismatches in understandings. Also – who is the community? So, I think they're thinking about these things, but there's still not really a way to do that*."

Functional diversity is relatively high due to the range of measures taken for water management that also work for the issue of heat. However as discussed in 6.2.1, this is mostly limited to green and blue infrastructure, and does not really include other measures in the built environment or within buildings. The main focus of the 2013 *Climate Adaptation Strategy* was large-scale infrastructural climate adaptation measures in the public space, but the 2019 *Climate Adaptation Strategy, Weatherwise,* aims to diversify its focus, expanding attention to include small-scale measures at the street level and on public and private land.

6.2.3 Redundancy

Scoring

The current level of *redundancy* for the threat of heat in Rotterdam is very weak. There is little knowledge on systems and functions impacted, and there are few formalised roles aimed at the threat and thus little overlap. Future planning has a neutral impact on this principle as the impact cannot be defined.

Elaboration

Redundancy is conferred if there is space system capacity: if functions of systems and system elements are shared, so one can pick up the slack if another fails. Despite high levels of redundancy to other climate risks like flooding due to the variety of measures pursued, Rotterdam has not well defined the impacts of heat on different system functions (e.g. power outage, loss of worker productivity, disruption to drinking water supply), and so there is little evidence of actions to address this. The other aspect of *redundancy* is overlapping governance responsibilities. Response organisations and the roles to be taken in a heatwave are referred to in the *National Heat Plan*, and this is likely to also be included in the local heat plan when published. Beyond this, most interviewees refer to the lack of ownership and awareness regarding the issue of heat, resulting in a lack of formalised roles and responsibilities directed towards the threat, and therefore a lack of overlap can be deduced.

As discussed in 6.1.3, the integration of heat into other sectors is weak, and thus does not account for a lack of overlapping governance roles for the threat of heat. *Weatherwise* does discuss the impact heat has on the opening and closing of bridges which impacts on city accessibility, but the measures to address this focus on heat-resistant construction and design – i.e. improving *robustness* of infrastructure – rather than finding alternative ways to maintain accessibility should the bridges break down, which would enhance *redundancy*.

6.3 Capacity to Recover

Whilst Rotterdam is governed in a decentralised nature, bureaucratic governance systems remain which limit the ability to which resources and information can quickly flow throughout the system. Community participation and partnerships is a strong focus of improvement.

Table 9 provides an overview of the assessment of each principle, scored against the operationalisation of urban resilience for the threat of heat detailed in Table 4. The following sections expand on this in further detail.

Table 9: The score per principle for both current practices and future practices as indicated by adaptation and resilience plans.

Principle	Current practices	Why?	Plans	Why?
Flatness	+	Decentralised governance with strong focus on citizen participation.	+	Focus on broad and diverse participation in plans.
High-Flux	0	Strong partnerships lacking at the community level, resourcefulness limited.	0	Focus on increasing partnerships but not on addressing structural limitations.

6.3.1 Flatness

Scoring

Rotterdam currently has a strong focus on enhancing participation in climate adaptation and resilience work within a decentralised governance system. Plans aim to continue this and enhance *diversity* of participation as discussed in 6.2.2, indicating a positive effect on this principle.

Elaboration

As discussed, Rotterdam is currently placing a heavy focus on improving the inclusion and participation of citizens in its decision making processes and public space design – through risk dialogues and through communicating the importance of individual awareness and involvement in climate adaptation. There is a large focus in the *Resilience Strategy* of enhancing citizen self-reliance and skill set, with a recognition of changing the role of government towards facilitation: "*The city recognises that in order to further the engagement and mobilization of citizens there is a need for a shift from top–down city level and framework approaches to bottom-up interests and initiatives at the citizen and neighbourhood level*" (p.99). As further indicated by both the *Resilience Strategy* and multiple interviewees, the municipality also aims to create more collaborative networks and platforms of citizens, institutions, businesses, and government to ensure wider knowledge sharing, as well as to further decentralise governance by enhancing organisation, effectiveness, and citizen participation within district-level activities. This is all supported by the Netherlands operating at a decentralised level anyway, with a strong tradition of consultation at different government levels (Mees & Driessen, 2011).

These aims are all at the level of general climate adaptation, and thus are likely to enhance *flatness* for the threat of heat. However, if heat is not explicitly put on the agenda in these networks, risk dialogues, or communications, low levels of awareness of heat specifically will remain despite high levels of citizen autonomy in general.

6.3.2 High-Flux

Scoring

Whilst Rotterdam maintains strong networks on a regional, national, and international scale and is known for being resourceful, partnerships at the community level are lacking, with bureaucratic administration systems preventing quick movement of information and resources. This principle therefore scores neutrally for the current situation. Whilst there is a focus on enhancing this in plans, this effect is scored as neutral as there is doubt as to the effect if bureaucratic ways of working are not addressed.

Elaboration

Rotterdam is part of numerous networks, on national, European, and international scales – for example Knowledge for Climate (*Kennis voor Klimaat*), C40, 100 Resilient Cities, and Connecting Delta Cities. Rotterdam is an active partner in many of these networks and prides itself on its participation and its status as a front-runner. Knowledge and financing are the key resources interchanged in these networks, with

Rotterdam often the provider of flood risk management knowledge and technology and the receiver of lessons regarding other climate adaptation and resilience related themes.

At a local level, Rotterdam has strong partnerships at the level of businesses and institutions, for example Climate Action Services (CAS), Rotterdam Resilience Centre, local universities and research institutions (Interview R5). However, strength in community partnerships and between these and businesses and institutions is lacking. As part of the communication strategy Rotterdam is committing to detailed in 6.1.2 in order to enhance community awareness and connection (which would also enhance the principles of *anticipation and foresight*, *preparedness and planning*, *diversity* and *flatness* as discussed), the municipality is planning to create a digital and physical platform for people to meet, be inspired by one another, and to exchange knowledge.

Structures within the national level climate adaptation plans help to ensure that a standardised process is filtered down to the municipal level, and ensures different municipalities are well connected. This helps, for example, to connect municipalities that are researching similar problems or implementing similar solutions, so that work is not repeated and resources are used more efficiently. However, although these structures exist there is doubt that they are as effective due to the bureaucratic nature of traditional governing systems: "*the capacity to recover: this in my view is missing. Decision-makers are of course resourceful and knowledgeable, but there is no widespread access to information and no quick movement at all – it's very bureaucratic*" (Interview R2).

Whilst the above is not linked explicitly to the threat of heat, it relates to climate adaptation and resilience more generally.

6.4 Capacity to Adapt

Rotterdam is a pioneer in the realms of climate adaptation and resilience, but there is room for improvement regarding implementing lessons learned from the many projects and experiments at an operational level. For heat especially, this is lacking due to the relative newness of the topic. No-regret measures are prioritised, resulting in linkages of heat measures with flood risk management measures, but *flexibility* at an institutional level requires improvement.

Table 10 provides an overview of the assessment of each principle, scored against the operationalisation of urban resilience for the threat of heat detailed in Table 4. The following sections expand on this in further detail.

Table 10: The score per principle for both current practices and future practices as indicated by adaptation and resilience plans.

Principle	Current practices	Why?	Plans	Why?
Learning	0	Known for strategy and innovation but lacking in learning and implementation of new knowledge.	+	Expanded focus on pilot projects for heat risk and subsequent learning and upscaling.
Flexibility	+	No-regret measures prioritised.	+	Weaknesses in institutional flexibility variously addressed in future planning.

6.4.1 Learning

Scoring

Rotterdam is known for its innovation and 'learning-by-doing' approach and is strong at the strategic level. However, the score for this principle is <u>neutral</u> because the necessary reflection on what is learnt, and subsequent inclusion and implementation of new knowledge is lacking. Experimentation and learning for heat generally are lacking, but this is a focus of future planning alongside a greater focus in scaling-up, having a <u>positive</u> effect on this principle.

Elaboration

Experimentation and innovation are a strong part of Rotterdam's climate adaptation history, being known internationally as a pioneer in flood risk management and an exporter of knowledge on the issue. Rotterdam is well known for 'doing': "*for starting working: for not only talking but also working*" (Interview R5), and "*in Rotterdam they say 'don't talk just do', and that's a very Rotterdam way of looking at life*" (Interview R1). However, the city struggles with monitoring and reflexively learning from its own work, and as a result scaling up and mainstreaming: "*They're also always about reinventing strategies but that's not what it's about. … the next step isn't necessarily doing another strategy it's about doing the learning from it. What are you learning? They have lots of knowledge about their conditions but not about what they are facing in terms of implementation*" (Interview R2).

This is an issue in both directions: lessons from pilot projects and experiments don't trickle down and become mainstreamed into other projects, but equally feedback on projects from citizens and stakeholders doesn't always trickle up – "*there are no spaces for learning from what is happening in these experimentations. There is a different way communicating with stakeholders and citizens. But also creating organisational space to come together once a week/month to step back from the doing and reflect on it, on various opportunities, how lessons from a particular experiment can be integrated as a 'proof of concept'*" (Interview R2). This links to the difficulties Rotterdam has with awareness and engagement of citizens as discussed in 6.1.2 and 6.2.2.

This is especially so for the threat of heat, which is a relatively new topic – Rotterdam is not yet at the stage of implementing pilots and projects specifically for heat (they are still in the information gathering stage) so the monitoring and indicators related to this threat are lacking (Interview R1). However, it is within the planning to improve this, with recognition that more knowledge needs to be developed and implemented on the impacts of heat and effective solutions. For example, the city plans to implement 'example projects' for more underexplored topics like heat that can act as both an 'icon' – maintaining Rotterdam's international image – and as an inspiration for citizens on climate adaptation – to enhance the community participation that is lacking (City of Rotterdam, 2019). The 2019 *Climate Adaptation Strategy* points out that particular attention will be paid to learning from these projects and scaling up – which points to an attempt to take account of Rotterdam's less well-developed ability to learn from its many pilot projects and experiments.

Rotterdam is practiced at learning from others – city-to-city learning is enhanced by the numerous multi-level networks of which Rotterdam is part (Ilgen, Sengers, & Wardekker, 2019). On a national level, learning between cities is well established. For heat, the Amsterdam University of Applied Sciences has created tools and guidelines for adaptation based on research in the city, as well as performed research on the impacts of these tools and guidelines[3]. Some of this work has been taken up into the National Spatial Adaptation plan and its National Climate Atlas for the climate theme of heat (Ruimtelijk Adaptatie, 2020a), and a lot of the work will be used in the creation of Rotterdam's local heat plan (Interview R4).

Learning at a national level also filters down – the *National Heat Plan* is assessed after each activation to see where improvements could be made. Its warning thresholds have been updated to reflect new knowledge on heat and an increasing frequency of heatwaves

6.4.2 Flexibility

Scoring

The prioritisation of no-regret measures confers significant *flexibility*, resulting in a current strong emphasis on this principle. There is room for improvement in terms of enhancing institutional flexibility, which is linked to good communications with a range of actors (*preparedness and planning*), *diversity*, *flatness*, and *high-flux*. The weaknesses in these areas are addressed by the various plans, thus having a likely positive effect on this principle in the future.

Elaboration

Flexibility in Rotterdam for the threat of heat is relatively high due to its prioritisation of 'no-regret' measures, (City of Rotterdam, 2013) 'reinforcing' measures (City of Rotterdam, 2019), and 'synergies' (City of Rotterdam, 2016) – i.e. those measures that address multiple climate themes, have additional co-benefits, and are likely to continue creating positive benefits into an uncertain future. The city's focus on green and blue infrastructure is the main no-regret measure pursued: effective for the issues of flood risk management and heat and having societal co-benefits such as improved liveability and wellbeing within the city. Another example being prioritised is multifunctional roofs – combining water retention facilities on roofs with cooling measures through green roofing, with an additional co-benefit of solar panels being installed on such roofs having higher yield (City of Rotterdam, 2019). *Diversity* and *redundancy* in the measures taken to enhance the capacity to *absorb* contribute to enhanced *flexibility*.

On the other hand, there are some potential negative future consequences of this focus on green and blue infrastructure. The 2019 *Climate Adaptation Strategy, Weatherwise,* for example states that more greenery in a city requires a higher water demand, which intensifies the effects of periods of drought. The impacts of periods of heat on this factor is important, but not discussed.

Institutional flexibility is likely to increase as Rotterdam attempts to move further towards a decentralised facilitating role that encourages citizen engagement and autonomy. The *Resilience Strategy* and *Weatherwise* recognise the need for improvement in this area, as also discussed in 6.1.2, 6.2.2, and 6.3.

[3] Available at https://www.hittebestendigestad.nl/

Flexibility in spatial planning is more difficult to assess – there is little emphasis or details on flexible structural modifications beyond committing to ensuring all new builds are built in a climate-adaptive and heat-proof way (City of Rotterdam, 2013; 2019).

6.5 Overview

An overview of the resilience emphases for Rotterdam is presented in Table 11. Whilst for other climate risks (like flooding) it would be easy to distinguish Rotterdam's strengths (for example its innovative focus, and thus *learning,* and the variety of flood risk measures, and thus the capacity to *absorb*), resilience strengths for the threat of heat are less easy to define. This is primarily due to a lack of focus on the threat of heat until recently, and heat having less of a negative impact in Rotterdam overall than in London. This indicated most clearly by its **greatest weakness in the capacity to *prepare***. Most of the measures to address heat have been linked to efforts to address flood risk – so whilst a significant amount of blue and green infrastructure strengthens *robustness and buffering*, this focus limits the range of other measures pursued, thus weakening *diversity* and *redundancy* and **weakening the capacity to *absorb*** overall.

Plans and policies assessed place a much greater emphasis on heat, indicating and increased strength in most of these principles in the future. However green and blue infrastructure remain the primary focus of measures, so the capacity to increase emphasis on all aspects of the capacity to *absorb* are not indicated.

Table 11: Overview of the scores per principle for both current practices and future practices in Rotterdam, as indicated by adaptation and resilience plans.

Capacities for Resilience	Principles	Current Situation	Future Situation
Capacity to **PREPARE**	Anticipation & Foresight	-	+
	Preparedness & Planning	--	++
	Homeostasis	-	+
Capacity to **ABSORB**	Robustness & Buffering	+	+
	Diversity	0	0
	Redundancy	--	0
Capacity to **RECOVER**	Flatness	+	+
	High-Flux	0	0
Capacity to **ADAPT**	Learning	0	+
	Flexibility	+	+

7. CASE EVALUATION: LONDON

Chapters 6 and 7 seek to answer RQ3 – the extent to which the resilience capacities are expressed in Rotterdam (Chapter 6) and London (Chapter 7) regarding the threat of heat. Each principle is scored according to the scale in Table 3, and thus the emphasis of each city on each principle is assessed in terms of current practices, and future practices as indicated by the adaptation and resilience plans assessed. An overview of each capacity is presented first, followed by a more in-depth presentation of the results per principle. The results of this assessment for London is illustrated in Table 16.

7.1 Capacity to Prepare

Heat has been higher on the agenda for a longer time in London than in Rotterdam, and this awareness, along with London's emphasis on emergency planning and response infrastructure, has resulted in improved knowledge of the threat and its cross-sectoral impacts, as well as supported its better integration into other sectors and levels. This capacity is therefore relatively strong, however there is much room for improvement, particularly in communicating the risk. Efforts for improvement are well considered within future planning.

Table 12 provides an overview of the assessment of each principle, scored against the operationalisation of urban resilience for the threat of heat detailed in Table 4. The following sections expand on this overview in further detail.

Table 12: The score per principle for both current practices and future practices as indicated by adaptation and resilience plans.

Principle	Current practices	Why?	Plans	Why?
Anticipation & Foresight	++	Heat risk and impacts are specified and focus on vulnerable groups, infrastructure, and cross-sectoral impacts.	++	Further modelling and research to establish quantitative thresholds, indicators, and cross-sectoral impacts is planned.
Preparedness & Planning	-	Low public awareness of risk and thus low large-scale preparedness, low effectiveness of emergency planning.	+	Focus on enhancing risk communication to public.
Homeostasis	+	Established focus on integrating heat into different sectors and levels.	+	Continued focus on improving this integration in future.

7.1.1 Anticipation and Foresight

Scoring

London has focused for longer than Rotterdam on urban heat risk, its impact and vulnerabilities, and as a result knowledge is much more specified, and covers multiple sectors. As result, this availability of quantitative data and mapping demonstrates a current very strong emphasis on this principle. Future work aims to develop further knowledge on quantitative thresholds, indicators, and cross-sectoral interdependencies, indicating a strongly positive effect on this principle.

Elaboration

Data and mapping for the threat of heat and its associated impacts and vulnerabilities is stronger in London than in Rotterdam, as the topic has been higher on the agenda for longer. Most interviewees referred to the fact that much of the research performed so far has focused on overheating risk and vulnerability within buildings: including work on energy efficiency (e.g. regarding mechanical air conditioning use now and into the future and efforts to reduce it in favour of more passive techniques), assessments of housing stock maladaptation in terms of building type and vulnerability, and climate adaptation of building stock (GLA, 2011; Interviews L1, L2, L3). There is a focus on critical vulnerable infrastructure like schools, hospitals, and care homes, with commitments that future work will focus further on mapping risk for the most vulnerable groups (GLA, 2011).

Research efforts have been multi-sectoral – data and mapping have been created in collaboration with academic researchers, boroughs, the Greater London Authority (GLA), faith-based organisations, community organisations, epidemiologists, and the building and infrastructure sector (GLA, 2020a; Interview L2). Whilst not using PET methodology, work done to map the heat risk takes account of the variety of factors that influence the subjective experience of heat, with the 2011 *Climate Adaptation Strategy* highlighting a 'triple jeopardy' of factors: high UHI intensity; poor thermal performance in buildings; and high personal vulnerability.

Air pollution is a big issue area in London, and due to the links between air temperature and air quality, research on exposure to air pollution has also considered heat impacts, especially on more vulnerable groups and their housing. New research on indoor environment quality, including heat, and its impacts in schools on children's cognitive function is being undertaken, again looking at existing building stock and testing this against various retrofitting interventions and risks, with the aim of eventually enhancing climate resilience in schools (Interviews L1, L2).

The above demonstrates London's strong focus on improving its monitoring and modelling of climate risks generally, and understanding their impacts in a cross-sectoral, integrated way. As part of the 2018 *Climate Adaptation Strategy,* aims include establishing threshold values for disruption in various sectors; setting monitoring baselines; establishing data collection to monitor the impacts of adaptation efforts; establishing relevant indicators for resilience; and performing more locally specific modelling of UHI on critical infrastructure and vulnerable groups. The 2018 *Climate Adaptation Strategy* aims to better include pre-existing socio-economic data within all this – for example including as within indicators for resilience the proportion classed as socially isolated, or the proportion of non-English speakers. Like Rotterdam, layered mapping tools are used in London for a range of interconnected issues – for example new tools like London's green infrastructure challenge map has layers that include the UHI, green infrastructure, sustainable urban drainage, and mitigation factors (Interview L1).

The 2020 *Resilience Strategy* seeks to improve the knowledge base on the above in relation to the condition and performance of infrastructure assets, to help predict and prevent failures, and on cascading impacts. For this the *Resilience Strategy* promotes more innovative usage of existing data to gain integrated knowledge on infrastructure interdependencies. This work aims to build on existing cross-sectoral work, for example London Resilience Partnership's existing 'Anytown' project, which helps identify interdependencies and potential cascading failures from disruption to infrastructure (GLA, 2020a).

The cross-sectoral use of this data is also highlighted – for example to develop better guidance on enhancing resilience and climate adaptation for infrastructure and infrastructure providers (this is a particular focus for the threat of heat), local authorities, and the business community. Additionally, the aim is for this work to enable the GLA to work more closely with such sectors in order to identify priorities for investment, something that providers have established as needed for enhancing resilience (GLA, 2020a).

7.1.2 Preparedness and Planning

Scoring

London scores weakly for this principle because like Rotterdam, although emergency response and management plans are in place, they are not judged to be particularly effective. However, unlike Rotterdam there is well-established local level planning in place for this threat. There is not an observable sense among interviewees or plans assessed of a need to improve the communications of the emergency response plans to enhance public and practitioner awareness, however other risk communications are set to be improved, with plans thus having a positive effect on *preparedness and planning*.

Elaboration

As discussed in 5.2, London has a historic focus on emergency preparation and response infrastructure, within which the threat of extreme heat has been included. Planning and preparation are thus a natural part of the city's general strategy. The alert system of the *National Heat Plan* and its local implementation are specific to London and its affected sectors and pay particular attention to messaging for at-risk groups. However, like the Dutch *National Heat Plan,* there are questions regarding its actual effectiveness on communicating risk to care practitioners, its ability of reaching high-risk groups, and the general awareness of the plan or its local implementation among both the public and care practitioners (Zaidi & Pelling, 2015; PIRU, 2019).

It is acknowledged in the climate adaptation and resilience plans assessed that risk communication in general can be improved. London aims to enhance this through social media to the public, as well as more formally by bringing together all the organisations with risk communication responsibilities under one umbrella. This has benefits: "*at present different agencies own different risk communication responsibilities: once this is overseen by an LRP-wide [London Resilience Partnership] approach, it will be possible to ensure collective support for communications, extend the reach of messaging and identify where gaps may exist*" (GLA, 2020a, p.37).

The development of a 'cool spots network' (a collaborative multi-stakeholder project establishing cool areas within heat hotspots) will be supported by a public communications plan, containing information about their location and accessibility, and tips on keeping cool. These communications, as well as communications surrounding extreme heat more generally, are to be directed towards a wide audience: "*we felt the messaging was very clear in terms of at-risk groups and we were doing a lot with at-risk groups. But we also wanted to do things for people that just get caught up in a heatwave in London – just going to* *work, or going to a medical appointment, or being out with friends or shopping etc. So, this project is designed to created cool spots where people can just go and take respite for a short period and then just go on their business*" (Interview L1). The city is also set to release some guidance aimed specifically at schools to manage short-term and long-term actions for climate resilience.

7.1.3 Homeostasis

Scoring

London currently scores strongly for this principle: whilst lacking in some areas, there is a much greater focus on integrating heat in various areas and levels than Rotterdam, although processes can be more integrative. Future planning does include consideration of measures that would enhance *homeostasis*, like improving regulations and enhancing collaborative working, and so are likely to have a positive effect on this principle.

Elaboration

Like Rotterdam, the main aspect regarding *homeostasis* that London focuses on is integrating the issue of heat into other sectoral programs and policies, but London has greater strength in this due to a better understanding of the impacts of heat on other sectors.

BOX 41: COOLING HIERARCHY

The cooling hierarchy is:

- minimise internal heat generation through energy efficient design
- reduce the amount of heat entering a building through orientation, shading, albedo, fenestration, insulation and the provision of green roofs and walls
- manage the heat within the building through exposed internal thermal mass and high ceilings
- provide passive ventilation
- provide mechanical ventilation
- provide active cooling systems

Figure 6: The Cooling Hierarchy from the London Plan, as republished in the GLA's 2018 *Climate Adaptation Strategy*.

Regulation is used to integrate heat mitigation efforts into the building sector: developers are required to follow the 'Cooling Hierarchy' in the London Plan (GLA, 2016), in order to reduce building overheating and to reduce its contribution to the UHI effect. Additionally, a tool is being developed that can assess planning applications in terms of their contribution to heat both internally and externally, whether the development is going to contribute to the UHI, and what kind of mitigation factors can be included. This is an example of assessing heat from different spatial scales – something that exists more so in London than in Rotterdam.

However overall, there is a significant lack of regulatory framework: "*the most important thing is that currently there is a lack of building regulations around the mitigation of indoor over-heating. There is one line in one of the parts of the UK building regulations talking about solar protection but there's not clear guidance on how to achieve this. The building regulations are currently being revised so I've been told that there might be more inclusion of indoor overheating in future versions*" (Interview L2).

Furthermore, working in a more integrated way is identified as something that needs to be improved, but is on the agenda and present in London's various plans: "*I think we're getting better at it, we're trying to look at it from a London IIA [integrated impact assessment] way. The new green deal which we're going to be working on … its key principle is about collaboration and integration*" (Interview L1). Working groups on heat do tend to involve people from multiple sectors – with the building sector, public health, national and local government, academia and others represented. However, like Rotterdam, general communication horizontally across sectors and vertically across levels needs to be improved.

7.2 Capacity to Absorb

Whilst the knowledge base on the impacts of heat and measures to account for it in London is relatively strong, as observed by a strong capacity to *absorb*, it is not clear the extent to which this knowledge is applied, particularly in terms of system *robustness* and *redundancy*. There is a focus on improving this in resilience and climate adaptation plans, but gaps remain.

Table 13 provides an overview of the assessment of each principle, scored against the operationalisation of urban resilience for the threat of heat detailed in Table 4. The following sections expand on this in further detail.

Table 13: The score per principle for both current practices and future practices as indicated by adaptation and resilience plans.

Principle	Current practices	Why?	Plans	Why?
Robustness & Buffering	0	Knowledge not necessarily implemented in practice.	+	Measures that enhance robustness set to expand.
Diversity	+	Diversification of certain elements is strong but can be improved.	0	Unclear whether plans address the gaps in diversity.
Redundancy	0	Unclear if knowledge on system functions and interdependencies translated in practice.	+	Plans promote investment towards measures that enhance redundancy.

7.2.1 Robustness and Buffering

Scoring

Currently, *robustness and buffering* in London is <u>neutral</u>: guidelines exist for heat-proof design through green and blue infrastructure and other spatial measures, although the knowledge in this area is not necessarily implemented in practice. Future planning focuses on increasing spatial and infrastructural measures, thus having a <u>positive</u> effect on this principle.

Elaboration

A range of infrastructural measures and spatial measures are used in London to reduce impact and risk. The 'cool spots network' aims to be accessible for all Londoners to use during a heatwave to rest, cool down, and access water. The spots will be found in both green spaces (e.g. parks, wooded areas), and public buildings (e.g. retail outlets, places of worship, museums). Green infrastructure is also encouraged and widely implemented throughout London for other reasons, including health and wellbeing, air and water quality, encouragement of more sustainable travel, and biodiversity enhancement (GLA, 2018). For example, the Cross River Partnership is helping implement the Mayor's Healthy Streets initiative, which assesses streets on a variety of indicators to make streets fair, inclusive, and sustainable environments. Heat is addressed within this through encouraging shading and shelter from direct sun and resting places for those with limited mobility (GLA, 2018; Interview L4). Both the 2011 and 2018 *Climate Adaptation Strategies* focus on enhancing green and blue infrastructure, and the 2018 *Strategy* sets out an aim of

London being the world's first ' National Park City': a network of parks, green spaces, gardens, woodlands, rivers and wetlands that cover over 50% of the city's area by 2050 (GLA, 2018).

Use of further spatial and infrastructural measures to tackle heat is encouraged (e.g. through the Cooling Hierarchy) and was mentioned by multiple interviewees, with reducing overheating risk and demand for mechanical cooling in infrastructure through retrofitting and regulations in new developments formed a significant part of the 2011 *Climate Adaptation Strategy*. However, such measures are limited in practice. Despite research being done on effective infrastructural design measures for mitigating heat risk, the knowledge is not necessarily being implemented: for example interviewee L3 discussed the following: "*I think we know that [what is good design for the threat of heat]– that knowledge exists. But I mean we've started to get excited about building things that have just loads of glass – we're going to regret that, if we're not already. In fact, I know of one council in London that have had penthouse apartments in their borough that are overheating, where the owners have said who can we sue because we can't live here. So, we're creating problems*".

However, more work is going into researching a range of measures, particularly for critical infrastructure (e.g. schools, hospitals, care homes). This work is assessing the different types of measures that can be implemented on a short/long-term basis, and their relative cost, looking at both green and blue infrastructure and other infrastructural and spatial measures (GLA, 2018; Interview L1).

7.2.2 Diversity

Scoring

The current situation scores <u>strongly</u> regarding this principle, due to the diversification of institutions and stakeholders that collaborate on the threat of heat. There are areas for improvement, for example in enhancing functional diversity and diversity of measures, however it is unclear the extent to which future planning may address this, therefore scoring <u>neutrally</u>.

Elaboration

London is quite strong at working across sectors, again as part of its emergency response and management, and aims to maintain and increase this. There is a diversity of actors and institutions involved in the *National Heatwave Plan* and its local implementation, as well as involvement of multiple sectors. However, this is mostly focused on the technical side and on the level of experts and policy, and there is an acknowledgment of the need for wider engagement – which would also result in a higher functional diversity.

Stakeholder diversity also arises from the connections the Greater London Authority has with researchers, boroughs, NGOs, community organisations, and businesses. Collaborative work aids in the practical constraints faced on the side of the municipality in terms of time and resources. However, there is also a focus on this in London due to the implication that good engagement and collaborative work results in legitimate, evidence-based policy (Interview L1). Networks such as the London Climate Change Partnership play a role in convening meetings of diverse groups, where knowledge is shared between actors, who then go away and take that knowledge with them into their own work (Interview L3).

London's *Climate Adaptation Strategies* (2011, 2018) demonstrate a focus on a diversity of measures to address the threat of extreme heat, however as discussed in 7.2.1 it is unclear whether this diversity of measures exists in practice.

7.2.3 Redundancy

Scoring

There are few formalised roles for the threat of heat in London, but there is a focus on mapping system interdependencies and cascading impacts, and therefore an awareness of the functions and systems affected. The current situation is however neutral regarding *redundancy*, as it is unclear whether this translates into increased system capacity through overlapping function or governance. This remains a focus as part of the *Resilience Strategy*, with interventions prioritised that increase *redundancy*, so plans have a positive effect on this principle.

Elaboration

Overlapping governance roles for the threat of heat in London have not been observed. Like Rotterdam, most interviewees refer to the lack of ownership and awareness regarding the issue of heat, resulting in a lack of formalised roles and responsibilities directed towards the threat, and therefore a lack of overlap can be deduced. More generally for climate adaptation and resilience, areas of adaptation and mitigation tend to work separately (Interview L1).

To counter disruptions to vital city functions and systems, cascading impacts and infrastructure interdependencies have been mapped as part of the Anytown project. Objectives in the *Resilience Strategy* aim to enhance and further this knowledge and account for it through directing investment towards interventions that have the greatest impacts in terms of *redundancy* and feedback management (i.e. *homeostasis*). This focus includes extreme weather (including the threat of heat) among a wide range of identified shocks and stresses, enhancing resilience overall. The *Severe Weather and Natural Hazards Plan* advises consideration of direct and indirect impacts of hot weather beyond health (e.g. economic impacts, transport infrastructure, power supplies, air and water quality, wildfire, and water shortage), followed by identification of mitigation measures and alternative supplies. The transportation infrastructure is of particular importance to London as an economic centre and commuter city, and thus this has a significant focus in terms of heat impacts. It is however unclear if the above, whilst enhancing *homeostasis* due to assessment and management of feedbacks, actually results in increased system capacity through multiple elements whose functions can pick up the slack if impacted by a heatwave.

7.3 Capacity to Recover

London has a relatively strong capacity to *recover*, with partnerships and networks existing across multiple sectors and levels, and the embeddedness of heat response measures embedded within emergency planning infrastructure, thus contributing to quick mobilisation of resources when required.

Table 14 provides an overview of the assessment of each principle, scored against the operationalisation of urban resilience for the threat of heat detailed in Table 4. The following sections expand on this in further detail.

Table 14: The score per principle for both current practices and future practices as indicated by adaptation and resilience plans.

Principle	Current practices	Why?	Plans	Why?
Flatness	+	Decentralised governance with strong focus on broad participation.	+	Continued focus in plans.
High-Flux	+	Quick mobilisation of resources enabled due to well established emergency response infrastructure.	+	Focus on improving knowledge on sectoral interconnections.

7.3.1 Flatness

Scoring

London has a decentralised governance system allowing authoritative local action and focuses on ensuring broad and inclusive participation in decision-making. *Flatness* in London is therefore strong, and plans aim to enhance the efforts and so have a positive effect on this principle.

Elaboration

Whilst the Greater London Authority (GLA) is the overarching governing body for London as a whole, London's 33 boroughs govern their own communities themselves, meaning local authoritative action can be definitively taken. How the GLA relates to these boroughs is dependent on the mayor and their priorities. The current mayor aims to work in alignment with the boroughs, and thus partnership with them is prioritised (Interview L1). The communication between the boroughs and the GLA is aided by the London Councils, a stakeholder group of the local authorities, and it is an aim of the *Resilience Strategy* to enhance relations between London's various levels of governance and to embed a common agenda for resilience across them all.

Furthermore, as related to the principle of *diversity* in section 7.2.2, London's approach to setting up programmes is broad and participatory: "*my approach is always to get your researchers around the table; to get your boroughs around the table if you're working with the boroughs; and to get the community organisations – the social infrastructure, for example the care home manager; and as far as practicable to get the users involved, so in terms of the care home we can't expect the frail elderly to come to our program advisory board meetings, but we did questionnaires and surveys with them. So, to have the user voice there as well is very important*" (Interview L1).

Networks like the London Climate Change Partnership and the Cross River Partnership also have an important role to play in encouraging participation and promoting autonomous action, primarily through promoting understanding of climate risks, what it means for the actors they work with, and what it is they can do about it: "*we are strongly encouraging stakeholder engagement from community and businesses, and a ground-up approach where businesses or communities feel empowered to go to their local authority and say – we want a parklet [a street space change intervention that involves greening] here, how do we get one*" (Interview L4).

7.3.2 High-Flux

Scoring

London scores strongly for this capacity, due to emergency response infrastructure ensuring a relatively quick response to threats and thus quick movement of information and resources. Plans are likely to positively effect this principle due to continued research on the interconnections between sectors.

Elaboration

London maintains multiple within-city partnerships and networks, sharing knowledge and resources across boroughs and sectors. The city's active presence within international networks like 100 Resilient Cities and C40 further enhances its ability to quickly access resources and share knowledge.

As discussed in 5.2, the national and local plans for heatwaves are set within various emergency response structures. This advance planning enables quick mobilisation of resources where necessary in the event of a heatwave and for communication systems to be quickly triggered. This is again all to be enhanced through the *Resilience Strategy*'s aim of enhancing knowledge of infrastructural interdependencies and cascading impacts.

7.4 Capacity to Adapt

Like Rotterdam, London seeks to be at the forefront of efforts towards climate adaptation and resilience and is similarly engaged in international sharing of ideas and best practices. However, in London there is a greater focus on the operational side than the strategic (as is Rotterdam's focus) with an emphasis on active *learning* from and up-scaling of small-scale projects. London's strength in emergency planning and response has resulted in a focus on shorter term impacts, thus *flexibility* in measures as a result of mid- to long-term planning is not so well established.

Table 15 provides an overview of the assessment of each principle, scored against the operationalisation of urban resilience for the threat of heat detailed in Table 4. The following sections expand on this in further detail.

Table 15: The score per principle for both current practices and future practices as indicated by adaptation and resilience plans.

Principle	Current practices	Why?	Plans	Why?
Learning	0	Strong on small-scale projects but unclear if knowledge implemented in practice.	0	Future planning to continue focus on learning at different levels but unclear if implementation of knowledge a focus.
Flexibility	-	Mid- to long-term planning not so well established.	+	Plans actively seek to address this issue.

7.4.1 Learning

Scoring

Whilst London is not so well known for its innovative experiments as Rotterdam, it has a greater focus on small-scale projects that are operationally successful and can be implemented at a wider-scale. There is a conscious effort for learning from such projects to be distributed, however overall, the extent of active implementation of the range of data on the threat of heat is hard to determine. The current situation therefore scores neutrally for this principle, with the potential impacts of future planning unclear, thus having a neutral effect.

Elaboration

Reflective monitoring is present in London. Like the Dutch *National Heat Plan,* London's implementation of the *National Heatwave Plan* involves significant monitoring and evaluation. Learning from other cities also occurs, especially from those that experience heat on a more routine basis. For example, best practice advice from Portugal and Spain on heat health risks at mass gatherings and associated actions to take has been integrated into the *National Heatwave Plan,* and the Extrema app discussed in 6.1.2 began in Paris and other cities. Networks like C40's Cool Cities network also facilitate exchange of best practice: *"partly in terms of how that affects buildings and vice versa, but also things we can do like opening cool spaces for people and stuff like that. And we've looked over at what other cities are doing like New York, for example with green and white roofs, cool roofs*" (Interview L3). Sharing ideas and *learning* from international best practices remains a focus on the 2018 *Climate Adaptation Strategy* (GLA, 2018).

Innovation for the threat of heat is low in London, for various reasons – there is a lack of capacity to work at the granular scale required for more experimental work, and more broadly, heat is not a policy area for innovation (Interview L1). However, Transport for London is increasingly looking into this area and working more with researchers around more innovative ways of implementing solutions for heat on the underground system (Interview L1).

Some small-scale projects are in place, with active learning occurring in the form of guidance documents and toolkits for wider application. Heat resilience or adaptation tends not to be the primary goal in these projects – for example greening projects or those focused on 'healthy streets', but it is still a benefit (Interview L4). The production of these guidance documents is seen as important: "*Although they have some cost, pilots and trials, relatively small-scale changes to a street – it can be interesting to see how that can long-term shift approaches in different boroughs. It's a lot about learning and moving forward. That's why we try to produce the guidance documents, but also case studies – people want to learn from each other…. A lot of effort goes into creating case studies*" (Interview L4).

However as discussed in 7.2, whilst there is an array of knowledge on the impacts of heat across different sectors and levels, it is unclear the extent to which this knowledge is actively implemented in practice or used to alter regulation and ways of working. Furthermore, it is again hard to distinguish from plans if whether plans will address this issue.

7.4.2 Flexibility

Scoring

Whilst London is good at emergency planning and assessing short-term impacts on critical infrastructure and sectors, its ability to plan for mid-term to longer-term impacts is not so well established. London thus currently scores weakly for this principle, despite the flexibility of small-scale projects. To improve, aims include focusing on longer-term impacts and using the ‘adaptive pathways’ approach for a wider array of climate risks beyond tidal flooding. Plans therefore have a positive effect on this principle.

Elaboration

London currently uses ‘adaptive pathways’ to plan into the future for tidal flood risk (Haasnoot, Kwakkel, Walker, & ter Maat, 2013; GLA, 2018). Adaptive pathways are a flexible decision-making and management plan, as they allow for various scenarios and changing priorities in the future, as well as uncertainty. The 2018 *Climate Adaptation Strategy* sets out an aim for the Greater London Authority (GLA) to identify, alongside the London Climate Change Partnership and critical sectors, further adaptive pathways for severe weather and longer-term climate risks. This approach is also an example of sharing international best practice, as it was developed in the Netherlands for long-term management of the Rhine delta.

The *National Heatwave Plan* involves a phase of long-term planning to reduce risk from heatwaves through integrating the issue across sectors: “*this involves influencing urban planning to keep housing, workplaces, transport systems and the built environment cool and energy efficient*” (PHE, 2018, p.13). The *Resilience Strategy* includes aims to make resilience a central consideration in all infrastructure decisions, and to further build on existing cross-sectoral collaboration.

Enhancing institutional flexibility in decision-making is directly addressed in the *Resilience Strategy,* with the aim of developing more agile governance within the GLA to keep up with the pace and complexity of change. This will take the form of a model pilot for agile governance that “*augments policy making processes to allow for adaptation to rapid change*” (GLA, 2020a, p.66) – it is however vague on the specifics of this.

A fallback is that currently the GLA works with long-term strategy, but climate risks are embedded within the London Resilience Partnership, which works with managing emergency frameworks for risk within a 5-year time period. As a result, longer-term climate risks are not considered within this so ‘long-term’ planning is actually relatively limited. The *Resilience Strategy* aims to address this mismatch by improving engagement between the risk management expertise of the London Resilience Partnership with the long-term policy and strategy of the GLA.

Finally, spatial flexibility is evidenced within the smaller-scale projects that London focuses on are often be flexible in nature. For example, as part of small street space changes temporary ‘parklets’ are being encouraged – small extensions of the pedestrian pavement onto the road which are usually covered in greenery. In terms of heat risk, there are useful in that they meet some of the Healthy Streets indicators as discussed in 7.2.1, through providing ‘a place to stop and rest’ (useful for those with mobility issues like the elderly) and shade and shelter. The flexibility of such local, small-scale interventions have the benefit of allowing a neighbourhood to experience something different, and potentially contributing to longer-term shifts: “*because they are temporary and flexible …they can be seen as a trial to see how areas change*” (Interview L4).

7.5 Overview

An overview of the resilience emphases for London is presented in Table 16. There is a clearer indication in London than in Rotterdam on the resilience pathways taken by the city, due to a more easily defined emphasis on certain principles. Heat has been on the agenda for longer in London, and so there is a significant amount of data and mapping of heat, its impacts, and vulnerabilities resulting in strong *anticipation and foresight*. This, in addition to the city's focus on emergency planning and response, indicates a **strong capacity to *prepare* and *recover***. However, evidence for active implementation for a lot of this *learning* is difficult to distinguish, contributing to weakened *robustness* and *redundancy*. The **capacity to *adapt* is also weakened** as a result, but additionally due to a lack of long-term focus. There are some mismatches between the strength of a principle now and a continued emphasis in the future – for example in *diversity* and *learning*. This may indicate some areas for improvement.

Table 16: Overview of the scores per principle for both current practices and future practices in London, as indicated by adaptation and resilience plans.

Capacities for Resilience	Principles	Current Situation	Future Situation
Capacity to **PREPARE**	Anticipation & Foresight	++	++
	Preparedness & Planning	-	+
	Homeostasis	+	+
Capacity to **ABSORB**	Robustness & Buffering	0	+
	Diversity	+	0
	Redundancy	0	+
Capacity to **RECOVER**	Flatness	+	+
	High-Flux	+	+
Capacity to **ADAPT**	Learning	0	0
	Flexibility	-	+

8. CONTRIBUTING FACTORS

This chapter seeks to reflect upon the scores of RQ3, as discussed in Chapters 6 and 7, and help answer why the principles are expressed in this way. This chapter therefore seeks to answer RQ4 – what factors and mechanisms affect the extent to which the resilience capacities are expressed in each city? The following subsections discuss key constraining or enabling factors that impact upon each city's resilience capacities and thus the strength of the resilience principles as discussed in Chapters 6 and 7. These factors have been either raised by interviewees as relevant, or inductively derived following interview and document analysis. Governance strategies to address these factors and enhance resilience are discussed in Chapter 9, in the context of a wider reflection upon the results of this thesis.

8.1 Heat-Specific Factors

The factors discussed here are features specific to heat as an issue area. They are interrelated, and negatively impact upon all resilience capacities.

8.1.1 Low Issue Legitimacy

Despite rising temperatures being one of the most widely recognised impacts of climate change, its specific impacts on urban environments in historically cooler or more temperate climates – like that of London and Rotterdam – has only recently been perceived as a serious threat. In the UK and the Netherlands, hot weather conditions are seen as rare events to enjoyed. It is only in the past few years that heatwaves have become more of a regular occurrence and are noticeably uncomfortable for a wider range of people, creating a greater recognition that heat is a legitimate problem to prepare for and deal with rather than an opportunity to relax and enjoy.

Flooding is the primary climate threat in Rotterdam and is a high priority in London – this threat is clearly visible and has a strong economic impact in terms of property damage. Heat is neither of these (research on productivity losses due to heat is lacking in Europe) – and so it is harder to attract policy attention: "*you have to question why we are preparing for heat when it rains a lot more. But we are noting changes with our climate"* (Interview L4). This is also a problem in terms of attracting research interest: "*this is again something I've encountered in a lot of funding applications I've submitted. Because a lot of my work is on overheating and heat vulnerability and I've had comments from reviewers that the proposal is fine, methods are appropriate, but they didn't consider the topic as timely or worthwhile to investigate… I don't think people take heat risk very seriously*" (Interview L2).

A controversial point raised by some interviewees was that the impacts on the elderly are not necessarily perceived by people to be legitimate. For example, when discussing the factors they thought contributed to a lack of focus on heat, some raised that people think that because heat only impacts strongly upon the elderly, and usually those elderly who are less able to look after themselves (i.e. in a care home and/or sick), these people are likely to die soon anyway, so what is the difference if they die only a few weeks earlier in a heatwave? This perception goes against factual evidence, with the *Heatwave Plan for England* stating that "*excess deaths are not just deaths of those who would have died anyway in the next few weeks or months due to illness or old age. There is strong evidence that these summer deaths are indeed 'extra' and are the result of heat-related conditions*" (PHE, 2018, p.6).

At the level of citizens, it can be difficult to raise awareness of heat as a legitimate problem, particularly among more disadvantaged groups: "*Getting poorer people in cities involved in climate adaptation and resilience, even heat stress, is still an issue, but it's on the agenda […] there are a lot of poorer districts in Rotterdam […] people without work – they are sceptical of this climate adaptation in general as they are looking for jobs and just trying to survive*" (Interview R5).

Despite the historic lack of awareness and thus perceived legitimacy, there is a sense in both cities that this is improving. The positions of interviewees R1 and R4 in Rotterdam directly consider heat as a relatively recent but important mandate, and there is increasing focus on the topic in the more recent policy documents assessed. London has had this problem higher on the agenda for longer than Rotterdam, in part due to heat having more of an impact in London – the risk is greater in London due to higher predicted temperatures and a greater UHI, and in part because heat has been positioned within the emergency response and management institutions like the London Resilience Partnership, which tracks and manages the risks London faces and the response to them.

Impact on Resilience

A lack of legitimacy due to a lack of awareness surrounding the threat of heat was a strongly expressed sentiment across all interviewees as a reason for a lack of prior focus on the issue at **both the level of citizens and governance**. It is a factor that has a significant impact on the strength of **all resilience capacities**, primarily because it results in a lack of relevant data and knowledge, and thus a lack of focus in research and policy. This barrier is discussed further in 8.1.2.

A lack of awareness **at the citizen level** is also impactful, mostly upon a **city's capacity to *absorb* and *recover*** – if there is a lower interest in the problem from the community level, then there is a lower *diversity* of measures pursued at the policy level (due to reduced public participation), less behaviour change on an individual level, less autonomous local action, and slower *flux* of resources to those who need it.

8.1.2 Vague Problem Definition

What is classed as extreme heat is difficult to define. There is no single definition of what constitutes heat risk as heat is a subjective and context-dependent experience, as discussed in 2.3. In London for example, this has contributed to a lack of definition of overheating in building regulations, impacting upon the robustness of infrastructure to heat. How vulnerability is defined further impacts on this – what is classed as a vulnerability hotspot? Who is vulnerable, and on what baseline or indicators is this vulnerability defined?

This issue is exacerbated by the lack of legitimacy regarding extreme heat as discussed in 8.1.1, which results in insufficient data to be able to properly define the problem's key indicators, risks, or impacts; as well as the ability to accurately monitor and test available 'solutions'. This is a key barrier in terms of putting the issue on the agenda and is cyclical in nature: if the risk is not adequately identified as a problem, work does not go into collecting necessary data and developing accurate indicators. The problem is then not identified in the specific terms required for positioning as a policy priority, which results in a lack of funding for research and implementation of measures to tackle the problem: "*there's not really money there yet. First we have to make the map, be very clear about what the problem is, how much is it costing us or* *damaging the city or harming the people, and then we can say okay we need this money to resolve this problem*" (Interview R1). As awareness of heat as a threat has only been recently increasing, plans and policies made in previous years do not attach enough urgency to the issue, again resulting in a lack of funding and focus in that particular policy cycle.

There can be issues regarding data collection for the most vulnerable groups impacted by heat, further contributing to the difficulties tackling the vagueness of the problem definition. London has struggled particularly with this, and interviewee L1 discusses some of the key issues in terms of defining heat health risk for the vulnerable elderly in care homes and young children in schools: "*it's also knowing where the vulnerable groups are, who they are, why they are at risk, what the risk factors are – it's really important and we've been trying to do some work with boroughs around this. Like if there was a heatwave, would they know who their at-risk groups are? And this has been really difficult to do because of GDPR rules and the sensitive nature of that data. […] It was really difficult getting into any care homes and talking to them about heat partly because they're so overworked, and partly because they don't necessarily see it as a priority. And I think partly it's an education issue because they think care homes should be warm and hot, because they're so afraid of contracting pneumonia – we know that from hospitals. And the other issues, which we found with schools, is that they don't really want to be exposed – if we went to care homes and said look there's a problem here, they would have to do something about it and they don't have the money necessarily*." To overcome issues of trust, sensitivity, and awareness, interviewee L1 described their focus on the importance of strong partnerships at the local level: "*we have to work very closely with the boroughs because they're the gatekeepers of data at a local level or with social infrastructure … so that's where we had to work really closely in building a relationship with the care home*."

Specific data in quantitative terms is important for effectively communicating knowledge into policy. Interviewee R4 expands on this regarding their work within Rotterdam municipality: "*if we [municipal department working on health and environment] tell them [other departments that are not used to working on the issue] to spend more on greenery, or create more shade – [they ask] what % shade do we need? It needs to be very specific. And that's a language we don't speak yet. We have to learn more about it, so it can be put into government documents*". This demonstrates that context-specific data that is brought together in concrete terms (i.e. exactly what, who, where etc.) is important for the inclusion of the issue of heat in policy documents and organisational practices.

Impact on Resilience

Most interviewees referred in some way to the **cyclical nature of an inability to define the problem, with the lack of relevant, accurate data impacting upon the ability to translate knowledge into action**. This is also a factor that impacts upon the strength of **all resilience capacities**, **but primarily on the capacity to *prepare*, *absorb*, and *recover***: a lack of data and indicators to identify the threat and those most affected (capacity to *prepare*) results in an ability to implement a *diversity* of measures that would enhance *robustness* and *redundancy* (capacity to *absorb*), and also prevents a timely response to an extreme heat event and reduces the ability to get resources to those who need them the most (capacity to *recover*).

8.1.3 Lack of Ownership and Accountability

An issue recognised by multiple interviewees is that heat is cross-cutting in nature. As a result, there is no one consolidated 'owner' of the issue, and therefore no one organisation to take accountability for the risk and measures to reduce it.

This results in a lack of institutional focus – if there is no consolidated 'owner' to push the issue, heat can get lost amongst other, often higher priority policy issues that fit more neatly into the traditional structures of siloed governance and decision-making as discussed in 8.2: "*It's always a puzzle to see who is the owner of this subject … everyone's like no it's not really my team, I don't really know what to do with it so I'll just put it to the back*" (Interview R4).

There are generalised dedications within policy documents that responsibilities towards maintaining 'system robustness' lay with the government and local authorities (City of Rotterdam, 2013), and Rotterdam's most recent climate adaptation strategy, *Weatherwise,* states that the city is responsible for the link between public health and emergency services, saying that disruptions from climate change must also be included in this. This is evidence for an increased move towards a different way of perceiving governance for cross-cutting problems. This again can be seen by the appointing of interviewee R1 and R4's positions in Rotterdam (who have a direct mandate for heat), however as discussed in 8.2, organisational structures and priorities may limit the extent to which these positions can be effective.

Impact on Resilience

The cross-cutting nature of heat and its consequent lack of ownership **negatively impacts upon all resilience capacities, due to the lack of consolidation of the problem across different sectors**. This results in other issues taking priority, and system interdependencies and cascading effects not well accounted for, which is especially important for the **capacity to *prepare* and *recover***.

8.2 Organisational Structure and Capacity

There is a lack of organisational structure and capacity to integrate and mainstream the complex issue of heat. Heat is a cross-cutting issue: whilst impacting upon sectoral domains like health, the built environment, and more recently climate adaptation, it also impacts upon other sectors like transportation and energy supply. However, organisational capacity to deal with heat is limited, resulting in a lack of mainstreaming of heat (and resilience) horizontally across sectors and vertically across levels within sectors. There is however acknowledgement that this issue exists, and whilst this factor impacts negatively on the resilience capacities some progress can be seen in Rotterdam and London to address it.

London has a better quantitative understanding of this cross-sectoral risk impacts than Rotterdam, as London maps cascading impacts and sectoral interdependencies as part of its emergency response and management focused resilience infrastructure. However, in both cities proper linkage between these sectors for the threat of heat is lacking. Linkage across sectors is hampered by the traditionally bureaucratic nature of public administration governance, which use structures of 'new public management' to focus on the efficient provision of services. In real terms this results in municipal-level governance working mostly in silos. Some interviewees noted that heat is either a health-related topic (i.e. social) or a built environment-related topic (i.e. physical), with a lack of connection across the two domains and a lack of integration into other domains. As stated by interviewee R3, "*as long as your organisation is split into different domains, it remains a big challenge to work in an integral way on issues. It's becoming better and better, but the traditional way of working is still there. … a city is not either of them [neither solely social nor solely physical] – we need to work on it together. A lot of people see that now, that they have to work together. … but we have a long way to go*."

Implementation of measures for heat is affected by this lack of linkage. In London retrofitting is recognised as an important action for the threat of heat, however in London most retrofitting programs focus mainly on energy efficiency. Interviewee L3 discussed the difficulties they face getting heat recognised within programs for energy efficiency: "*I get a bit frustrated because I think we know what we need to do. You need to retrofit a hell of a lot of properties. So whether it's the Mayor's Green New Deal or new retrofit programs that come out the central government in response to the climate emergency, you know if funding streams come online that are about retrofit for normally energy efficiency, then we need to be influencing that money. We need to be saying those programs must consider overheating risk. You cannot have just single issue retrofit energy efficiency measures, we've done that for several years and we've seen the dangers of that*." This also demonstrates the need for vertical linkage as well as horizontal – priorities at the national level dictate local focus and funding, indicating the need to promote the issue of heat at the national level agenda.

Most interviewees indicate that there is an understanding within the municipalities that their fragmented way of working needs to change, and tackling it is included in both city's resilience strategies as a goal. Rotterdam seeks to 'change urban governance' through various actions to improve cooperation, collaboration, and decentralisation (City of Rotterdam, 2016). London has various actions aimed at improving 'process', including improving the adaptiveness and inclusivity of Greater London Authority policymaking (GLA, 2020a).

The bureaucratic nature of public administration governance is also addressed by Rotterdam's resilience department, and the 100 Resilient Cities funded Chief Resilience Officer. These function to straddle multiple other departments to specifically address these issues, helping to push resilience as a strategic focus throughout the municipality and organise and connect across domains: "*Our team also provides training – we are not presenting ourselves as experts, we are not, but we try to get our colleagues to think in an integral way about an issue. We ask them triggering questions. We try to organise – whenever there's a training for stedenbouwgundige [urban planners], people that work in physical part of city [we make sure] that there's always someone from MO – those are the people working on social part of city with citizens themselves"* (Interview R3). This integration has worked well in Rotterdam in terms of linking heat to the enhancement of green infrastructure as a flood risk management measure.

To overcome these issues for heat more specifically, it is observable that both London and Rotterdam are characterised by individuals who expand their working scope to include heat, and then actively push the issue in different sectors, domains, and levels. This is important as although heat can be raised in various policies and plans, many sectors have higher priorities or low capacity to focus on this issue (due to e.g. lack of resources, or the issues perceived lack of legitimacy or definition as discussed in 8.1). It needs people to proactively keep putting it on the agenda. Interviewee R4, who works on environmental health, tries to integrate heat across their work and those they work with: "*you don't only want to put it there [in the* *climate adaptation program] – you want to put it in all the different disciplines. So that's what we try to do, mention this subject everywhere. And hopefully people will listen and try to do something with it."* Cooperation is also enhanced by regular meetings and active participation of each domain in the work of the other – in London, interviewees L1 and L3 often act as an intermediaries and organisers in such cooperative work.

Finally, multiple interviewees referenced that departments, and municipalities overall, do just have other priorities, making mainstreaming in heat difficult: "*for integration they try, but Rotterdam also has a big task on urban development, not only climate adaptation. The need for housing still very big, and there are a lot of poor areas*" (Interview R5). Interviewee P9 describes pragmatically how they deals with this in their role: "*I do think there's a need to say: look, this [heat] is one of those things where if you counted the top 3 things that affected X piece of infrastructure or X urban system, heat probably isn't number one, in a lot of them [cities]. But I bet you if you look across the city, it is number two, three, or four, in a way that almost no other challenge will be. I think there is really a need to help cities fund and shine a light on that, because it's maybe not going to rise to the top of any other issues*."

Impact on Resilience

Multiple interviewees acknowledged heat as a **cross-cutting issue but noted a lack of linkage across the different domains** heat affects. This impacts upon the holistic conception of urban heat resilience as a property of a complex urban system (rather than individual parts), but specifically upon the following principles: ***homeostasis*** – if connections between different sectors is lacking, understanding of the feedbacks between different systems and system elements is low and cascading impacts may be unaccounted for; ***redundancy*** – cascading impacts cannot be accounted for by expanding capacity to ensure overlapping functions of systems and system elements; and ***high-flux*** – quick mobilisation and movement of resources of resources are impacted by bureaucratic organisational structures, and whilst individual decision-makers can be resourceful and knowledgeable, if the system they work within remains stuck in traditional forms then *flux* cannot be enhanced.

This problem is not unique to the threat of heat, but is one that limits moves towards overall resilience generally, as resilience itself is a cross-cutting 'solution' that functions across blurred system boundaries (Coaffee, et al., 2018). However, there is a definite awareness in both London and Rotterdam that this is an issue (maybe not yet for heat specifically) and so progress can be observed in breaking down these organisational barriers.

8.3 Path Dependency

Both Rotterdam and London indicate varying levels of path dependency, in their institutionalised reflexes when it comes to responding to heat, and in the technical lock-in that creates challenges for heat resilience. The first factor has a neutral to positive impact on resilience capacities, being a greater indicator of the 'pathway' taken by each city towards resilience than the strength of each capacity. Technical lock-in has a negative impact on resilience in both cities. However, both factors indicate the usefulness of the pathways approach to resilience in making the most of existing strengths and weaknesses in the urban system that are difficult to alter.

8.3.1 Institutionalised Responses to Heat

Both London and Rotterdam demonstrate different responses to heatwaves, observable in part due to different institutionalised reflexes, impacting upon the path followed towards resilience and climate adaptation. Rotterdam, with its primary issue of flood risk, focuses on innovation and strategy, with London having a more operational focus on urban risk and emergency management.

In terms of climate action and adaptation, the Netherlands is a world-leader in delta technology and Rotterdam in urban flood risk management, and the country is an exporter of innovative knowledge and technology in both these areas. When it comes to resilience, Rotterdam municipality's resilience department is also internationally renowned, functioning to straddle the boundaries between different sectoral domains (8.2 discusses this further). However, a few interviewees referenced that the work of the department (and that of the municipality's work on climate adaptation and resilience overall), as strong at the strategic level, but with a lack of follow-through to the operational level. For example, interviewee R1 says "*we don't reflect well enough to say it was successful, so we can't really convince politics to give money for it. Because if we were reflective and the results were very positive, then I think we would scale it up […] I think if you were to compare Rotterdam to another city, it is very innovative […] in Rotterdam they say, "don't talk just do" and that's a very Rotterdam way of looking at life. So, I think it is pretty okay in Rotterdam to start something without being really sure it will be a success. That's with the culture.*"

In London, resilience thinking is conceptualised within emergency management infrastructure. Such infrastructure is focused on urban disaster risk and emergency management. This focus is historic, and the language used in the city's *Resilience Strategy* emphasises this with references to the historic emergencies London has faced and overcome: terror attacks, economic recession, the Blitz in World War 2, all the way back to the Great Fire of London and the Black Plague. London is adept in preparing for and responding to disaster –the city's fire brigade and resilience team merged into one department. The concept of resilience in London is widening as demonstrated by the release of the *Resilience Strategy* in 2020.

Impact on Resilience

As can be seen in Chapters 6 and 7, despite following the same definition of resilience from 100 Resilient Cities, London and Rotterdam display **different conceptions in reality due to different institutionalised reflexes**. This impacts on the emphasis placed on each resilience capacity in each city.

In London, heatwaves are prepared for and reacted to: the city has a strong focus on the **capacity to *prepare* and *recover*** through the national and local heatwave management plans that focus on risk management (*preparedness and planning*); a strong understanding of cascading impacts and impacts across sectors which help to strategically manage feedbacking systems (*homeostasis*); and through a quick mobilisation actors and resources in the event of a heatwave (*high-flux*). Mitigating heat is not a focus, and thus the capacity to *absorb* is low. Despite a lack of innovation for the threat, the operational focus results in strong mechanisms for monitoring and reflexive *learning*, contributing to a relatively **strong capacity to *adapt*.**

Rotterdam is more proactive, strong at creating innovative plans and pilot projects and advertising them as examples of Rotterdam's status as a boundary-pusher and front-runner. However, monitoring of innovative projects with the aim of addressing issues and upscaling is limited, resulting in **a trade-off in the capacity to *adapt***, as many projects remain at the experimental level. Despite a strong focus on the capacity to *absorb* for the threat of flooding, mostly through infrastructural robustness, this has not (yet) translated to the threat of heat most likely due to a combination of the other factors discussed in this chapter.

8.3.2 Technical Lock-In

In both London and Rotterdam, there is evidence for a certain degree of technical lock-in which impacts upon the ability to follow certain paths towards resilience. Both cities have never faced heat as a regular, serious issue, as discussed in 8.1. This has resulted in maladaptive infrastructure that is difficult and expensive to retrofit, a regulation environment that makes new measures for new threats expensive and difficult to access, and maladaptive behaviours at an individual level.

For example, external shades are a relatively simple, non-mechanical measure to reduce the 'solar gains' inside buildings. However, this is not common in the UK – interviewee L2 explains: "*internal shading tends to be the most commonly used design measure because it's easier to install, it's cheaper. With external shutters it might not always be possible to install them cos you might need planning permission, it might be a listed building, and most importantly you have window types that make it quite tricky.*" An interesting point raised from the preliminary study noted that because of the uncommon usage of different measures (for the variety of reasons alluded to in the quote), there is limited trust among building developers and contractors surrounding their use (Interview L5). Interviewee L5 points to the role consultants have to play tackling this, in putting new technologies on the table and communicating them in a way that developers resonate with, and gives the following example – do developers find it difficult to relate to the point of these measures? Then consultants can show them examples from tall buildings in Norway that use a lot of dynamic shading and have an even cooler climate than the UK, as opposed to showing examples from less climate-relatable countries like Spain or Italy.

Practical problems are also present when homes are built for keeping heat in, rather than out. Such buildings need to get ventilation in hot weather, but multiple interviewees referred to the fact that simply throwing open a window in the middle of a city comes with issues of security, noise pollution and air pollution. Fans and air conditioning then become the main private behavioural response to hot weather. However, the use of air conditioning is contentious, with it understood as both an inflexible measure that has negative impacts in the long-run (due to e.g. high energy usage and carbon emissions) in climate adaptation and resilience plans, but also understood as an admittedly realistic solution to tackle overheating by some interviewees. Interviewee L3 explains: "*what we're not really getting a grasp on is that the answer is going to be air conditioning. It's as simple as that – we don't want it to be, because obviously we want to be reaching net-zero targets […] [cities in warmer climates have] known that's their climate and their homes are built that way. They're built to withstand high temperatures, they put external shutters and shadings on the buildings, whereas we tend to resist doing that. So, we've kind of locked-in those decisions."* Interviewee L2 further illustrates that this lock-in reduces *flexibility* in the long-run: *"our fear is that if we have a few more heatwave events, most people will just go out and purchase an air conditioning unit and install it […] I think my fear is a lot of the solutions which are quick fixes are kind of* *blocking solutions. So, once you have an air conditioner installed one summer, if there's another heatwave a few summers later you're not going to start considering retrofitting your home to passive cooling solutions. You are just going to stick with the air conditioning".*

In care homes and hospitals, there are several technical issues regarding, as interviewee L1 puts it, "*why they can't just turn the heat down*". In the UK especially, many buildings housing such institutions are old, containing a single boiler that heats up an entire building rather having thermostats in individual rooms. Care homes may house older people with dementia, who present a unique challenge to tackling heat in maladapted buildings – in these peoples' rooms, windows cannot be left open for natural ventilation due to potential hazards for the patient, but air conditioning is also a difficult option: interviewee P6 referred to evidence that older people with dementia perceive air conditioning as a draft and so feel cold, or feel cold if they do not see a heat source in their room e.g. if there is underfloor heating but no radiator, even in warm weather conditions. Furthermore, particular healthcare practises and routines are normalised, which exacerbate these technical issues. As interviewee P6 expanded: "*it's not the technology so much itself as the social environment in which the technology is used. So, what we saw a lot is that care workers don't actually change their regimes in cases of heat. So they will be still be serving cups of hot tea, Sunday roasts, asking people whether they want a jumper or a cardigan, in 30 degrees heat*". This demonstrates a challenge for caregivers to try to meet the various competing needs of their patients.

An additional important point regarding the most vulnerable groups is how to decide what solutions are most justified and when: "*when you have very vulnerable people of course you have to prioritise immediate impacts and benefits to human wellbeing and health versus carbon emissions. So you need to strike this very fine balance"* (Interview L2). As heat is an issue that cuts across the domains of health, built environment, and climate adaptation, it is likely there will be competing voices for what solutions are most 'effective' as it comes higher onto the agenda.

Impact on Resilience

Technical lock-in results in maladaptive infrastructure, maladaptive behaviour, and a non-conducive regulation environment. This impacts most clearly on the **capacity to *adapt*, due a lack of *flexibility***, and on the **capacity to *absorb*, due to a practically reduced *diversity* of measures, resulting in low *robustness* and *redundancy* in the built environment**. The 'lock-in' aspect means that the choices and paths available going forward are limited as a result of the difficulties faced now – demonstrating that whilst the resilience pathways are useful, prior technical focus limits the ability to which paths may be changed. On the other hand, utilising the pathways approach can indicate that if a city struggles with e.g. maladapted pre-existing infrastructure that is hard to retrofit, it might direct focus away from adapting and absorbing and instead towards further developing the capacity to *prepare* and *recover*, and still overall build a degree of resilience.

8.4 Presence of Networks and Partnerships

This factor is observable in both cities to have a positive impact on resilience, mostly be helping to overcome much of the negative impact of the previous factors. Both cities engage in networks and partnerships, from the local to national level. In Rotterdam for example, participation within the 100 Resilient Cities network has enhanced the city's reputation as an innovative hub for climate action and resilience, allowing it to gain partnerships both locally and internationally, and to promote and export the skills of its private sector partners (City of Rotterdam, 2016).

At the city level climate adaptation work in London and Rotterdam is characterised by numerous networks linking communities, the private sector, strategic agencies (e.g. the Greater London Authority, Transport for London, Rotterdam municipality), boroughs and neighbourhoods, centres of expertise (e.g. the London Climate Change Partnership, the Cross River Partnership), and research institutions. In London, maintaining a connection with the private sector is emphasised: *"lots of partnerships across London like the CRP [Cross River Partnership] are keen to involve private sector. There's a need to address the private sector and businesses as well because you want as much buy-in as possible"* (Interview L4). In Rotterdam, partnerships between research institutes and industry appear to be particularly highlighted, contributing to the focus on innovation and experimentation. However as discussed, Rotterdam is particularly struggling with engaging communities and building partnerships between that level and the municipal level – limiting the emphasis on *preparedness and planning*, *diversity*, and *flatness*.

For the threat of heat, its cross-cutting nature and lack of ownership result in issues. Networks help to overcome these barriers, particularly in London where the issue has been higher on the agenda for longer.

Impact on Resilience

Both the documents analysed and the interviewees focused on the usefulness and importance of knowledge sharing from participation in networks and partnerships across different levels and sectors. This is observed to impact positively upon resilience: the knowledge and resources shared across these strengthens the **capacity to *recover***, and the principles of ***anticipation and foresight*, and *learning***.

8.5 External Shocks

External shock events have impacted upon how both cities perceive and conceptualise extreme heat. One is the increasing numbers and intensity of heatwaves experienced each summer, which contributes to greater awareness and understanding of the threat.

A second is the Covid-19 pandemic. This is an ongoing situation at the time of writing this report, and its impacts on resilience, on city-level and national policy, as well as on broader societal and cultural shifts, cannot be predicted or fully commented upon. However, the interviews for this research took place between March and July 2020 – the time during which Covid-19 lockdowns began and reached their peak in both the UK and the Netherlands (as well as in the countries of the other interviewees in the broader research performed for Sweco). Multiple interviewees pointed towards the parallels between Covid-19 and extreme heat in terms of the interlinkages between health and the environment, with the ongoing crisis resulting in new perspectives on those most vulnerable (see the finding in 8.1 on low perceived urgency of the threat of heat due to its impacts being primarily felt by the elderly). It is therefore insightful to reflect upon how, up to this point, Covid-19 has impacted how extreme heat is dealt with.

The sentiment of the policy makers at the time they were spoken to was that Covid-19 was becoming an opportunity for a variety of sectors to come together to work more closely on cross-cutting issues regarding health and the environment – the pandemic being one, and other issues related to city liveability and sustainability being others: "*Especially now [corona] – people are communicating more with each other –*

what are you doing, maybe I can do something with that also. And in future people need to work more like this, together" (Interview R4). In both cities, although more prevalent in Rotterdam, space was being created for better cross-departmental coordination and integration, and longer-term sustainability strategies.

New questions were being raised: what to do in a hot summer where people were supposed to be isolating inside? How to promote vigorous hand-washing during months where hot weather may come hand-in-hand with a drought, and water resources are in shorter supply? Both Dutch and British national advice on heatwaves were updated to include new considerations in terms of social distancing and quarantining requirements.

It is not possible to comment on the resilience impacts of such an ongoing situation, nor on whether such new perspectives as a result of the external shock of Covid-19 will continue.

9. DISCUSSION

This chapter presents a reflective discussion on this research. 9.1 reflects on the results of this thesis, discussing governance strategies that are utilised to address the factors mentioned in Chapter 8 and thus enhance resilience. These strategies are discussed using the insights of this thesis and within the broader social and scientific context, helping to answer RQ5: what insights can be inductively derived from these findings regarding suitable governance strategies to enhance resilience capacities? 9.2 reflects on the analytical framework and its operationalisation for the threat of extreme heat. Finally, 9.3 reflects on the limitations of this research and discusses directions for future work.

9.1 Reflections on Results

These reflections follow the factors that affect the extent to which the resilience capacities are expressed in each city, as discussed in Chapter 8. Key governance strategies are highlighted in bold, answering RQ5, alongside wider discussion and insights based on surrounding literature. The factor discussed in 8.5, 'External Shocks', is not reflected upon as this refers to the Covid-19 crisis, which at the time of writing is ongoing.

9.1.1 Heat-Specific Factors

Chapter 8 finds that certain factors specific to heat as an issue area contribute negatively to all resilience capacities. These are: the low perception of heat as a legitimate problem; its cross-cutting nature and thus lack of consolidated ownership; and its vague definition.

The vagueness attributed to defining heat can be addressed by **improving availability and accessibility to accurate data and indicators**, however as referred to in 8.12 there are often barriers to this. **Standardisation of methodologies** and **regulation** can help overcome these barriers. As discussed in 6.1.1, the Netherlands actively seeks to address this issue by creating freely available mapping of heat risk using a standardised method (PET) that is accessible to all. Furthermore, heat is included at a national level as one of four identified climate themes for which municipal level stress tests are required. These strategies help overcome issues of municipal budgets and available resources.

One of the key governance strategies that can be observed in London and Rotterdam to tackle issues of low legitimacy and lack of ownership is to **couple heat to higher priority issues in the public sphere**, mainly public health. This is shown by the heat response plans of both cities that focus on warning vulnerable groups and their caregivers of health risk, and due to the main focus of both cities on vulnerable people as opposed to e.g. vulnerable infrastructure or sectors (although London also has a strong focus on the latter). In Rotterdam, Boezeman and Kooij (2015) find that heat was included as an 'extra' topic in Rotterdam's first *Climate Adaptation Strategy* in 2013, but this was contested due to urban heat not being perceived as a real problem in an urban adaptation discourse dominated by flood risk. Subsequent coupling of the issue to more legitimate, 'stable' topics in the public discourse like public health helped increase its legitimacy as a problem, and hence its institutionalisation into the adaptation and urban planning agenda (Boezeman & Kooij, 2015). Another key strategy demonstrated is **targeted communications** aimed at private individuals and health care workers, used to raise awareness and alert vulnerable groups, with both cities aiming to improve such communications for this purpose.

However, when it comes to public health the wider literature points to further considerations when recommending the highlighted governance strategies for enhancing resilience.

Heat and Public Health

Fairness versus legitimacy: Targeted communications focus on individuals taking responsibility for action to reduce personal risk, often for an issue that is often not caused by them. Individual health and physiological characteristics are not the only determinants of heat risk – environmental and socio-economic factors are also at play, and there can be little an individual can do about their surrounding environment as heat impacts other sectoral domains like the built environment, transport, and energy. Issues of fairness are raised when the burden of action is placed at those little to blame, rather than at a structural level (Mees, Driessen, & Runhaar, 2012). However, when it comes to who takes ownership of health interventions to address heat, research finds this to be a contested issue. In London and the UK in general, older people have been found to not perceive themselves as vulnerable to heat (Abrahamson, et al., 2009; PIRU, 2019), with some older people in both London and Rotterdam perceiving targeted health interventions directed at them (such as a national heat health plan) as patronising and paternalistic (Mees, et al., 2015; Abrahamson, et al., 2009). Mees et al. (2015) found that when it comes to third parties implementing targeted interventions that focus on the health of vulnerable citizens (like a targeted heat plan) there is a lack of consensus on the legitimacy of these interventions. There is therefore a trade-off between fairness in terms of the importance of placing accountability not at the feet of those most impacted by heat, and the legitimacy of external interventions in the eyes of these people.

Reactive approaches to healthcare: Whilst this thesis has used the presence of localised heat plans as a signifier of a strong capacity to *prepare*, research in both the UK and the Netherlands has found that the knowledge contained in these plans does not necessarily always trickle-down to where it is most needed, or even that vulnerable individuals are effectively targeted (Zaidi & Pelling, 2015; Gupta, et al., 2016; van Loenhout, Rodriguez-Llanes, & Guha-Sapir, 2016). In the Netherlands, care organisations in Amsterdam (including both hospitals and elderly care homes) lacked awareness of the national heat plan and placed heat as a low priority, with the most vulnerable individuals insufficiently considered and local tasks and responsibilities insufficiently defined (van Loenhout, et al., 2016). In the UK, practical implementation of the national heat plan is difficult in elderly care homes due to a lack of awareness of the plan among frontline staff in combination with a focus on reactive approaches to heat management (Gupta, et al., 2016). In London specifically, Zaidi and Pelling (2015) find a "good availability of disaster response equipment, medical facilities and staff to manage heatwave disaster response in extreme conditions, but the failure to involve agencies and departments outside of health and emergency services has resulted in limited awareness of the plan. Limited outreach and information on heatwave risk within the community and private sector means that at-risk groups and caregivers are often unprepared and untrained to identify and respond to emergencies resulting from extreme hot weather" (p.1227). As can be seen, despite attempts to raise awareness of the heat risk through national and local plans and other sources of communication, there is a focus on reactive approaches to heatwaves. Proactive action that may take better account of the most vulnerable is lacking. This also points to the fallbacks of the pathways approach to resilience, whereby London focuses on the capacity to *prepare* and *recover*.

Institutionalised healthcare norms and practices: A lack of knowledge of a national heat plan does not of course mean that health professionals cannot care for patients in advance of and during a heatwave. However, the general lack of awareness and prioritisation of heat as a legitimate problem in health care for the vulnerable elderly in the UK is exacerbated by the complex issue of the impacts of institutionalised care routines. Gupta et al. (2016) found a 'culture of warmth' extant in UK care homes, meaning that there was a "prevalent perception, from care scheme designers to frontline care staff, that older people 'feel the cold', and that cold represents a bigger threat than heat to older occupants' health" (p.1). This means that care schemes, care scheme management, and care home design, are all focused on providing warmth, with this focus reinforced by regulation. A 2018 government audit into heatwaves (Envrionmental Audit Committee, 2018), commissioned in part due to mortality spikes in care homes during heatwaves, found that in 2016/17 there were nearly 3,000 instances of overheating in healthcare trusts with many heated above 26°C, with hospitals sometimes exceeding 30°C (when outside temperatures are around 22°C). Reducing this temperature is not easy, due to the combination of the prevalent 'culture of warmth' and technical realities, which were referred to by interviewees as discussed in 8.3.2. The caregivers thus must deal with competing needs and this strongly institutionalised 'culture of warmth'.

The position of the most vulnerable in society: Finally, as discussed in 8.1, the issue remains whether the public health impact of heat on vulnerable groups like the elderly is itself seen as an urgent, legitimate problem. The perceptions discussed in 8.1 point to cultural norms surrounding equality, care, and the value of life in society. Ageism, or stereotyping, prejudice, or discrimination toward people on the basis of age, is a growing concern for public health with research showing that ageism towards older people is prevalent across many countries and contributes negatively to health outcomes (Burnes, et al., 2019). These issues are especially apparent in light of the COVID-19 pandemic, whose impacts have been most pronounced on the elderly and people with disabilities.

What does the above mean for governance strategies to enhance resilience? In sum, efforts to address the low legitimacy of heat and its lack of ownership by coupling heat to a 'stable' topic like public health, or through targeted communications via a national heat plan, is not enough. Perceived legitimacy and institutionalised healthcare norms for the most vulnerable need to be addressed, as does the important but overlooked interactions of these norms and the ways in which we design our infrastructure. **Enhanced public participation, co-creation, and public-private partnerships**, as exemplified by the 'risk dialogues' in Rotterdam, can help to address and overcome such complex issues (Mees et al., 2012).

Heat and other Social Issues

Fitting heat into the box of public health can overlook the important intersections heat has with other domains that impact highly on our most vulnerable. Whilst the social side of the results of this research are focused in the domain of public health, the discussion of impacts within the built environment is mostly technical. Social issues relating to equitable access in urban public space is an important topic within the urban sustainability and justice discourse, but interestingly was not raised by this analysis (these issues were however raised by interviewees in Barcelona for the Urban Insight report, and were discussed in terms of equity and access).

Enhancing green and blue infrastructure in urban public space, including parks, ponds, water ways, open spaces, urban forests, and street trees are a key element of both London and Rotterdam's resilience and climate adaptation strategies, and directly associated with efforts towards mitigating the impacts of extreme heat and the UHI effect (Bowler, Buyung-Ali, Knight, & Pullin, 2010). The attraction of these kind of interventions lies in the multiplicity of additional benefits to be gained, including physical and mental health benefits (Maas, Verheij, Groenewegen, de Vries, & Spreeuwenberg, 2006); flood risk mitigation and management (Liu, Chen, & Peng, 2014); biodiversity conservation (Goddard, Dougill, & Benton, 2010); and social benefits including supporting social interaction and integration (Smith, Nelischer, & Perkins, 1997). However, there is a growing question around the topic of who actually benefits from such developments, as well as who decides what about them is beneficial (Anguelovski, Connolly, Garcia-Lamarca, Cole, & Pearsall, 2018). 'Green gentrification' occurs as greening interventions and the environmental amenities that come with them attract further investment and development to an area, eventually pricing out and displacing the residents who were supposed to gain (Dooling, 2009; Checker, 2011). Inevitably, this displacement is often racialised and classed, with lower income and minority groups feeling the most negative effects (Dale & Newman, 2009; Wolch, Byrne, & Newell, 2014).

When prioritising green and blue infrastructure, it is vital to attend to how the planning, design, and creation processes of such interventions mitigate or reinforce these distributional inequities (Anguelovski et al., 2018). As London and Rotterdam move further into efforts towards resilience, it is necessary to consider these impacts on the most vulnerable, especially due to both cities struggle with the issue of affordable housing. Again, **broad, informed public participation in the planning and design processes of public space** is therefore an important governance strategy to ensure interventions address issues of equity and access.

9.1.2 Organisational Structure and Capacity

This thesis found that in both London and Rotterdam, siloed, bureaucratic organisational structures and limited capacity to focus on lower priority issues to be a key factor negatively impacting upon resilience capacities and the mainstreaming of the issue of heat across sectors. Such fragmented governance structures are an identified issue within sustainability science and systems thinking, and there is a scarcity of research on what makes mainstreaming effective (Runhaar, Wilk, Persson, Uittenbroek, & Wamsler, 2018). There is evidence however that in both cities this issue is being actively worked on.

As discussed in Runhaar et al.'s (2018) review on the 'state-of-the-art' in this area, there is an identified need to move beyond just incorporating climate adaptation objectives into different sectors. This conclusion is also a finding of this thesis: as discussed in 9.1.1, trying to fit the cross-cutting issue of heat into siloed domains can have negative impacts. The two main perceptions of extreme heat as a problem lay within healthcare and the built environment (Mees et al., 2015; Zaidi & Pelling, 2015), and the challenge is to bring **cooperation *between* and coordination *across* these two main areas, as well as other key sectors,** as opposed to just ensuring heat is raised without any cross-sectoral linkage. This effort needs to be collaborative, between the social side that takes into account issues like equitable access and the needs and behaviours of the vulnerable elderly and their caregivers, and the physical side that takes into account technical realities of older infrastructure and a regulation landscape that focuses on risk management.

A **sustained political commitment to climate adaptation mainstreaming** is an important strategy to account for this (Runhaar et al., 2018), which is reflected in the efforts London and Rotterdam are making to attend to these barriers. As discussed in 8.2, both cities consist of civil servants with knowledge and expertise, who proactively put the issue of heat on the agenda in their own department, as well in other sectors, domains, and levels. In the literature, such individuals are variously named: '**issue ambassadors', 'intermediaries', and 'boundary crossers'**. This thesis found that the civil servants who work in this way are mostly centered within climate adaptation departments but aim to also create linkage to healthcare and built environment domains.

Another strategy observable is the presence of the resilience department in Rotterdam, which was established as a result of the 100 Resilient Cities membership. **Cross-departmental offices for coordinating sustainability and resilience** can help cross-cutting issues like heat fit into overarching sustainability goals like climate resilience, healthy cities, and city liveability, and help to consolidate political commitment to such goals. In terms of resilience, this enhances *redundancy* by sharing functions and governance responsibilities across scales and sectors. Furthermore, **leadership in the form of individual policy entrepreneurs** is also a key strategy for mainstreaming such across sectors (Runhaar et al., 2018). The role of Chief Resilience Officer in London and Rotterdam, established and funded by 100 Resilient Cities, is an example of this.

Finally, **subsidies and incentives from higher levels of government related to consolidated cross-sectoral policy goals** are key, as a lack of financial resources is a frequent barrier to mainstreaming (Runhaar et al., 2018). This was also found to bey a key barrier by this thesis, e.g. regarding municipal level data-availability and the consequent lack of identification of heat as a problem in plans and policies (discussed in 8.1.2).

9.1.3 Path Dependency

This thesis found that institutionalised reflexes in how each city responds to heat, and technical 'lock-in' contribute to varying degrees of path dependency. A key governance strategy to address path dependency is sustained political commitment as discussed above, and the **active prioritisation of long-term over short-term planning**. Long-term perspectives towards climate resiliency in urban governance can help strengthen synergies and reduce trade-offs between adaptation and mitigation efforts, and promote more systemic investments (Ürge-Vorsatz, et al., 2018). This can then incentivise, for example, investment in a full-building retrofit rather than investment in air conditioning units.

9.1.4 Presence of Networks and Partnerships

A range of networks and partnerships are in existence in London and Rotterdam, and these positively impact on the level of resilience. However, both cities cite the improvements to be made in forming genuinely **cooperative and productive partnerships with communities**. Community level partnerships are vital to a more integrated vision of the problem and its solutions, as well as contributing to self-organisation and ensuring decentralised, autonomous action – all of which are key elements of resilience. Furthermore, multi-level partnerships facilitate shared learning and co-creation: creating spaces where stakeholders can come together allowing the "creation of opportunity contexts" which "establishes framework conditions for clarifying costs, benefits and responsibilities and incentivising and assisting actions towards long-term goals" (Hölscher, Frantzeskaki, McPhearson, & Loorbach, 2019; p.847). Hölscher et al. (2019) additionally find that sustainability and resilience offices can act as intermediary spaces in this regard. Multi-level partnerships also include private actors, with the importance of strenthening **partnerships with private actors** like businesses raised in this thesis, particularly in London, as important. Runhaar et al. (2018) also found cooperation with private actors to be a key factor in mainstreaming.

Bahadur and Tanner (2014) note that to enhance awareness and participation at the local level, it is important for **communications to focus on the transformative potential of resilience**. This takes communicative strategies beyond highlighting the attractiveness and enjoyment of climate adaptation measures, which is a part of Rotterdam's most recent climate adaptation strategy to improve participation. The transformative potential of resilience, i.e. its potential to redress systemic vulnerabilities and power imbalances, can attract citizen awareness and encourage active participation, resulting in 'conscientisation' (Pelling, 2011) – a critical awareness-raising that is important for transformational approaches.

9.1.5 A Shift in Focus?

The governance strategies discussed and highlighted throughout this section (9.1) are interlinked and may benefit from being re-framed within wider scholarship on 'transformative' urban governance. Cities are increasingly recognised as important actors in movements towards sustainability in the face of climate change and environmental degradation – as can be seen from the example in this thesis of 100 Resilient Cities – whereby change is actively and voluntarily catalysed at the city level as opposed to the national level (Castán Broto, 2017). However, to cope with the complex and uncertain nature of the challenges faced, urban governance needs to fundamentally shift away from modes of short-termism and efficiency-optimisation. Transformative urban climate governance moves away from a view of climate change impacts as isolated problems, but instead a symptom of unsustainable path-dependencies and maladaptation in urban planning (Hölscher et al., 2019).

Hölscher et al. (2019), for example, present a framework of transformative governance capacities which in many ways mirror the urban resilience capacities framework (e.g. by including the importance of knowledge generation, innovation, and decentralised multi-actor governance), but also addressing the underlying aspects of urban systems that need to be addressed in order to enhance resilience (e.g. by focusing the knowledge generation on understanding complexity in socio-ecological systems, by anchoring innovation and novelty in context and ensuring its up-scaling, and ensuring multi-actor governance is strategically aligned and linkages are created across sectors). In this way, **developing transformative urban governance capacities develops resilience as an emergent property as opposed to prescribed goal, whilst simultaneously addressing the barriers to resilience** as identified in this thesis**.**

9.2 Reflections on Analytical Framework

This section reflects on the analytical framework, firstly extending the specifications of Chapter 4 using insights from the in-depth study, and secondly reflecting on the usability of the urban resilience capacities approach.

9.2.1 Reflection on Operationalisation for Heat

Following the initial operationalisation of the urban resilience capacities framework for the threat of heat in Chapter 4, the results of Chapters 6 and 7 indicated that much of the framework was applicable in this way. However, a further few key specifications would be recommended if this operationalisation were to be used in further research. An altered analytical framework that includes these further specifications is included in Appendix C.

Firstly, as heat is a cross-cutting issue, the importance of cross-sectoral knowledge on interdependencies and cascading impacts was found to be a key element of the data required to develop a strong capacity to *prepare*. Furthermore, thinking about heat at different spatial scales was raised, mostly in the work of London where there is a greater distinction between measures within buildings, outside of buildings, on the street level, and at the neighbourhood level. Future work might aim to specify these spatial and sectoral distinctions further. Additionally, an enhanced knowledge of interdependencies and cascading impacts as a result of a strong capacity to *prepare* indicates enhanced *flux* of resources and knowledge, and thus a stronger capacity to *recover*.

In Chapter 4, it was posited that 'business' should be removed from the analytical framework. However, the results demonstrate the importance of business to the strength of multiple principles, primarily through ensuring a wide range of actors are included in efforts towards resilience. Businesses are also of course key to public-private partnerships – an important level not covered by the scope of this thesis.

Communication was highlighted as important, particularly in Rotterdam, to get people involved in climate adaptation and resilience efforts. Communication to tackle the barriers to increased resilience for the threat of heat are discussed in 9.1, and this points to an important aspect of the analytical framework regarding this point: a key element of *preparedness and planning* is communicating for awareness, but this should be specified to go beyond just making people aware. The aim of communication should be engagement, which again as discussed in 9.1 is a small but important distinction.

Biodiversity was not raised by any interviewees; however, this remains an important element of resilience for the threat of heat. Much of the measures taken by London and Rotterdam involve green and blue infrastructure, however from an ecological perspective, such infrastructure needs to actually function in terms of provide ecosystem services – such as contributing to the reduction of the urban heat island. Maintaining biodiversity is key to the provision of functioning ecosystem services, which enhances *homeostasis*.

Finally, ensuring a *diversity* of actors involved appears to be key to almost all aspects of resilience in this framework. Public participation of a diverse group ensures more diverse knowledge sources, and that knowledge is co-created (capacity to *prepare*): this is illustrated well by the use of 'risk dialogues' in Rotterdam for precisely this purpose to supplement quantitative knowledge production. More diverse, co-produced knowledge results in a wider range of measures that target the issues identified by stakeholders as more important (capacity to *absorb*), which is more effective on the longer-term (*flexibility*), and contributes to a greater degree of autonomous action at different levels (capacity to *recover*).

9.2.2 Reflection on Urban Resilience Conceptualisation

Conceptualising urban resilience into four capacities, that also represent the different pathways to be taken towards resilience, has been found to be useful in assessing the contributing factors to the resilience emphases and thus aiding recognition of the different resilience focus in London and Rotterdam as a result of different institutionalised reflexes. This, as intended by Wardekker et al. (2020), helps make the "choices regarding resilience principles transparent and explicit", consequently enabling "informed choices on which principles matter most for the local experts and their stakeholders" (Wardekker et al., 2020, p.11). Furthermore, for an issue such as heat which is relatively new to the climate adaptation and resilience agenda in both cities, the differentiation between present resilience emphases and future emphases as indicated by policies and plans is useful in illustrating how the choices made further influence the pathways to be taken into the future.

However, resilience is an abstract, nuanced, and complex concept conceptualised within socio-ecological systems thinking. Breaking it down into more useable parts for practical application/diagnoses of resilience can be viewed as reductionist, complicating the concept by moving it further from the original ecological conception. Thinking in terms of ten principles and four capacities reduces the ability to see links and interdependencies between principles, of which there are many. This all risks missing the point of the concept as an emergent *property* of a complex *system*. Others have found that indices and frameworks to measure resilience are often found by practitioners to be difficult to use strategically and regularly, and ones with large sets of criteria (like this one) to be time and resources intensive (Coaffee, et al., 2018). There are secondary impacts of this: the professionalisation and systematic adoption of codes of resilience governance to provide the necessary detail for assessment, likely including forms of information management, is likely to slot resilience back into new public management framing (Coaffee & Lee, 2016; Coaffee, et al., 2018) – bypassing the point of resilience thinking. There is thus always a trade-off between resilience as a useful perspective with which to tackle complex problems, and its complexity reduced for ease of understanding and applicability in practical situations.

There are valuable insights gained here on the limits of prioritising buzzwordy policy goals like resilience at the policy level of cities whose urban governance relies on bureaucratic structures that prioritise efficiency-optimisation and problem management. It is therefore posited that rather than integrating resilience thinking into these structures (and its subsequent reductionism and professionalisation), prioritise and integrate the indicators of transformative governance instead (e.g. Hölscher, et al. 2019). Resilience then emerges and evolves as a property of a transforming, increasingly flexible, multi-level, and integrated governance system. Changing the perspective of the goal of the governance strategies recommended here (from building resilience to transforming governance) can then better consolidate overall efforts across multiple levels and sectors, and furthermore contribute to 'critical awareness-raising'.

9.3 Research Limitations and Validity

There are limitations when it comes to the validity of the results of this research. COVID-19, as well as time and resource constraints, limited the extent to which a wide variety of interviewees could be accessed. The research therefore focuses on a small range of stakeholders, likely narrowing or biasing responses gained. Attempts were made to account for this by including document reviews and wider literature as well as interviewee responses. Furthermore, it is suspected that the limited interaction format of a video calling acts as a barrier to more natural communication, with some interviewees perhaps not being as open and mutual understanding not flowing as freely as it would in face-to-face communication. Furthermore, the variety of interviewees is likely to convey a narrower perception of urban resilience, as there is a focus on actions originating at the level of city-level governance and their partners, as opposed to also considering broader action at the level of communities and how this also contributes to urban resilience.

Although London and Rotterdam represent two specific cases – frontrunners in embedding resilience and only recently considering heat higher on the agenda – the insights gained from Chapters 8 and 9 are externally valid in terms of their broad applicability. Firstly, in understanding heat as a problem area in historically temperate climates, in which cities can easily overlook many of the societal interactions that make it so tricky; and secondly, in understanding the relations between urban resilience and urban governance as discussed above.

Finally, despite the literature reporting frequent negative feedback from practitioners when it comes to implementing resilience indices and frameworks as discussed in 9.2.2 (Coaffee, et al., 2018), there was positive feedback on Wardekker et al.'s (2020) urban resilience capacities framework. Interviewees generally found it useable and easy to understand in comparison with previous encounters with the concept. It is therefore recommended for future assessments of resilience, but with the following considerations. Assessment of twenty principles overall (ten principles in two cities) was found to be an unwieldly number of analytical units when considering the boundaries of a Master's level thesis project. Therefore, as discussed in 9.2.2, the framework is time and resource intensive, and does lose some usability when applied to a specific threat like heat – as the aim of the original framework is its use by practitioners (Wardekker, et al., 2020), it consequently is likely to contribute to the negative secondary impacts discussed in 9.2.2 as a result of professionalisation. Alternatively, as climate change is one threat of many that an entire urban system experiences, extreme heat may be too narrow/specified a risk for this framework. It is therefore recommended that further research applies this conceptualisation to an analysis of a city's resilience in the face of more generalised climate risks. In this way, usability and potential reductionism of the analytical framework can be assessed, and it can be tested whether similar conclusions regarding urban governance are found.

10. CONCLUSION

Like many of the threats currently faced by urban environments, heat is the archetypal 'wicked problem'. Resilience is an increasingly applied complex solution to help tackle such problems, however analysis of its application to the threat of heat is lacking. This thesis research sought to address this knowledge gap and answer the following question – how resilient are two European cities to extreme heat, and what governance strategies can enhance resilience, with particular regard to vulnerable groups like the elderly? A conceptualisation of urban resilience capacities – the capacity to prepare, absorb, recover, and adapt – has been specified and further operationalised for the threat of heat following a broad overview of resilience in cities across Europe for use by a societal actor in a publicly available report. The insights gained were able to frame a more in-depth analysis of urban resilience to the threat of heat in London and Rotterdam.

Each of these cities displays different levels of resilience, owing to externalised factors such as institutional reflexes. This is clearer in London, due to the greater threat heat poses to the city and its subsequent stronger focus in policy and action: London's resilience emphasis lies within the capacity to prepare and recover. Detailed, cross-sectoral data and a focus on emergency and risk response and management are the underlying reasons for this focus.

Rotterdam, whilst emphasising the capacity to absorb and adapt through robust infrastructure and innovative strategy for its priority climate threat of flooding, is significantly less resilient to the threat of heat. The underlying reason for this is primarily a lack of awareness, owing to the fact that heat is only just becoming more serious an issue. The resilience and climate adaptation plans of both cities indicate an increased emphasis on resilience, with this thesis indicating particular areas that may require greater attention.

Beyond the differences in resilience emphasis, both cities struggle with the overarching features of heat as an issue area: its low legitimacy, its vague problem definition, and its lack of ownership due to its cross-cutting nature. Such features interact with the bureaucratic realities of urban governance that both London and Rotterdam experience, despite efforts as part of the membership of 100 Resilient Cities to move towards more adaptive and flexible forms. These efforts are reflected in the governance strategies pursued in Rotterdam and London, that are also recommended in wider literature as part of moves towards more transformative forms of urban governance that can better take account of the embedded status quo, which in many ways results in the weaknesses regarding resilience. In this way, it is recommended that rather than perceiving resilience as a policy goal and dealing with the barriers that come up on the way, to instead switch the focus and address the barriers directly whilst witnessing resilience emerge as a property of a transforming system.

When considering the impacts of resilience on more vulnerable groups, important factors are raised by this thesis. When it comes to heat, the topic is mostly conceptualised and managed within the sector of public health, and from a top-down perspective. Where heat impacts other domains, this is considered to a lesser extent and not integrated within the impacts on public health. This is impactful in two ways. Firstly, the siloed consideration of heat overlooks the interactions of sectors like public health and the built environment – between the social and the technical, between people and place: how vulnerable groups like the elderly interact and behave in their environment, if they have access to it, and how institutionalised regimes in their environment impact upon their level of vulnerability. Secondly, a top-down focus removes questions regarding how the most vulnerable are actually affected and how they can be most effectively reached. Inclusive, decentralised policy processes that kindle genuine opportunities for participation and co-creation are key to improving awareness of and engagement with climate threats like heat, and effectiveness of measures to address them, helping again to overcome barriers and transform urban governance for resilience.

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APPENDIX A

In-Depth Interviews

Reference	Position and Focus Area	Organisation
Rotterdam		
R1	Advisor – climate adaptation	Municipality of Rotterdam
R2	Researcher – transitions governance	DRIFT Research Institute and Consultancy
R3	Officer & Advisor	Municipality of Rotterdam – Resilience Department
R4	Advisor – environmental health	GGD (municipal public health service) & Municipality of Rotterdam
R5	Specialist – climate adaptation	Sweco NL (consultancy)
London		
L1	Programs Manager – climate change and adaptation	Greater London Authority
L2	Expert & Advisor – climate adaptation and built environment	University College London; Greater London Authority; & local authorities
L3	Manager & Coordinator – climate change and environment	London Climate Change Partnership; Greater London Authority
L4	Project Officer – sustainability & air quality	Cross River Partnership
L5	Consultant – sustainable buildings	Sweco UK (consultancy)

Preliminary Interviews for Urban Insight Report

Reference	Position and Focus Area	Organisation
P1	Researcher – urban green infrastructure and ecosystem services	Autonomous University of Barcelona; Barcelona Laboratory for Urban Environmental Justice and Sustainability, Spain
P2	Officer	Barcelona Municipality – Sustainability Office, Spain
P3	Officer	Barcelona Municipality – Resilience Office, Spain
P4	Consultant - environment	Sweco UK (consultancy)
P5	Researcher – architecture	Manchester University, UK
P6	Researcher - aging	Avans University of Applied Sciences, Breda NL
P7	Specialist – climate adaptation and water	Sweco Sweden (consultancy)
P8	District Deputy Mayor	Warsaw Municipality, Poland
P9	Director	Global Cool Cities Alliance

APPENDIX B

Measures used across Europe that enhance the capacity to *absorb*:

Behaviour changes: get up earlier in cooler times of day, go outside or exercise in the morning/evening when it is cooler, take mid-day naps, use fans, install air conditioning, shower more, drink water, wear hats, sleep on the ground floor, open windows, use blinds, stay in the shade.

Passive cooling: internal shading (sun blinds), different types of external shading (more efficient than internal shading as with that heat is already trapped inside), reflective paint, green roofs, green walls, white roofs, easy-to-open windows, insect screens, Passivhaus building design.

Mechanical cooling: fans, air conditioning

Building design: Passivhaus building design, improved insulation and airflow, strategic use of space (bedrooms on lower floors and north sides of buildings, not near laundry room/kitchen, especially for more vulnerable infrastructure like care homes), building position, consider occupants' needs (e.g. air conditioning that can be altered in individual rooms in care homes), consider landscaping.

Green and blue infrastructural measures: larger-scale measures like parks, gardens, woodland, green spaces, rivers, wetlands, larger bodies of water, green cycling and walking routes; and smaller-scale measures like removal of paving and installation of permeable paving/greenery, green roofs, green facades, street greenery, water squares, fountains. Focus of these measures also at transit stops, more vulnerable/critical infrastructure (e.g. schools, care homes, hospitals, densely built areas with significant paving/little greenery).

APPENDIX C

Following the results of the in-depth research in Chapters 6 and 7, there are a few further specifications to the analytical framework. These are described in more detail in 9.2.1, and are shown below in red.

Capacities for resilience	Principles	Specified operationalisation for heat
Capacity to PREPARE	Anticipation & Foresight	- Relevant heat-related data and mapping is available and accessible for a wide range of actors - Mapping and data include socio-economic and environmental variables, and cover different sectors and scales - Socio-economic and environmental trends ('slow variables') that enhance vulnerability are monitored e.g. elderly population, pollution levels - Active implementation of knowledge into preparation actions - Knowledge co-created using a variety of actors
	Preparedness & Planning	- Localised extreme heat event response and management plans are in place - Risks and vulnerabilities are communicated to the public, businesses and healthcare workers, who are engaged and aware of their responsibility
	Homeostasis (i.e. strategic management of feedbacks)	- Heat is integrated into other sectoral programs and policies in areas like public health, urban planning, and climate adaptation - Responsibilities of actors are integrated into law - Integrative policy process ensure equitable inclusive benefits, including consideration of those most impacted by heat - Communication channels are in place and functioning horizontally across sectors and vertically across levels - Green and blue infrastructure is well maintained
Capacity to ABSORB	Robustness & Buffering	- Climate impacts can be withstood or lessened due to policy, spatial, private and infrastructural measures that focus on impact and risk reduction (see Appendix B for examples of measures that enhance robustness)
	Diversity	- Diversification of governing authorities, resources, management strategies, means, institutions, and stakeholders, resulting in diversification of response - Functional diversity (multiple ways to fulfil a need, i.e. a function, exist; see Appendix B for a diversity for measures that enhance capacity to absorb) - High biodiversity
	Redundancy (i.e. spare system capacity)	- Shared functions and governance responsibilities across scales and sectors for heat preparation and response - Vital city functions and resources have backups and alternative sources
Capacity to RECOVER	Flatness	- Non-hierarchical, decentralised governance allowing competent, authoritative, and autonomous local action - Broad, active, and inclusive participation in decision-making (including the vulnerable and marginalised) - Participatory and context-specific design of buildings and urban spaces
	High-Flux	- Quick movement of resources through a system, allowing quick mobilisation in response to threat - Cross-sector networks and partnerships facilitate widespread access to information and financial and human resources and enhance connectivity between sectors - Decision-makers are resourceful and flexible in responses and strategies
Capacity to ADAPT	Learning	- Reflective, participatory learning across sectors and levels from previous extreme heat events - Room for experimentation, innovation, and 'learning-by-doing' - Active application and implementation of new knowledge
	Flexibility	- Institutional flexibility: flexible decision-making and cooperation arrangements - Flexibility in spatial planning: 'structural elbowroom' for future modification, extension, or retrofitting in spatial planning - Flexibility in measures: prioritisation of 'no-regret' measures