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Empirical insights and theoretical reflections from case studies in Amsterdam and Mumbai

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RISE-UP: Resilience in urban planning for climate uncertainty-empirical insights and theoretical reflections from case studies in Amsterdam and Mumbai

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ABSTRACT

Climate change is one of the main drivers of uncertainty in urban planning, but only a few studies systematically address these uncertainties, especially in the long term. Urban resilience theory presents principles to manage uncertainty but largely focuses on individual urban systems rather than complex interdependent dynamics. Further, most planning and resilience theory originates from the Global North and is unsuitable for capturing the dynamics of the Global South. This study uses an exploratory multi-case analysis towards developing an enhanced understanding of urban planning for climate uncertainty. We argue that long-term urban planning for climate uncertainty can benefit from systematically integrating resilience principles. We use a two-step qualitative research approach: (1) To propose a conceptual framework connecting urban resilience principles, approaches to urban planning under uncertainty and planning responses in urban systems. (2) To use the conceptual framework to analyse climate-related planning responses in two contrasting case studies in the Global North (GN) and Global South (GS) (Amsterdam and Mumbai). We conclude with four propositions towards an enhanced understanding of urban planning for climate uncertainty by drawing upon the empirical insights from the two case studies.

1. Introduction

> "The complexities and uncertainties associated with climate change pose by far the greatest challenges that planners have ever been asked to handle."
>
> (Susskind, 2010)

In its recent chapter on 'Urban Areas,' the Intergovernmental Panel on Climate Change (IPCC) highlighted the importance of promoting the resilience of urban areas as a central policy consideration (Lwasa et al., 2022). Especially for long-term urban planning, climate change brings significant uncertainty compounded by environmental, societal, and economic drivers. To manage uncertainties, urban resilience theory presents several principles to guide appropriate planning responses (Dhar & Khirfan, 2017; Jabareen, 2013; Kim & Lim, 2016; Wardekker, 2018). Despite integrating these principles, planning responses remain largely incremental and emphasize *"bouncing back"* (Meerow & Stults, 2016; Muñoz-Erickson et al., 2021). They focus on individual urban systems (buildings, open spaces, and highways) for a single future scenario (Folke et al., 2010; Kates et al., 2012; Sharifi et al., 2017).

The need to navigate uncertainty has also led to the emergence of approaches such as decision-making under deep uncertainty (Marchau et al., 2019), transition management (Frantzeskaki et al., 2018), agile planning, storylines approach (Shepherd et al., 2018), and the *adaptive-modeling-managerial* perspective in infrastructure planning (Dominguez et al., 2011). While these approaches advocate planning for multiple futures, they do not see a wide application in urban planning because they usually work with probabilistic or fixed futures. This is unsuitable for urban systems with multiple spatiotemporal dynamics and path dependencies that must be accounted for in a planning timeframe (Hayes et al., 2019).

Urban planning under climate uncertainty requires expanding existing planning approaches and theories to systematically modulate responses based on disruptions or new insights. While the literature on resilience and uncertainty individually offer principles and approaches to manage disruptions, they have drawbacks that impede their application in long-term urban planning. Combining the field of urban planning with theories on urban resilience and urban planning under

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Table 1
Definitions of key terminology used in this study.

Concept	Definition
Urban Resilience	Urban resilience is the ability of an urban system to maintain or rapidly return to desired functions in the face of shocks or stresses(Meerow et al., 2016).
Urban Resilience Principles	They are specific mechanisms and behaviors that make an urban system/s resilient such as flexibility, multifunctionality, etc. (Wardekker, 2018).
Planning Response	In the context of resilience, Planning Responses refer to the full range of measures or initiatives undertaken to prepare, absorb, recover, and adapt to climate-related disruptions (Ataman & Tuncer, 2022; Linkov et al., 2014; Ribeiro & Gonçalves, 2019). This could target single or multiple urban systems and may include measures such as preserving ecological zones, improving engineering standards, introducing new urban functions, etc.
Conceptual Framework	A structure that highlights and links key concepts from literature and their application area (Ravitch & Riggan, 2016). In this study, we connect Urban Resilience Principles, Approaches to Urban Planning under Uncertainty and Planning Responses.

uncertainty may, therefore, have great potential.

In this study, we take the first steps towards an enhanced understanding of urban planning for climate uncertainty. The study is positioned in the early stages of urban planning, where strategic decisions are made in multiple urban systems. It adopts a rigorous methodology where a conceptual framework that ties together resilience and planning under uncertainty are systematically connected to planning responses. We use this framework as a basis for empirical research in using a combination of Multi-Case analysis (Eisenhardt, 2021) and Systematic Combining (Dubois & Gadde, 2002).

The paper is structured as follows: First, we examine academic literature to develop our conceptual framework connecting the literature on resilience and planning under uncertainty, and exploring how they can together determine planning responses (Section 2.3). Second, we use the conceptual framework (Fig. 2) as the basis to analyse two case studies from the Global North (GN - Metropolitan Region of Amsterdam (MRA)) and Global South (GS - Mumbai Metropolitan Region (MMR)) (Section 3). The cases are selected to reflect the inherent variability in planning processes in the GN and GS and not to generalize findings for the GN and GS.

Using official planning documents and extensive semi-structured interviews, we assess to what extent the cases integrate resilience and address approaches for planning under uncertainty when proposing climate-related planning responses (Section 4).

Third, we formulate four propositions using our empirical findings to reflect on the current gaps in urban planning for climate uncertainty. Each proposition is substantiated using comparative insights from the two cases, such as narrative accounts and structural findings that characterize the planning process. We use the insights to make the first steps towards an enhanced understanding of urban planning for climate uncertainty (Section 5).

2. Background

In this section, we provide the theoretical background for our work. First, we analyse academic literature on urban resilience, focusing on planning frameworks that provide guiding knowledge for implementation (Section 2.1). Second, we discuss approaches for urban planning under uncertainty (Section 2.2). Although closely connected, there is no definitive theory connecting urban resilience and urban planning under uncertainty. The following section delves into both theories to highlight gaps and consolidate learning from the two streams into a conceptual framework for urban planning for climate uncertainty that forms the basis for analyzing the case studies. Table 1 presents a list of terminology and definitions used in this study.

2.1. Urban resilience principles

Integrating resilience into urban planning requires planners to identify disturbances such as precipitation and heatwaves (*resilience to what?*) that a region may face and propose planning responses to ensure that urban systems (*resilience of what?*) remain in a functional state (Ahern, 2011).

To identify urban resilience principles, we broadly assessed urban

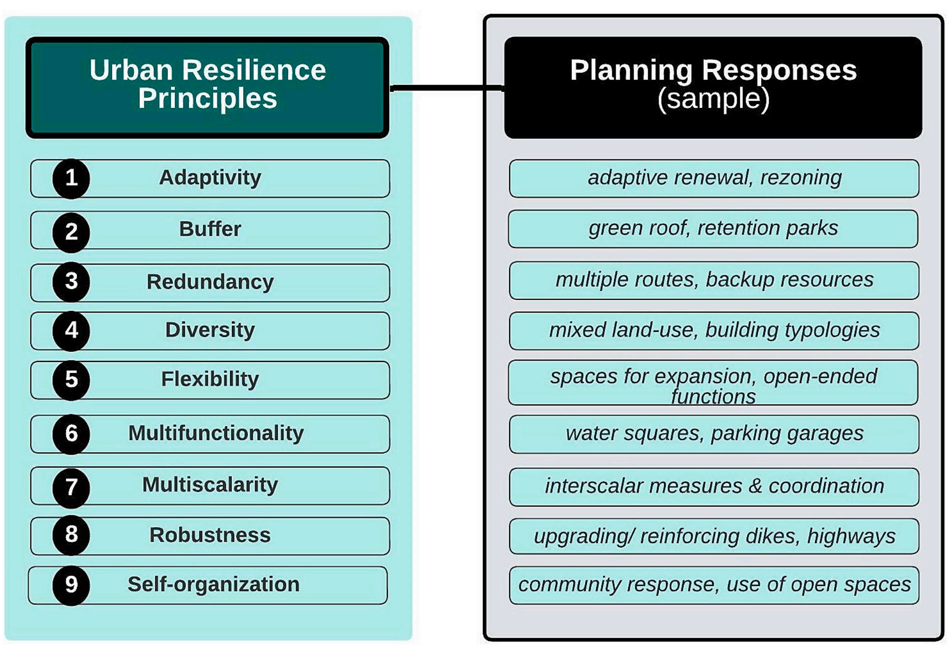

Fig. 1. A selection of recurring *Resilience Principles* from academic literature that is widely applied through certain *Planning Responses* in the urban environment. A principle can inform multiple planning responses, and a response can be impacted by more than one principle.

resilience frameworks in academic literature in the context of climate change. We conducted a systematic search in the online database Scopus using the terms:

$$((urban\ \ OR\ \ city)\ AND\ \ climat^*(e)\ AND\ (resilience\ \ OR\ \ \text{adaptation})\ AND\ \ (\text{framework}\,)$$

We expanded the search string to include urban climate adaptation, sometimes used interchangeably with urban resilience. From the 1460 results, we screened the titles and abstracts to select 51 papers that explicitly discuss the implementation of resilience in urban planning. We then conducted a detailed consolidated review of 20 papers focusing on urban resilience 'planning frameworks.' These papers specify *Resilience Principles*, which provide guiding knowledge that planners can implement through design and planning responses. The final list of papers we analyzed and the resilience principles they mention are in (Appendix B).

Fig. 1 presents a selection of recurring *Resilience Principles* from the literature that is widely applied through certain Planning Responses in the urban environment.

They include Adaptivity, Buffer, Connectivity, Diversity, Flexibility, Modularity, Multifunctionality, Multiscalarity, Redundancy, Robustness, and Self-organization (Appendix B). While there is no single accepted set of principles, several frameworks use principles under different conceptual denominators to inform similar planning responses (Ribeiro & Gonçalves, 2019). Fig. 1 therefore also highlights how the resilience principles can be applied through common Planning Responses, also derived from literature. In Section 2.1, we elaborate on the principles and later assess their relation to concrete planning responses in our two case studies 3.3.

Principle 1 *Adaptivity*, involves adjusting urban systems to changes using responses such as adaptive renewal, reuse, and rezoning (Dominguez et al., 2011; Giordano, 2012; Spaans & Waterhout, 2017).

Principle 2 *Buffer*, absorbs disturbances by creating reserve capacities (Godschalk, 2003; Spaans & Waterhout, 2017; Wardekker et al., 2010). Greening is a popular strategy to improve the latent potential of urban spaces to absorb excess rainfall (Kim & Lim, 2016) through responses such as water retention parks in low-lying regions and compartmentalizing regions using water channels.

Principle 3 *Redundancy*, keeps systems operational during crises by offering functional alternatives (Godschalk, 2003; Spaans & Waterhout, 2017; Wardekker et al., 2010). It includes strategies like multiple access routes to critical facilities such as train stations and hospitals, and setting up energy backups. Enhancing accessibility and risk absorption through denser urban fabric land divisions increases redundancy (Marcus & Colding, 2014).

Principle 4 *Diversity* is managing multiple risks or spreading risk impacts across different urban systems to minimize damages. Spatial diversity can be achieved through mixed land-use functions and distributing critical amenities to avoid simultaneous impacts (Dhar & Khirfan, 2017; Kumagai et al., 2010; Lak et al., 2020; Tyler & Moench, 2012).

Principle 5 *Flexibility*, is a system's ability to *leave things open* to manage changes (Godschalk, 2003). It can be achieved using open-ended functions to respond to multiple futures. Flexibility is restricted due to space scarcity, competing for spatial claims, unequal distribution of resources (Wardekker et al., 2020) or reliance on heavily engineered responses like dikes that create an artificial sense of stability.

Principle 6 *Multifunctionality*, draws from the concept of polyvalent spaces (Dhar & Khirfan, 2017). It uses preemptive design such that the same space can serve different uses without significant physical changes (Roggema et al., 2012b). Planning responses include public water squares that double up as playgrounds, floodable parking garages, and schools as temporary shelters.

Principle 7 *Multiscalarity*, involves understanding interactions across spatial scales to determine planning responses (Brown et al., 2012; Chelleri, 2012; Meerow et al., 2016; Wilkinson, 2012). In practice, it includes policies to ensure coordination between the local, regional and national levels and determine trade-offs between scales to minimize negative impacts and reduce regional imbalances when a major city is made resilient at the cost of surrounding regions. Multiscalarity can also enable understanding the speed of change at different scales to set short and long-term responses (Davoudi et al., 2013).

Principle 8 *Robustness*, is the potential to resist the negative impacts of disturbances by anticipating potential system failures and reducing damages by over-dimensioning the capacities of the system (Davoudi et al., 2013). Planning responses include designing flood defence infrastructure to withstand a very low probability of floods. In the short-term, robustness has proven adequate to manage risk impacts. However, as climate impacts become increasingly dynamic and extreme, robust systems with inherently low flexibility can suffer catastrophic damage.

Principle 9 *Self-organization*, implies maintaining an urban system's internal structure, function, and organizational patterns during a disturbance without significant external institutional interventions. A self-organizing system can preserve overall functionality by making changes at faster scales in its subsystems (Allen et al., 2005). Planning responses include community-led responses and aid distribution centres, schools as temporary shelters, and using water-based transport during a flood.

2.2. Approaches to urban planning under uncertainty

The central idea for urban planning under uncertainty is *'maintaining a fit'* of an area under changing dynamics (Rauws, 2017). This involves updating planning responses based on a changing environment such that systems can avoid or reduce undesirable lock-ins, keep the plan functional, reduce negative impacts and adjust urban configurations based on changing risks.

Conventional approaches for addressing uncertainty, such as performance monitoring and assessment, have successfully solved probabilistic uncertainties that can be predicted based on (past) statistics (Dessai & van der Sluijs, 2007). Examples are growth trends or frequently re-occurring weather phenomena. However, long-range climate uncertainties are so-called *deep* uncertainties, which cannot be defined by probabilities (Walker et al., 2003). They are conventionally addressed by adaptive planning or scenario approaches, for instance, in projects such as the Dutch Delta Program (Haasnoot et al., 2018).

However, there is no widely accepted and comprehensive set of responses that addresses uncertainty (Moroni & Chiffi, 2021) across

Fig. 2. Conceptual Framework for urban planning for climate uncertainty that is used to analyse the case studies. It illustrates that: (A) Urban Resilience Principles; and (B) Approaches to Urban Planning Under Uncertainty; together determine (C) Planning Responses; that impact (D) Urban Systems.

complex urban systems and over long time horizons. Hence, responses rely heavily on practitioners' intuition, experience, and preferences. To address this gap, we assess the available theoretical approaches to inform decisions in overall urban planning for uncertainty. We draw from the literature on deep uncertainty (Maier et al., 2016; Marchau et al., 2019), sustainable urban futures (Frantzeskaki et al., 2018), infrastructure management, and complexity in urban planning (Moroni & Chiffi, 2021) and synthesize four approaches to manage uncertainty in urban planning.

Type a *Pragmatic approach* is the dominant approach that targets planning responses for individual urban systems such as roads, buildings, and parks. It is perceived as a feasible approach that commits to short-term actions while keeping options open for the future. However, it relies on the most probable risk or "best guess" future for that system based on conventional cost-benefit assessments that restrict the scope of alternatives and are not viable for the long-term (Dominguez et al., 2011; Maier et al., 2016).

Type b *Nomocratic/Procedural approach* includes broad regulations to reduce exposure to risks and negative impacts from uncertainties. The approach focuses on prohibitive rules such as 'no-development zones' and restrictive building codes. It works on the premise that it is easier to avoid negative actions than to formulate positive actions that are resource-intensive and are eventually not used by planners (Rauws, 2017).

Type c *Methodological approach* considers a full range of possible, plausible, and unlikely future climate scenarios. It works on the premise that coping with uncertainties requires moving beyond linear predictions and historical trends. Scenarios that present undesirable lock-ins or interference with large complex systems, including those that are prima facie unlikely to happen, such as extreme climate trends, must be considered (Moroni & Chiffi, 2021). However, in practice, even cities with well-developed planning processes are limited to considering a few fixed planning or climate scenarios in decision-making.

Type d *Integrated approach* includes consideration of a range of societal values and normative issues that are related to or will impact responses to the main uncertainty being tackled (Van Asselt & Rotmans, 1996). Planners must consider state-sponsored ambitions for economic prosperity, democracy, policy preferences and other innovations that impact larger goals for climate risks and urban transitions. Responses include integrated area development plans, and finding clever sectoral combinations like the water-energy nexus.

2.3. A conceptual framework for long-term urban planning for climate uncertainty

We propose a conceptual framework (Fig. 2) that connects the two prevailing theoretical streams shaping urban planning discourse for climate uncertainty discussed above – *Urban resilience principles* (Section 2.1) and *Approaches to urban planning under uncertainty* (Section 2.2). The intersection of these literature streams illuminates differing, yet fundamental, thought processes that underpin the formulation and scaling up of climate-related planning responses. Together, resilience principles and approaches to planning under uncertainty can provide a framework to analyse how specific planning responses are selected and implemented by considering the historical risk exposure and institutional planning structures in any region. *Planning Responses* are the common denominator to assess how the two streams interact and manifest in space and impact single or multiple urban systems.

As discussed in Section 2.1, urban resilience theory presents principles that can be applied through planning responses to managing the impacts of climate change. Despite integrating resilience, there is a tendency to propose planning responses for fixed short-term risks (Adger et al., 2011). Some climate objectives may also require the implementation of principles that may have the opposite impacts on space (such as robustness v/s flexibility), which restricts the ability of urban systems to respond and adapt to evolving uncertainties in the long-term (Hayes et al., 2019; Holling & Gunderson, 2002). Hence, urban planning for climate uncertainty requires integrating resilience and expanding existing planning processes to systematically modulate responses based on new insights.

To systematically assess how resilience and uncertainty impact urban systems, we use a classification offered by the *Urban Layers Approach (ULA)*. ULA classifies urban systems into five groups based on their spatio-temporal characteristics, i.e., the spatial scale and the lifecycle over which the system tends to change (Roggema, 2010). Understanding this change window enables planners to propose appropriate planning responses to integrate resilience to uncertainty.

The five urban systems or layers with their spatio-temporal lifecycles: Layer 1: Unplanned/Open spaces (1–10 yrs), Layer 2: Occupation/Buildings (3–20 yrs), Layer 3: Focal Points (5-20 yrs), Layer 4: Networks (20–100 + yrs), and Layer 5: Natural Resources (20–100 + yrs).

We illustrate the application of the conceptual framework using the example of highways that see heavy investments in urban regions (Hub and Economics, 2017). From resilience literature (Section 2.1), we derive that **Highways *(Layer 4: Networks)***, become resilient by integrating principles such as *Redundancy (3)*, *Flexibility (5)*, *Robustness (8)*, and *Self-Organization (9)*. These can be achieved through planning responses such as alternate routes, reserving spaces for future vehicle volume, better engineering standards, and preempting self-organization behaviour in a crisis. Resilience must be integrated over the highway's lifecycle to manage long-term uncertainty. Using the *Type-b: Nomocratic Approach*, and *Type-c: Methodological Approach* for planning under uncertainty (Section 2.2) may ensure performance standards to minimize failure under extreme climate scenarios. Use of *Type-d: Integrated Approach* would involve reserving space required for future energy goals and the advent of autonomous vehicles that will significantly impact its use.

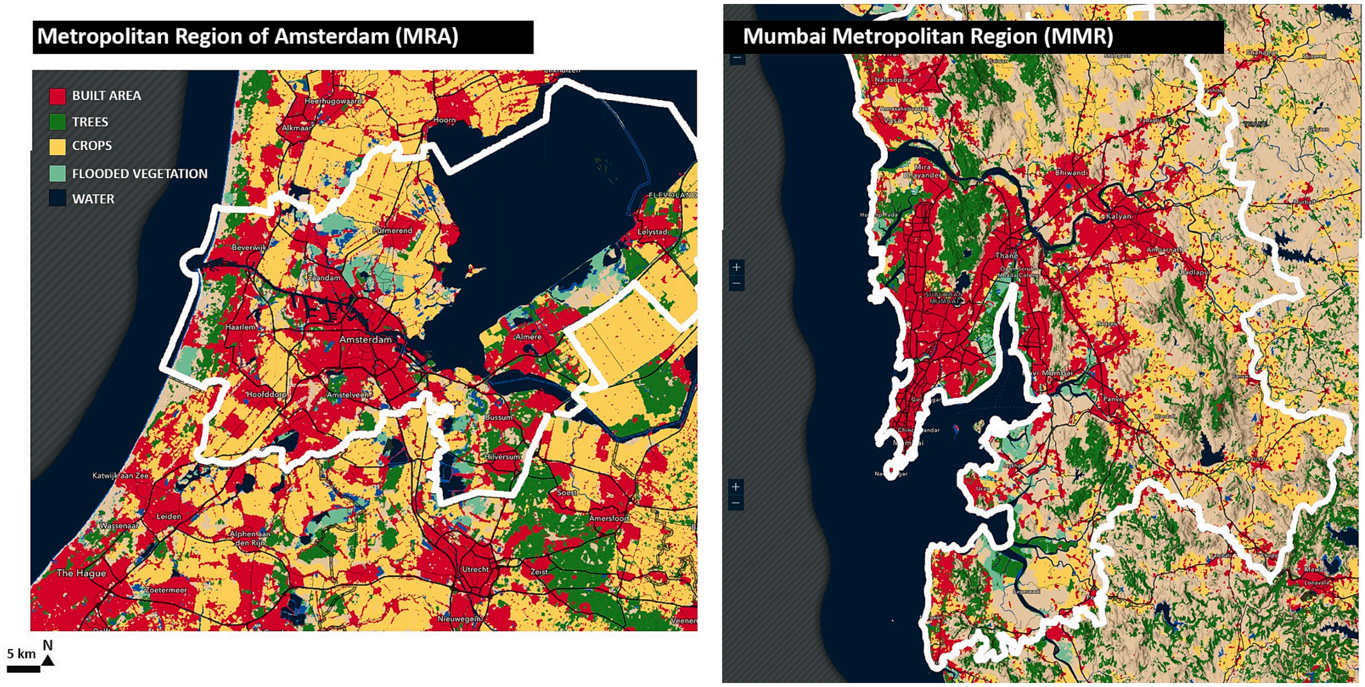

Fig. 3. Selected Case Studies: Metropolitan Region of Amsterdam (MRA - left) and Mumbai Metropolitan Region (MMR).
(Source: Sentinel-2 10-Meter Land Use/Land Cover.)

The conceptual framework is used for analyzing two case studies. The framework serves as the common basis to map and analyse how these two theoretical streams inform Planning Responses and how each planning response impacts one or multiple Urban systems in a region. These impacts influence the longevity of responses and their role in long-term uncertainty.

3. Methodology

This section elaborates on our research approach, case study selection, and data collection and analysis.

3.1. Research approach

This study aims to make the first steps towards towards an enhanced understanding of urban planning for climate uncertainty. The objective is to understand, through empirical insights from contrasting case studies, how cities are formulating climate-related planning responses and how these planning responses relate to urban resilience theory and planning approaches under uncertainty.

We use a multi-case analysis (Eisenhardt, 2021) together with Systematic Combining (Dubois & Gadde, 2002). The multi-case approach allows us to assess contextual variability in the case studies. We use *Systematic Combining* to develop the findings of the case studies through the interplay between the conceptual framework (theory world) and the empirical findings (real world) (Dubois & Gadde, 2002). A requirement for *Systematic combining* is clear boundaries for assessing empirical data, without which the research may expand (or shrink) based on each case and distort analysis to inform a common theory. We rely on the conceptual framework as the common reference to analyse the two case studies and identify gaps and missing links. Subsequently, we present four propositions to reflect on the current gaps in long-term urban planning for climate uncertainty.

3.2. Selected case studies

The conceptual framework is applied to two case studies. To contrast the Global North (GN) and Global South (GS) and investigate the divide in planning and resilience literature (Marin, 2021), we opt for one case study in each of the two contexts (Fig. 3). Further, the case study cities are selected based on the following requirements: (1) cities that have strong planning ambitions to address climate change; and (2) cities that invest in a large volume of new infrastructure or systematically renew ageing infrastructure.

Based on these requirements, we selected two urban regions: the Metropolitan Region of Amsterdam (MRA) in the GN and the Mumbai Metropolitan Region (MMR) in the GS. Both regions are their respective countries' economic and cultural centres but have different planning processes and institutional structures. Both recognize the urgency to meet climate-related goals and are drafting spatial strategies that frame the opportunity to derive diverse insights.

While these are not the only 'types' of cities in the Global North and South, they exhibit major urbanization characteristics that presented the variability required for this study. Amsterdam exhibits characteristics of a developed GN economy with high per capita income, technological advancement, and political stability, but an ageing society and ageing infrastructure. Mumbai, on the other hand, can be characterized as a developing GS economy with medium per-capita income, in the process of industrializing, with a majority youth population and investments in new infrastructure.

3.2.1. Case Study 1: Metropolitan Region of Amsterdam (MRA)

The Metropolitan Region of Amsterdam (MRA) in the Netherlands is an agglomeration of 32 municipalities housing 2.48 million people. MRA has a polycentric structure with Amsterdam as the dominant core, supported by eight sub-centres. Among one of the highly developed areas in the world, MRA is characterized by a mature spatial planning approach with well-coordinated public investments, consensus-driven political processes, and robust urban planning structures (Healey, 2006).

Table 2
Combined Participants grid for MRA (P1 to P20) and *MMR (P21 to P39)* classified based on their role in the urban planning process and their domains of expertise. 'X' indicates that we did not receive responses from the right participants from that domain.

Domain	Role in the urban planning process			
	Strategic/Policy Advisors/ Bureaucrats	Academic researchers	Sustainability/Climate/Environment/ Engineers	Urban planners
Urban Planning, Geography	P1, P2, P26, P30, P33, P38	P11, P20, P34, P35, P36	P3, P15, P18, *P27*	P4, P5, P17, P19, *P21*, *P22*, *P37*, *P39*
Climate and disaster risks, environmental planning	P6, P7, P9, *P24*, *P28*	P10	P12, *P31*	P8, P13, *P23*, *P25*
Infrastructure	P14, P16, *P29*	X	P23	X

MRA's economic attractiveness has resulted in high inward migration and outward expansion of the urban footprint, which has led to a significant housing crisis. This has added immense pressure on its mobility systems and meeting sectoral goals like energy transition.

MRA's vulnerability stems from the fact that large areas lie below sea level and are protected by engineered dikes. Around 70 % of MRA's area is threatened by one or more risks that it must respond to extreme heat periods, rainfall, prolonged droughts, and sea-level rise. In addition, the region faces labor shortages and increasing socio-economic disparity.

Planning is driven by a regional urbanization strategy (*verstedelijkingsstrategie*) supported by city-level Structural Vision (*structuurvisie*, detailed urban plans (*bestemmingsplan*), and thematic documents on mobility, environment, energy, and climate. From a climate perspective, MRA is critiqued for its highly regulated planning process, limiting its flexibility to absorb fluctuations and make constant adjustments.

3.2.2. Case Study 2: Mumbai Metropolitan Region (MMR)

The Mumbai Metropolitan Region (MMR) in India is the fourth-largest urban agglomeration globally, consisting of 8 municipal corporations, nine municipal councils, and houses over 22 million people. MMR has a polycentric structure, with Greater Mumbai as the dominating core supported by several densely populated sub-centres.

MMR's economic attractiveness has led to high inward migration. Its urban growth has rapidly increased to crushing densities adding immense pressure to its urban infrastructure systems. Formal planning could not meet the requirements of the growing population, which is why more than half the urban population lives in informal settlements. The region is now making high-value investments in roads, high-speed rail, metro, and coastal roads.

MMR is vulnerable as the city is built on reclaimed land, and large portions along the coast lie below the high tide level. The city must have planning responses to chronic flooding, inadequate civil infrastructure, outdated stormwater systems, and insufficient open spaces.

MMR's official planning is guided by the Regional Plan (RP)

Table 3
Case Study 1 (MRA): Table presenting dominant resilience principles discussed by participants, with the number of mentions and sample quotations. (+) and (−) indicate principles with high application and low application respectively.

S.	Resilience principles	Terms included	Mentions	Participants	Example quotes
1	Adaptivity (+)	adaptable, adaptation, agile, accommodate, adjust	180	ALL	"Greenwashing is synonymous to climate adaptation" (P2) "Big decisions on where to plan…is not taking climate adaptation or future uncertainties into account" (P8), "We need to try to not make big investments, where we later regret it. We need to find a way to make progress, but keep different adaptation options open." (P7)
2	Buffer (+)	retention, infiltration, storage, garden, green roof	31	1, 2, 5, 6, 8, 10, 11, 12, 13, 14, 15, 18, 19, 20	"The 'retain-store-drain' strategy in the Netherlands is translated into a multi-level flood protection strategy."(P10), "we have spatial plans on a local level, where you can include requirements for new buildings…, increase infiltration/buffer capacity of roads and not immediately discharge it to the sewers" (P6, P12)
3	Multi functionality (+)	alternate, water square, mixed use	17	1, 5, 9, 10, 14, 16, 17	"The water square is only a solution to one issue. I don't know anyone who likes to live at the water square"(P1), Different elements in a city have different frequencies. The user that occupies a building changes few years, but the function changes slower" (P1)
4	Robustness (+)	strong, reinforce, maintain	29	1, 2, 3, 5, 6, 7, 8, 9, 10, 12, 13, 14, 16, 17, 18, 19	"A redevelopment offers a moment of renewed interest and gives us the opportunity to review what we wrote down 10 years ago, make a new perspective where we integrate climate adaptation" (P5), "Can you use a small percentage of your maintenance projects to test new techniques?" (P14)
5	Diversity (−)	diverse, various, range, multiple	16	1, 2, 5, 6, 7, 10, 17	"by spreading the risk to 1000 planning options, there's always one that works" (P1), "there is an optimal balance between structure and diversity in an ecosystem, in order to be resilient." (P1)
6	Flexibility (−)	frequency, updating	60	1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 17, 18, 19	"It's not very flexible because of the lack of space." (P6), "We have to skip the blueprints" (P14)
7	Multi scalarity (−)	scale, local, regional, community, neighbourhood, scalar	108	all except 4 and 9	"If you really want to work on climate adaptation, you have to do it on a regional scale."(P2,13), "Scale is connected to types of climate. You cannot cope with sea level rise in the design of your urban areas. Cities are limited by their administrative boundaries"(P12, P16, P18, P19)

Table 4
Case Study 2 (MMR): Table presenting dominant resilience principles discussed by participants, with the number of mentions and sample quotations. (+) and (−) indicate principles with high application and low application respectively.

S. no.	Resilience principles	Terms included	Mentions	Participants	Example quotes
1	Adaptivity (−)	adaptation, agile, accommodate, tipping, rapid, adjust	30	21, 22, 24, 25, 28, 27, 30, 31, 33, 38	P28: "Urban adaptation schemes elite-driven. You see a major role for transnational corporations, and the projects cater to urban middle class" P21: "Adaptation is perceived as a cop-out for governments because they have failed to limit emissions."
2	Buffer (+)	retention, infiltration, store, garden, green, permeate, park	28	21, 22, 26, 27, 30, 31, 33, 35	P22: "A lot of land designated for public purposes like parks eventually became a slum." P30: "Buffers are hard to achieve when the city is 97 % built-up"
3	Flexibility (−)	frequency, update	29	22, 27, 29, 30, 31, 33, 35, 36	P27: "We have to make a master plan every year to cater to the current trends. It is the only instrument and can be very flexible and be allowed to change as we move along. P33: "What we should freeze is ecological areas which will remain permanently as no development zones. The other areas should be very flexible to expand and absorb intense construction."
4	Multi scalarity (−)	scale, local, regional, community, neighbourhood, context, ward	110	21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39	P34: "You have to look at at least 30–50 years and think regionally for climate resilience". P29: "The Metro will last for 200 years. That kind of (scale) will change the whole city's life. So projects with long-term impacts must be given a special consideration in the planning process, which is not happening. P36: "Follow a flexible approach for macro level planning. Use local area plans for micro level urban development by following a market driven logic to enable equitable distribution of land."

supported by the municipal corporations' Development Plans (DP). The RP presents guidelines for growth across infrastructure, socioeconomic, and environmental sectors, and the DP presents more detailed zoning and building regulations. These plans are augmented by a state-level action plan for climate change and a city-level disaster management plan guiding response and recovery measures. MMR's planning documents are critiqued for being overtly prescriptive, regulatory, and prohibitory instead of building integrated visions. They do not identify entry points for climate-related goals but stick to broad recommendations (Krishnankutty, 2018).

3.3. Data collection and interview design

The analysis is based on two data collection processes. For both case studies, we first assessed grey literature in the form of primary planning documents and how they discuss climate-related planning responses (Appendix C). In the context of resilience, *Planning Responses* planning, preparatory, and recovery measures that target single or multiple urban systems (Table 1). Hence, we selected official planning documents for both cases, such as development plans, urbanization strategies, regional plans, climate action plans, and disaster management strategies, to extract the full range of climate-related planning responses.

Second, we conducted 39 semi-structured interviews with senior practitioners and scholars directly involved in the development and implementation of urban plans. The interviews were conducted over one year (2020−21) and each interview was approximately 60 min long and conducted online using Zoom/Teams calls due to travel restrictions during the Covid-19 pandemic.

The interview protocol was framed to dive into the thinking processes for climate-related planning and to what extent they are guided by theories of resilience and planning under uncertainty. The interview questions were structured into four main sections: Climate-related planning responses and sectoral focus; Long-term thinking (beyond current planning timelines); Knowledge gaps and institutional challenges; and Planning variables and values. A semi-structured protocol allowed us to vary the sequence of questions and ask follow-up questions to enable richer discussions. Appendix D presents an indicative interview protocol. A detailed protocol with a consent form may be accessed here:https://github.com/supadupa09/TFG_Interviews.git

The authors used their professional networks to identify participants in a 2-step process. A list of 20 experts was made for each case, which was expanded to approximately 200 using snowballing sampling, personal referrals, and social media. The objective was to select between 17 and 20 participants per case, which is the suggested sample size saturation in empirical research using interviews (Hennink & Kaiser, 2021). Short introductory conversations were conducted based on the research's intent to arrive at a combined list of 39 experts to ensure a reasonable representation of sub-domains - 20 for MRA and 19 for MMR. Participants came from four sub-domains that play crucial roles in planning: urban planners, strategic/policy advisors/bureaucrats, academic researchers, and specialists in sustainability, environment, and engineering (Table 2).

3.4. Data analysis

The goal of the data analysis was to (1) Analyse grey literature to map climate-related planning responses for different urban systems; and (2) Analyse interview content for the application of urban resilience principles, planning responses, challenges, and approaches for planning under uncertainty.

To analyse interviews, we developed a corpus of the 39 interviews by transcribing recordings and combining memos written during the interviewing process. Interviews for each case were analyzed separately using systematic qualitative coding on *Atlas TI*. Qualitative analysis of interviews was conducted in three steps (Bryman, 2016).

In *Step-1*, we used open coding to extract broad findings on integrating climate goals, planning approaches, urban systems, values, and challenges. The coding scheme was derived from findings from the literature review in Section 2. In *Step-2*, we used selective coding to extract findings in four categories to focus on the research gap: Application of urban resilience principles, planning responses, approaches to uncertainty, and associated challenges (see Fig. 5). As there was a

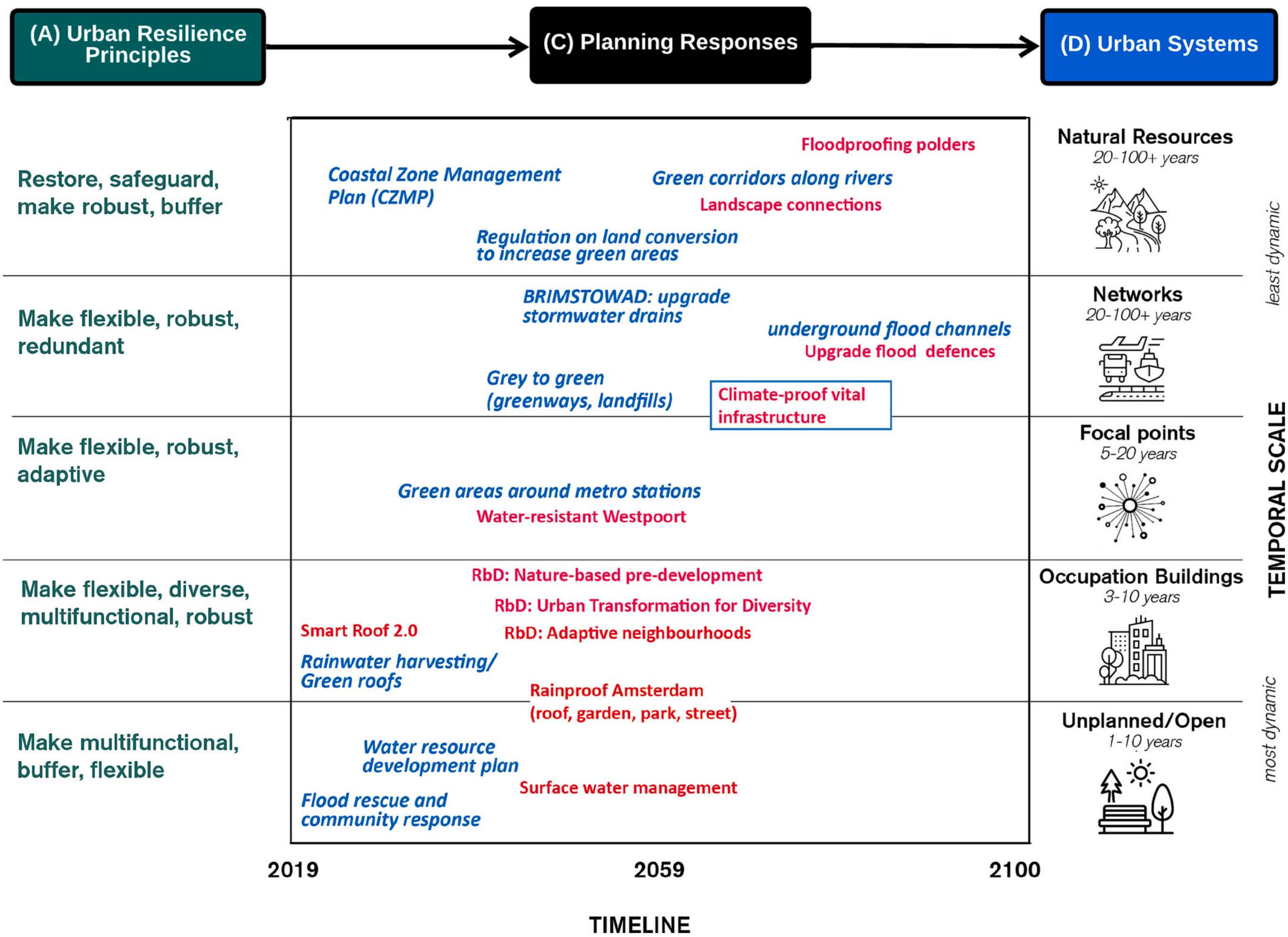

Fig. 4. Final coding scheme for the content analysis of interviews for MRA and MMR. Categories were utilized to identify components of the conceptual framework including Urban Resilience principles, Planning Responses, Urban Systems, and Approaches to Uncertainty; as well as Challenges in Long-term Planning.

heterogenous participant group, there was significant variation in terminology between interviews. Tables 3 and 4 enlist the dominant resilience principles discussed for MRA and MMR, respectively, together with terms that were grouped and sample quotations.

Finally, in *Step-3*, we revisit the coded data for both cases to conduct a cross-case analysis to observe similarities and dissimilarities in resilience principles applied in both contexts, variations in planning responses, and approaches to uncertainty. The following section elaborates on the findings for each case.

4. Results

4.1. Findings from grey literature

In Fig. 4, we map proposed and 'in-progress' climate-related planning responses for both case studies. In the context of resilience, *Planning Responses* may include planning, preparatory, and recovery measures that target single or multiple urban systems (Table 1). Hence, we assessed a selection of official planning documents for both cases, such as development plans, urbanization strategies, regional plans, climate action plans, and disaster management strategies, to extract the full range of climate-related planning responses (see Appendix C).

We connect the responses to *Urban Systems* they target and describe *Resilience principles* that are relevant for each system (see Section 2.3). Standard planning responses include rainwater harvesting, upgrading and streamlining stormwater drains, reinforcing landscape connections, and climate-proofing vital infrastructure.

MRA's planning documents recognize climate adaptation as a key goal and include a conceptual strategy for 2050. Responses target all five urban systems with a heavy emphasis on building resilience to manage excess water and climate-proofing assets. Hence, *Adaptivity* and *Robustness* emerge as the dominant resilience principles. Rainproof Amsterdam is a well-developed project targeting *Layer 2: Occupation* and *Unplanned/Open Spaces* to capture excess water (see Fig. 4 in red). In addition, the MRA is taking concrete steps through the *Resilience by Design* initiative that proposes demonstration projects for climate adaptation, including an adaptive tree plan, adaptive neighbourhoods, and urban transformation for diversity (MRA, 2021). While the projects apply multiple resilience principles like *Adaptivity*, *Diversity* and *Flexibility*, most are targeted at the scale of buildings.

Climate-related goals in the MMR are heavily reactive and focused on building resilience to urban flooding through community response and recovery. Planning is incremental and prescriptive, with most actions focused on upgrading infrastructure. BRIMSTOWAD is an ongoing long-term project to expand the capacities of stormwater drains. In the absence of a formal climate program while writing this paper, MMR (see

Fig. 4) integrates climate into several scattered projects where it becomes a secondary objective. With a scarcity of open spaces, MMR emphasizes restoring and expanding natural *Buffer* using green corridors along rivers, regulating land conversion, and a Coastal Zone Management Plan (CZMP). MMR enforces norms for rainwater harvesting only in new greenfield developments.

4.2. Findings from interviews: Case Study 1 (MRA)

4.2.1. Dominant resilience principles with high application

The dominant resilience principles discussed by participants are to manage risks using *Adaptivity*, *Buffer* and *Multiunctionality* and to resist risks by increasing *Robustness. Adaptivity* is widely applied at the *Layer 2: Occupation* as adaptive neighbourhoods, adaptive tree plans, and nature-based development. Participants criticize the lack of an empirical foundation or proven planning instruments in applying adaptivity *(P1, P2, P13)* and note that it relies on its thematic popularity rather than the urgency to act *(P8, P17)* (Fig. 6).

MRA adopts the *'retain-store-drain'* strategy for flood management used in the Netherlands and implements it in planning (P10). Due to MRA's space scarcity, most participants endorse the use of *Buffer* in conjunction with *Multifunctional* urban spaces to create water squares, floodable parking garages, and retrofitted rooftops *(P10, P13, P15)*. The 'Amsterdam Rainproof' program applies these actions to improve urban capacity to manage rain. It has led to policies that require every area to retain a rainfall volume of 60 mm/h *(P8, P13)* (City of Amsterdam, 2014).

The popularity of applying *Multifunctionality* has made it a convenient answer to integrated resilience irrespective of its small spatial scale and relatively short-term impact *(P1)*. Hence, '*Greenwashing*' dominates planning responses, especially at the plot level. Making spaces multifunctional also affects their living quality if not maintained well (like, parking lots that do not drain well). Additionally, *Multifunctionality* for larger urban systems such as *Layer 2: Occupation* and *Layer 3: Focal Points*, requires managing changing demographic demands and there may be *"a potential misalignment between the structure and the expected function" (P1)*. For instance, the building occupants change every few years, but the function of the building changes much slower. Understanding these change frequencies and *Flexibility* will be vital to introducing new functions into existing buildings.

Finally, *Robustness* emerged as a recurrent principle to resist risk while also being criticized for making the MRA less flexible to changes. Planning in the Netherlands is highly regulated and focused on definitive outcomes (Healey, 2006). This has counter-intuitively made the MRA vulnerable to uncertainties as the system is presumed to be fail-proof, and expansion continues on land that could be flooded from dike breaches *(P8, P10)*. *P21* explains that *"If (MRA) gets flooded, the government is held responsible. Therefore, we offer one of the highest levels of protection in the world"*. Hence, MRA's extensive network of dikes and sluices against flooding are continually upgraded until they reach their tipping points.

4.2.2. Dominant resilience principles with low application

The principles discussed due to low applications are *Flexibility*, *Diversity, and Multiscalarity.* MRA's lack of flexibility was attributed to an inflexible water system and an over-reliance on engineered dikes *(P7)*. *P7 & P14* critiqued the heavy focus on rainfall, which is 'ready to solve' and hampers the development of regulations for emerging, lesser-known risks from heat and prolonged drought. Planners critiqued the master planning instrument as *"being tightly wound blueprints that offer no flexibility" (P14)*. *P2* emphasized that zoning plans are flexible at the plot scale but not at a larger scale. Participants proposed updating the master plan every ten years or less based on changing needs. P1 proposes a ratio of *"one-third structure two-thirds diversity"* in master planning to keep it flexible, to adapt or diversify as needed. Participants from different domains conceded the need to *"think about flexibility at the conceptual stage"* to avoid undesirable lock-ins and higher re-investment costs *(P8, P9, P10)*.

On *Multiscalarity*, the urban planners and climate specialists discussed the regional scale as ideal for long-term planning *(P2, 12, 13)* as most urban systems with long lifecycles are planned on that scale *(P1)*. However, most climate-related planning responses are targeted towards *Unplanned/Open Spaces* and *Occupation/Buildings* where it is effective to introduce small-scale fitted solutions. Urban designers find the local scale feasible *(P6)* and find regional planning futile for climate *(P3)*. Multi-scalar thinking is essential as different climate risks can be addressed effectively at different scales. For instance, municipalities are *"limited their administrative boundaries"* and cannot make strategies to cope with a sea-level rise at their scale *(P12, P16, P18, P19)*. Urban planners *P17 & P8* emphasized matching the spatial scale with the risk to form viable business cases for investing and avoiding roadblocks.

4.2.3. Implication for urban resilience theory and planning under uncertainty

Resilience

Redundancy and *Self-organization* find no mentions in interviews, possibly because both principles typically emerge or are applied in systems that are constantly exposed to risks and must continually adjust (Liao, 2012). In the recent past, MRA has offered a relatively safe environment except for prolonged drought and extreme heat days for which localized energy and water backups are arranged. Creating a redundancy of transport networks and water sources for low-probability events like flooding does not receive any attention, though it can cause significant damage.

Uncertainty

MRA's approaches to planning under Uncertainty emerges from a risk-resistant attitude where planning responses are designed to resist failure (Liao, 2012; Walker et al., 2013). A risk-resistant system is planned in a fail-safe manner where its inherent variability is suppressed, and it becomes less resilient to sudden changes (Holling et al., 2002). Participants also blame an over-reliance on flood-protection engineering for cultivating a culture of planning for the worst case without accounting for emerging risks like winter storms, heavy rains, or prolonged drought in the detail that they should be.

In theory, MRA's planning incorporates all four approaches to planning under uncertainty with varying degrees of application (see Section 2.2). The dominant approach is *Pragmatic*, where responses are targeted towards individual urban systems like reinforcing flood defenses, climate-proofing energy networks, and improving the buffer capacity of open spaces. *Nomocratic* approach is seen in regulations to protect ecological and cultural sites. *Methodological* approach can be partially observed in MRA's use of forward-looking scenarios for energy and mobility systems. It also benefits from four well-researched, predictive national climate scenarios for climate risks. P9 emphasizes that *"MRA plans within these plausible scenarios and dealing with outliers, extremes and emerging risks are where things go wrong."* While MRA discusses different scenarios for its sectors, alternative urbanization strategies are not thought of. P9 proposed a robustness analysis of the urban plan to identify long-lasting urban systems and use a mix of uncertainty approaches accordingly.

4.3. Findings from interviews: Case Study 2 (MMR)

4.3.1. Dominant resilience principles with high application

As MMR does not have a dedicated program on climate action, resilience does not find many mentions but is integrated into different

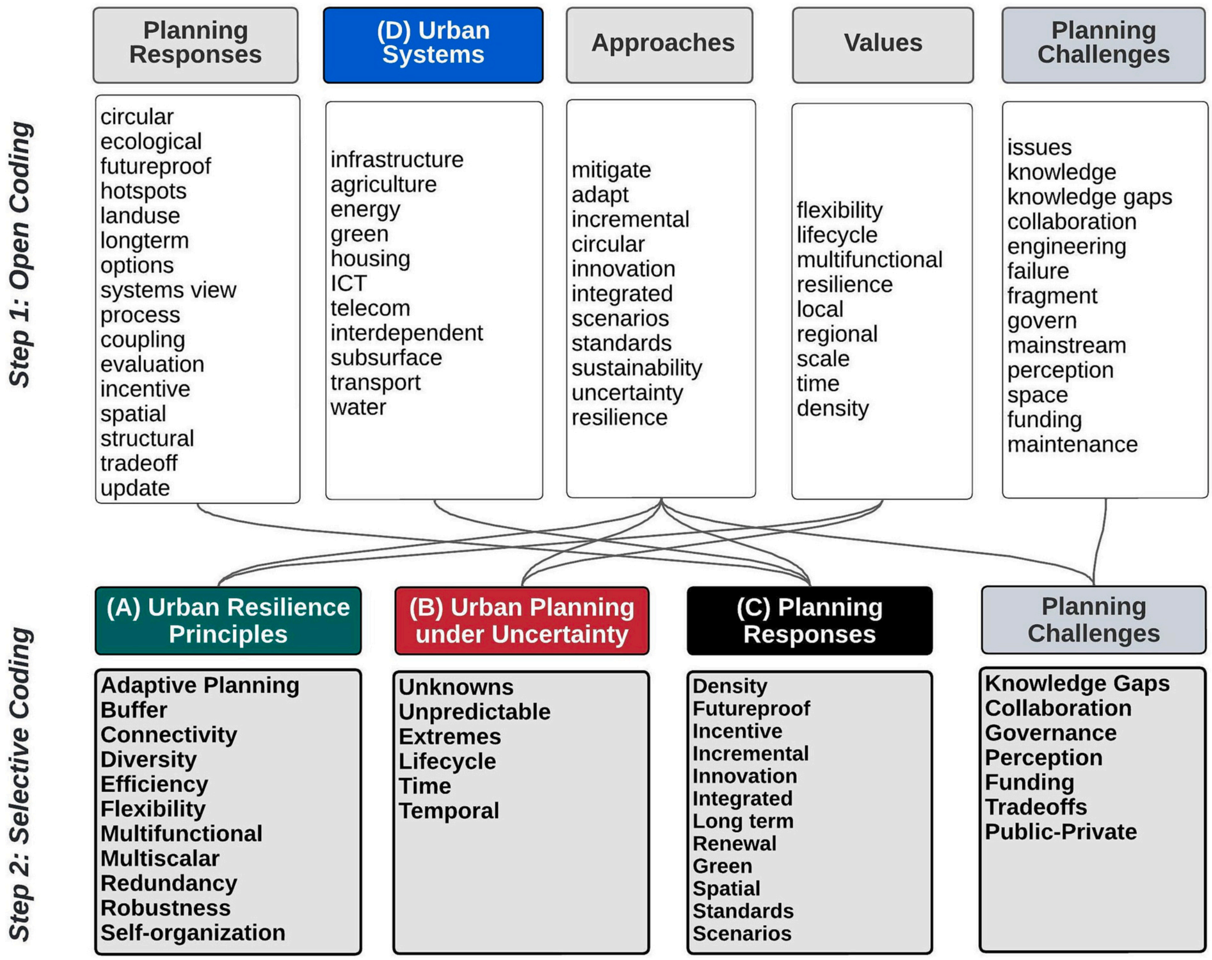

Fig. 5. Mapping climate-related Planning Responses for MRA (in red) and *MMR (in blue and italics)* to the Urban Systems they target. Each Urban Layer has a recommended resilience principle to make it most effective in managing climate uncertainties (Roggema et al., 2012b). ('RbD' indicates projects proposed as part of MRA's Resilience by Design programme) (MRA, 2021). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

planning projects and policies. The dominant principles discussed by participants are to manage urban flooding using *Adaptivity* and *Buffer* and the need to bring in more *Flexibility* and *Multiscalarity* in planning to manage uncertainty (Fig. 7).

Due to Mumbai's chronic flooding, improving *Robustness* of storm-water drains is a significant project *(P31)*. The State of Maharashtra's Action Plan on Climate Change also presents system-specific strategies for transport, energy, and ecosystem-based adaptation actions *(P24)* (GoM Department of Environment, 2014). The transport sector is considered to be most effective in improving *Adaptivity* given the heavy future investments and high traffic volume (P33). However, a robust, data-driven understanding of adaptation, including the implications of maladaptive planning and undesirable tradeoffs, does not exist *(P21)*. For instance, Mumbai's metro rail construction requires acquiring land preserved under natural resources. But, the tradeoff between the mitigating properties of public transport versus the adaptive properties of damaged natural ecosystems is not assessed. P21 criticizes that *"Adaptation is viewed as a cop-out action when the urban planning mechanism fails."*

Buffer is widely applied in MMR across spatial scales. New development schemes are mandated to harvest rainwater onsite at the building level. A buffer is introduced at the neighbourhood/ward scale through land reservations and assigning recreation areas as 'no-development zones.' There are policies to protect mangroves, wetlands, and other natural ecosystems at the city scale, which act as a sponge for coastal flooding. A city-wide blue-green network was initiated but not completed as Mumbai has few large open spaces to capture rainwater within urban limits *(P30,33)*. In addition, Mumbai is considering developing an underground floodwater channel similar to Tokyo to store surplus water.

Unlike MRA, what hinders the application of *Multifunctionality* is that public spaces are viewed purely from a consumption standpoint to cater to a large existing population *(P31)*. It is challenging to find synergies as the planning responses are not tied to a common climate strategy, which brings in competing priorities in a hyper-dense region.

4.3.2. Dominant resilience principles with low application

On lack of *Flexibility*, more than half the participants criticized existing planning instruments for being overly regulatory. Rigid norms for land reservations and a moderate Floor Space Index (FSI) encourage illegal expansion in a city facing intense land scarcity. *"Instead of anticipating changes, the planning instruments are prescriptive and go into (unnecessary) details"* which impedes inherent Flexibility *(P22, P36)*. Like MRA, MMR participants also recommend that the Development

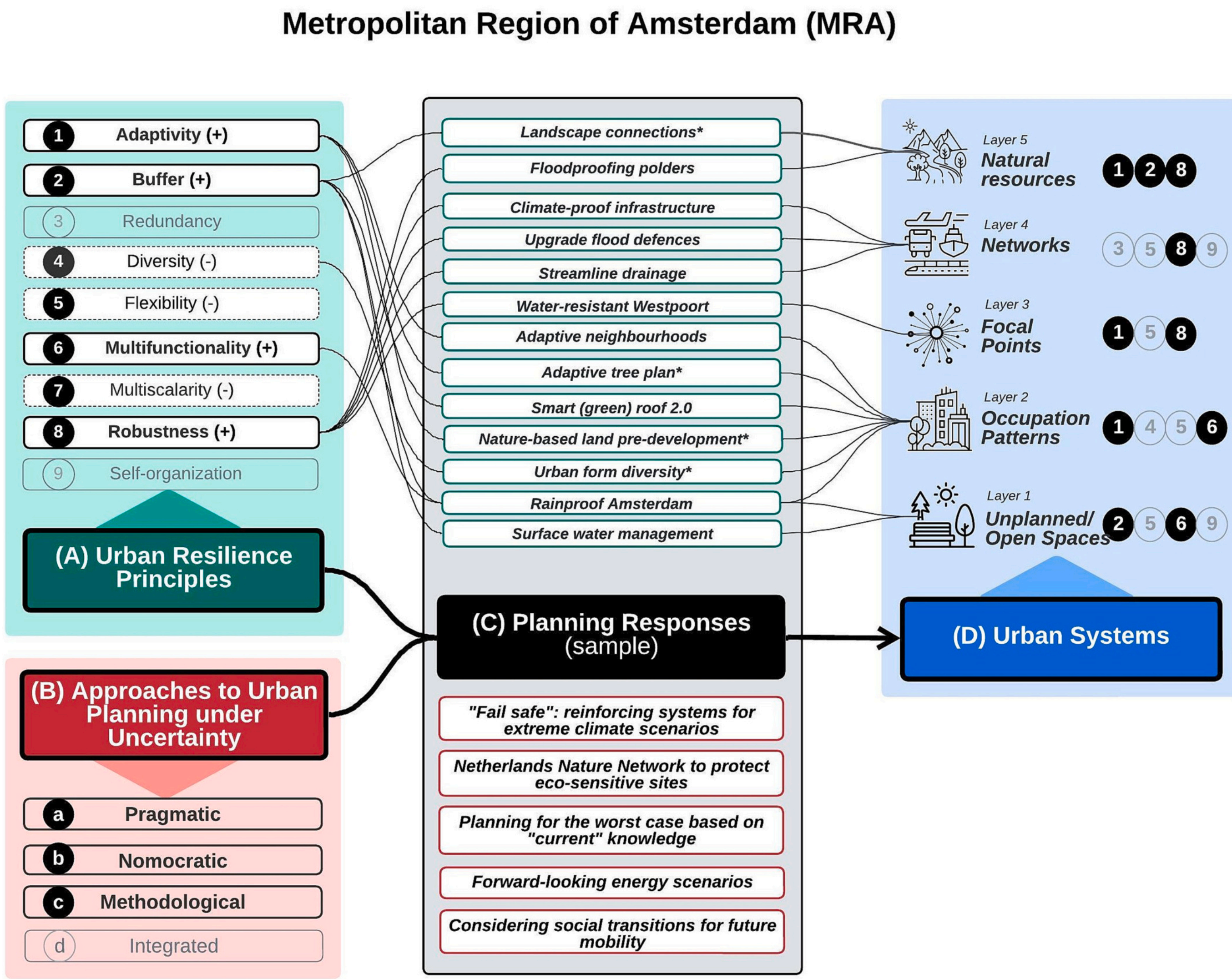

Fig. 6. Case Study 1 MRA: Assessing climate-related planning responses using the Conceptual Framework (Fig. 3) and findings from interviews to highlight: (A) Dominant Urban Resilience Principles; ((+) and (−) indicate principles with high application and low application, respectively.); (A) Dominant Approaches to Urban Planning under Uncertainty; (C) How 'A' and 'B' together determine Planning Responses; and their impact on (D) Urban Systems.
(Grey box indicates no mentions. Dotted lines indicate terms mentioned but not discussed in detail in literature or interviews. (*) indicates proposed Planning Responses.)

Plan (DP) be updated every 5–10 years to cater to changing trends *(P27, 31, 33)*. *P33* recommends developing adaptation pathways and scenario planning for Mumbai not to be locked into blueprints.

On *Multiscalarity*, the role of the correct spatial scale was discussed extensively. Participants recommend multi-level engagement but recognize the regulatory challenges of coordinating between scales. For instance, the Regional Plan is not binding upon the local wards and has a lower legal standing in the planning process *(P22)*. Moreover, the mix of formal and informal growth and massive peri-urban expansion establishes a standardized planning template for inter-scalar coordination. Hence, the city adopts tactical planning responses to manage risks at the project-level or plot level. *P29* points out that the planners must give infrastructure projects like the Mumbai Metro special consideration due to the long lifecycle and impacts on the region's economy. However, the climate is not fundamental to its planning.

MMR's local flood response capacity points to a mature level of *Self-organization* illustrated by a strong community response in flood rescue and sheltering. The disaster management plan also presents guidelines to develop *Redundancy* plans during a crisis through alternative transport routes and energy and communication backups.

4.3.3. Implications for urban resilience and planning under uncertainty

Resilience

While the urgency of climate change is recognized, it is not integrated into urban planning *(P24)*. *Diversity*, *Redundancy*, *Robustness*, and *Self-organization* find little to no direct mentions in the interviews. From a resilience perspective, Mumbai's annual urban flooding becomes an agent for resilience-building and self-organizing since each flooding event leads to small to medium-scale disruptions that allow urban systems to readjust. This has led to the emergence of a diverse set of coping strategies and high inherent *Adaptivity* (Smit & Wandel, 2006). However, planning responses have not systematically tapped into the

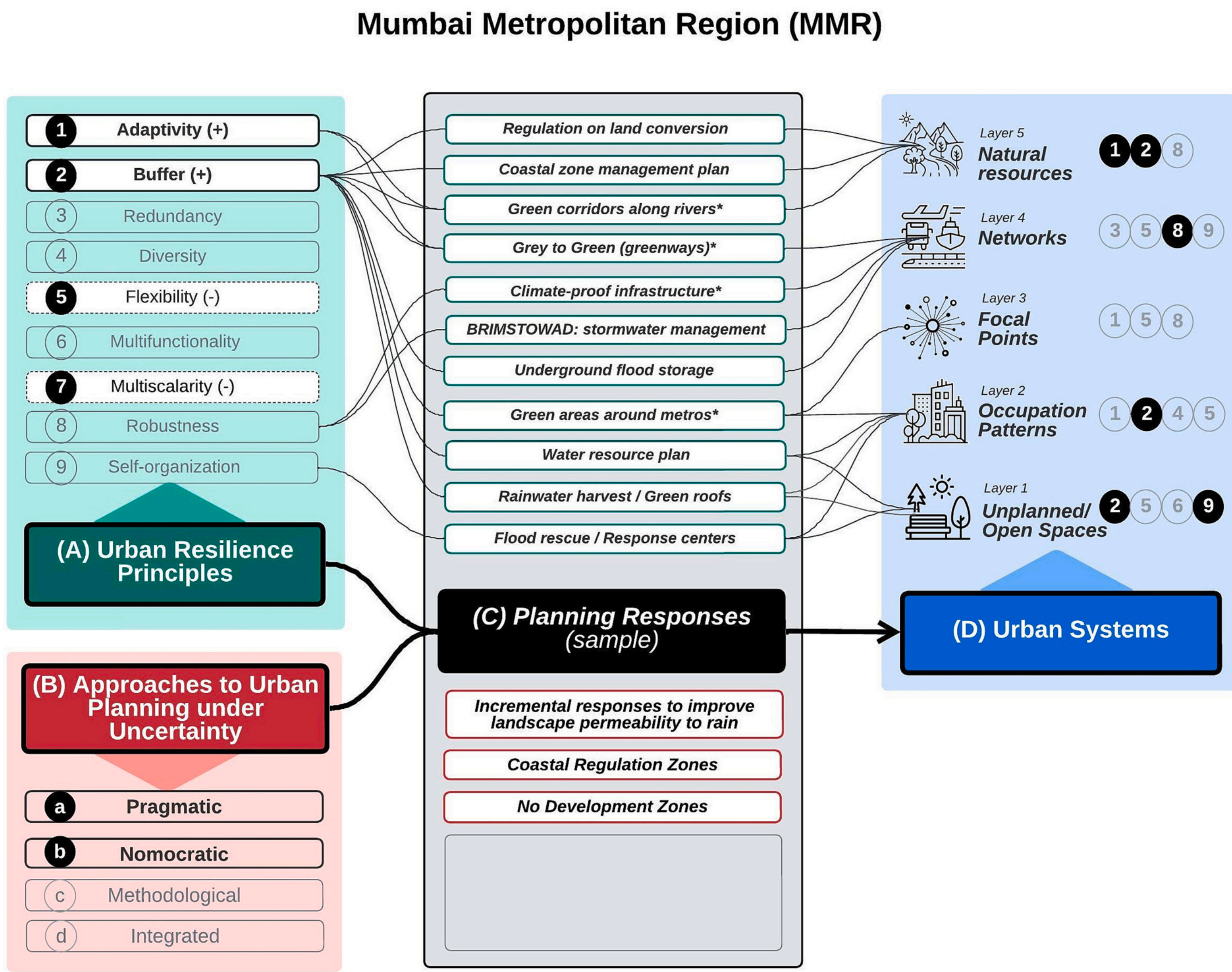

Fig. 7. Case Study 1 MMR: Assessing climate-related planning responses using the Conceptual Framework (Fig. 3) and findings from interviews to highlight: (A) Dominant Urban Resilience Principles; ((+) and (−) indicate principles with high application and low application, respectively.); (A) Dominant Approaches to Urban Planning under Uncertainty; (C) How 'A' and 'B' together determine Planning Responses and their impact on (D) Urban Systems.
(Grey box indicates no mentions. Dotted lines indicate terms mentioned but not discussed in detail in literature or interviews. (*) indicates proposed Planning Responses.)

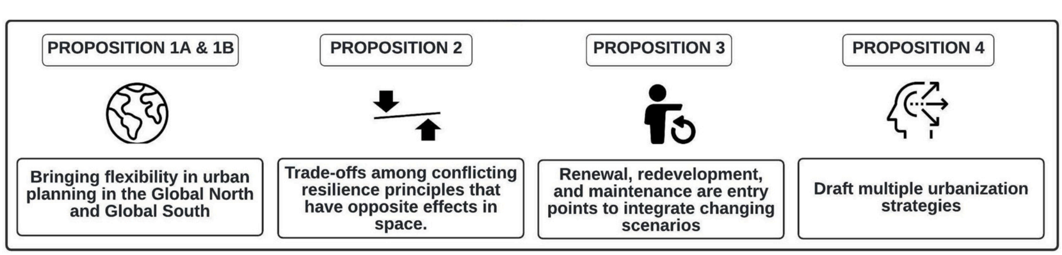

Fig. 8. Four propositions towards an enhanced understanding of urban planning for climate uncertainty, using theoretical reflections from literature and empirical insights from case studies.

usefulness of *Multifunctionality* or *Robustness* to use space efficiently and absorb the recurrent impacts of flooding.

Uncertainty

MMR's approaches to uncertainty emerge from the experience of a region that faces recurrent flooding and is forced to embrace it as an environmental dynamic. Due to limited resources and a complex urban fabric, the region has not realized intensive engineering responses like underground flood channels to manage floods. However, it relies on reinforcing natural ecosystems to absorb risks. Only two participants explicitly discussed uncertainty and pointed to the urgency of introducing it to planning *(P33, P35)*. Given the expanding urban footprint of the MMR, participants propose *"decentralized planning as an antidote to uncertainty"*. This implies empowering local decision-makers to experiment with new strategies to manage flooding, pollution, and urban heat islands. This reflexive approach may help fulfill market demands to utilize land efficiently to manage changing risks *(P36)*.

MMR dominantly uses the *Nomocratic* and *Pragmatic* approaches (Section 2.2). Nomocratic approaches can be seen in blanket regulations to conserve green areas and reinforce green corridors. This has proven insufficient to manage floods from fluctuating rainfall patterns and inadequate civic infrastructure. *Pragmatic* approaches are targeted towards increasing *Open Spaces* and regulating the density of *Occupation/Building*. No system-wide strategy exists for resilience of *Focal Points* and *Networks*.

From a *Methodological* perspective, MMR plans for a single future scenario, relying mainly on past trends and fixed predictions. *P22* emphasizes that *"Mumbai is stuck with the impacts caused by the 2005 deluge - a 1 in 100-year flooding disaster. Most policy documents, as well as academic studies, are written considering the impacts of that single event"* (Gupta, 2007). Participants acknowledge that the formal planning framework does not recognize uncertainty or the need to consider 'what-ifs' to plan for alternative scenarios. For instance, infrastructure and building codes consider flood levels from 2 to 3 decades ago.

4.4. Cross case analysis

This section conducts a cross-case assessment of findings from MRA and MMR to examine similarities and dissimilarities in applying urban resilience principles, planning responses, and approaches to uncertainty.

4.4.1. Similarities

From a general planning perspective, both MRA and MMR foresee growth that must balance new development and several renewal projects. Both cite a scarcity of space as a roadblock to implementing climate-related projects like expanding stormwater drains or adding buffers. Participants in both cases confirmed the ease and cost-effectiveness of implementing climate-related projects on public land as they have more control *(P2, P6, P8, P14, P22, P28)*. Introducing measures on private land or expropriation of land was recognized as a significant barrier to scaling up climate-related responses.

On resilience principles, participants explain the lack of *Flexibility* as a critical barrier to long-term planning. While MRA's lack of Flexibility came from a heavily regulated planning system, MMR deals with significant capacity gaps that do not allow it to consider a flexible planning regime. *Multiscalarity* emerged as a common goal, but its implementation was also a common point of conflict in both cases. Climate specialists and strategic planners made solid arguments supporting top-down, centralized planning, especially for large-scale decisions where multiple infrastructure systems must be coupled together *(P7, P21, 22, 33)*. On the other hand, urban planners and bureaucrats who implemented detailed plans endorsed bottom-up, decentralized planning at the local scale to manage climate risks *(P3)*.

Both participants acknowledge that uncertainty is not part of the formal thinking process. Planning responses are *Pragmatic*, low-regret *(P3, P7)*, and emphasize incremental actions in individual urban systems. A common conflict for both regions is prioritizing incremental over transformative planning projects.

Both cases successfully use *Nomocratic* planning to manage uncertainty. For instance, MRA preserves natural areas under Netherlands National Ecological Network (NEN) (Nature Ministry of Agriculture and NL Food Quality, n.d). Similarly, MMR has a Coastal Zone Management Plan to conserve ecologically sensitive zones (Forest Ministry of Environment and GoM Climate Change, 2011).

4.4.2. Dissimilarities

The first dissimilarity between the cases is urban development and the maturity of planning instruments. MRA has fulfilled its basic urban infrastructure needs but needs to transform standards for emerging risks. On the other hand, MMR must manage a significant infrastructure deficit while meeting climate goals. MRA has a mature spatial planning system that primarily uses a combination of top-down and community-based planning. MRA benefits from national policies on climate adaptation and well-researched climate scenarios as benchmarks for long-term planning. MMR has a hybrid planning approach where top-down formal plans are supported by tactical responses, especially for growth outside the purview of formal regulations. MMR's planning for climate risks is mainly reactive, and open-ended, and relies on feasible short-term targets. In the absence of detailed climate scenarios, planners consider only high-level assumptions, and plans are designed to absorb forecasted growth.

Second, the capacity gap in MMR hinders an integrated approach to long-term planning in MMR. MRA has a solid regional authority to develop and implement climate programs. Hence, planning responses address all five urban systems, and it is possible to have a template to propose resilience principles and predict planning outcomes. Climate programs in Indian cities are outsourced to independent consultancies or international agencies due to a lack of internal capacity, leading to fragmented projects, generic responses, and inequality *(P23)*.

5. Discussions: propositions towards an enhanced understanding of urban planning for climate uncertainty

This study analyses two case studies to build an enhanced understanding of long-term planning under uncertainty by combining concepts from urban resilience and urban planning under uncertainty. Despite the contrasting planning contexts, participants in both cases - MRA and MMR - confirm the lack of a systematic way for planning to manage climate impacts. This section presents four propositions developed using findings from theory and empirical insights from the interviews to reflect on the current gaps in adopting long-term planning and where theory can play a role in filling this. Each proposition is substantiated using comparative insights from our two case studies and 39 interviews. We present narrative accounts and structural findings that characterize the long-term planning process. We further present propositions on four themes: planning processes, urban resilience, planning under uncertainty, and types of planning responses, towards an enhanced understanding of long-term urban planning for climate uncertainty (Fig. 8).

5.1. Proposition 1: On urban planning processes

Proposition 1A. *Bringing flexibility in urban planning is a pivotal way Amsterdam (MRA) and Mumbai (MMR) can develop a process to continuously integrate changing variables essential for planning for climate uncertainty.*

One of the key findings of this study is the dissimilarity in planning and resilience capacities in the MRA and MMR. MRA and MMR must manage major long-term transitions under climate change, but the approach differs based on their position on the development spectrum. It is widely known that developed regions like MRA are expected to not prioritize climate due to high inherent adaptivity (Denton et al., 2014). However, several recent events like hurricanes, tornadoes, and prolonged droughts have caused significant losses in industrialized regions of the Global North due to damages to existing protection structures.

MRA must deal with locked-in risks because of the massive investments made in the past, which today face more extreme hazards than intended. It must ensure that future climate-related responses do not disturb the well-functioning status quo. On the other hand, MMR must address the dual goals of meeting its fundamental infrastructure deficit while ensuring resilience. However, planning processes in MMR face significant institutional and capacity gaps, which leaves little incentive for substantial long-term thinking (P25, 32, 35).

Proposition 1B. *The lack of flexibility in planning in Amsterdam stems from rigid outcome-oriented planning regulations, and in Mumbai, stems from insufficient planning structures.*

MRA has made steps to integrate climate into formal urban planning instruments, but it is applied only to small-scale pilot projects based on fixed variables. Conceptually, the value and interpretation of flexibility in planning remain ambivalent as it could improve resilience and provide unfair development advantages based on market forces (Tasan-Kok, 2008). MRA participants, especially the strategic planners, criticize its overtly regulated, outcome-oriented planning for impeding its flexibility to integrate new information. The lack of flexibility in the planning process hinders applying other resilience principles and uncertainty approaches that demand integrating emerging variables.

MMR is yet to develop and implement actions based on a strategic understanding of the interaction between climate and development priorities (Khosla & Bhardwaj, 2019). It relies on conservative measures like reinforcing green spaces and reactive measures such as emergency response and rescue to manage disasters. This makes it challenging to have long-term planning trade-offs to improve resilience (Bartlett et al., 2009). MRA participants view open-ended planning systems, like the one in MMR, as advantageous to integrating unprecedented changes to build resilience. From an uncertainty perspective, not having definite outcomes is a mark of a flexible system open to change. Participants in the MMR criticize that Mumbai's open-ended approach has led to a high tolerance to risk, recurrent infrastructure damage, and low trust in the government to protect it.

A second important planning highlight is that urban growth in the MMR spreads beyond formal physical and institutional boundaries. While there are some ways to characterize informal growth, managing unprecedented changes is challenging as planning responses may not have the expected outcome.

5.2. Proposition 2: on urban resilience principles

Proposition 2. *Conventional thinking assumes that different resilience principles mutually reinforce each other's impacts. However, transformative long-term urban planning requires resolving trade-offs among principles with opposite impacts in space. Three such conflicting combinations that emerge in discussions of the cases are Robustness versus Flexibility, Structure versus Diversity and Redundancy versus Efficiency.*

Section 4.3.1 discussed how resilience principles like *Buffer* and *Multifunctionality* are used in combination to improve urban capacity to manage rain. However, participants from both cases emphasize that long-term planning requires applying principles that have opposite impacts in space (Zimmerman, 2001). Implementing conflicting principles creates a deadlock in spatial decisions.

An overarching planning conflict that emerged in MRA (See Propositions 1B) was maintaining its fixed planning structure with a robustly engineered water system versus making it flexible to future changes. A risk-based conflict also arises when a city must manage prolonged droughts while increasing green cover to mitigate the impacts of urban heat islands. A thematic dispute arises between meeting goals for climate adaptation and energy transition when "*Buildings with rooftops must find a trade-off between using the roof space to store water from rainfall or to install solar panels to generate energy*" (P3).

MMR participants recommended striking a balance between flexibility and rigidity, like imposing strict regulations to protect natural resources but a flexible approach for all local areas to absorb growth. Counter-intuitively, P36 emphasized that increasing flexibility in local area plans will only benefit private developers in a hugely market-driven economy. Hence, planners must prioritize the land's endemic and endogenous potential before setting flexible norms.

In urban morphology, a conflict arises in decision-making for increasing density versus adopting low-impact, medium, or low-density. Dense centers are known for their Efficient urban form for better transport accessibility and lower energy consumption which is desirable for building resilience (P27) (Jabareen, 2013). However, the same density increases concentrations of the at-risk population leaving less space for rainwater infiltration and increasing susceptibility to urban heat islands (Solecki et al., 2015; Wamsler et al., 2013). Several MMR participants endorse medium-density ecological planning to offset the impacts of a dense urban footprint around existing business districts. Few participants strongly argue against this, since loosely regulated ecological planning leads to uncontrolled urban sprawl. Practitioners recommend making clever connections between urban systems to use opposing responses to advantage and avoid undesirable temporal trade-offs and deadlocks. P2 proposes a balance of "*one-third fixed structure two-thirds diversity*" in an urban plan to keep it responsive to changes.

5.3. Proposition 3: on planning under uncertainty

Proposition 3. *Renewal, redevelopment, and maintenance of urban systems present an entry point to integrate or align with emerging risks and to change scenarios - through iterative learning. These entry points are essential to overcome the aversion to uncertainty planning prevalent in existing practice.*

Long-term planning requires responding to a changing environment. Participants emphasized the need to integrate climate goals at the conceptual planning stages rather than bearing high re-investment costs later (P8,9,10). However, new and greenfield development opportunities are limited in urban regions already built up, like in the MRA, or are incredibly dense, like in the MMR. A planning challenge for MRA was *"to replace the entire City of Amsterdam"*, referring to a large stock of urban infrastructure waiting to be renewed that can potentially become resilient (P14). Similarly, MMR's routine planning is dominated by redevelopment projects which present a lucrative opportunity to review old regulations and adopt a new perspective to manage uncertainties expected in the lifecycle of a system (P5, P34). However, MRA and MMR participants critique that planning encourages experimentation and empowers errors essential to nurturing innovation (P7, P33). Hence, renewal, redevelopment, and maintenance of projects or individual urban systems become entry points to integrate new variables and standards.

5.4. Proposition 4: on overall planning responses

Proposition 4. *Mainstreaming climate in long-term urban planning requires that cities present multiple urbanization strategies within formal planning documents that can proactively adapt based on changing scenarios.*

The *Methodological* approach to urban planning under uncertainty proposes consideration of the full range of future scenarios to manage unforeseen changes and offer appropriate responses (ref. Section 2.2). Variations in strategies may include reconfiguring and recombining planning responses for different urban systems that require different degrees of 'transitional,' 'incremental,' and 'transformational' changes.

MRA adopts this by proposing multiple strategies for individual urban systems like water, energy, and transport, anticipating future changes. However, the final urbanization strategy that brings these systems together is one master plan. The fixed master planning regime does not possess the flexibility to update plans for multiple degrees of 'transitional,' 'incremental,' and 'transformative' changes (Chelleri et al., 2015). MRA also benefits from well-researched climate scenarios, leading to a single climate adaptation strategy.

MMR plans for a single scenario without anticipating any variation, which goes against long-term thinking as an evolving process open to changes. Long-term planning under climate change will require considering changing futures and their impacts on different urban systems based on their lifecycles. These can be developed using a combination of *Predictive (forward-looking)* and *Normative (inverse-looking)* approaches to planning. For instance, cities can adopt predictive approaches to plan for changing capacities of *Networks* like energy and mobility. Normative approaches can be adopted to preserve *Natural Resources* in the same state for the future.

6. Conclusion

The need to plan for uncertain futures has led to the realization that planning theory must present methods to systematically integrate rapidly changing insights. In this study, we take the first steps towards an enhanced understanding of long-term urban planning for climate uncertainty. We develop a conceptual framework (Fig. 2) that bridges two critical streams of literature essential to future urban planning: *Urban Resilience Principles* (Section 2.1) and *Approaches to Urban Planning Under Uncertainty* (Section 2.2). To develop the conceptual framework, we draw upon the sprawling academic literature on urban resilience and the limited literature on planning approaches under uncertainty. We connect the two theories by systematically assessing how they manifest in space through *Planning Responses* and their impacts on *Urban Systems*.

We use the conceptual framework to analyse two case studies.

We use an exploratory approach to derive insights from 39 interviews with senior practitioners across two contrasting case studies from the Global North (Metropolitan Region of Amsterdam (MRA)) and Global South (Mumbai Metropolitan Region (MMR)) that offer contextual, theoretical, and geographical variations to address the gap in planning. An exploratory approach provides initial insights into planning patterns and formulates propositions for future investigations into other case studies. We then use systematic analysis to unpack the thinking processes behind climate-related planning responses, challenges, opportunities, and planning values that are similar and dissimilar.

To connect theoretical and empirical findings in a scientifically robust manner, we use a Multi-case analysis together with Systematic Combining. It enables deriving detailed insights on the knowledge and procedural aspects of using resilience theories and approaches for planning under uncertainty (see Figs. 6, 7).

The cross-case analysis illustrates the need to integrate long-term climate goals at the regional scale. Participants in both cases criticized the lack of flexibility in the planning process and the low mentions of uncertainty. The dissimilarities lay in the level of maturity of planning, capacity gaps, the absence of well-researched climate scenarios, and the debate between outcome-oriented and open-ended planning.

Based on theoretical and empirical findings, we formulate four propositions to reflect on the current gaps for a theory on long-term urban planning under climate uncertainty that focus on:

- Bringing flexibility in planning processes to integrate changing variables for long-term planning continuously.
- Resolving spatial trade-offs among resilience principles that have opposite impacts in space for long-term urban planning strategies to work (such as between achieving Robustness versus Flexibility).
- Renewal, redevelopment, and maintenance of urban systems as an entry point to integrate or align with emerging risks.
- Drafting multiple urbanization strategies within formal planning documents that can be proactively adapted based on changing scenarios.

Implications for Urban Resilience and Planning Under Uncertainty. Participant P17 mentions that "As an operative notion, resilience is extremely useful because it forces you to embrace complexity and unpredictability in urban planning." Although resilience theory has evolved into a global discourse, most literature continues to emerge from a Global North point of view that has benefited from a well-structured, standardized approach to planning (Marin, 2021). In conclusion, we hope this study contributes to advancing the conceptual understanding of resilience and uncertainty using place-based research in the Global North and South.

6.1. Future research

The study's exploratory nature is a starting point to formulate broad propositions that can be used to investigate other case studies using the conceptual framework. The study acknowledges that each planning context is unique and requires different resilience and uncertainty approaches, enabling researchers to test further the propositions presented in this study and to reinforce a theory for long-term urban planning. Expanding this study to more case studies will be necessary to arrive at a generalizable understanding of integrating resilience in urban planning for climate uncertainty. Concerning planning for uncertainty, a key line of inquiry is temporal dynamics in urban planning and how that differs between the GN and GS to enable strategies and implementation of long-term goals. An additional line of work would be to dive deeper into spatial aspects using long-term urban scenario building, combining theoretical and real-world insights. This can enable the drafting of dynamic urbanization strategies that can adapt over time.

CRediT authorship contribution statement

Supriya Krishnan: Conceptualization, Methodology, Software, Formal analysis, Writing – original draft, Writing – review & editing, Visualization. **Nazli Yonca Aydin:** Conceptualization, Methodology, Supervision, Writing – review & editing, Project administration, Resources. **Tina Comes:** Conceptualization, Methodology, Supervision, Writing – review & editing, Project administration, Resources, Funding acquisition.

Declaration of competing interest

There are no competing interests to declare.

Data availability

The data that has been used is confidential.

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Appendix A. Process of identifying academic literature on urban resilience ‘planning’ frameworks (Accessed on: 30 Nov 2021)

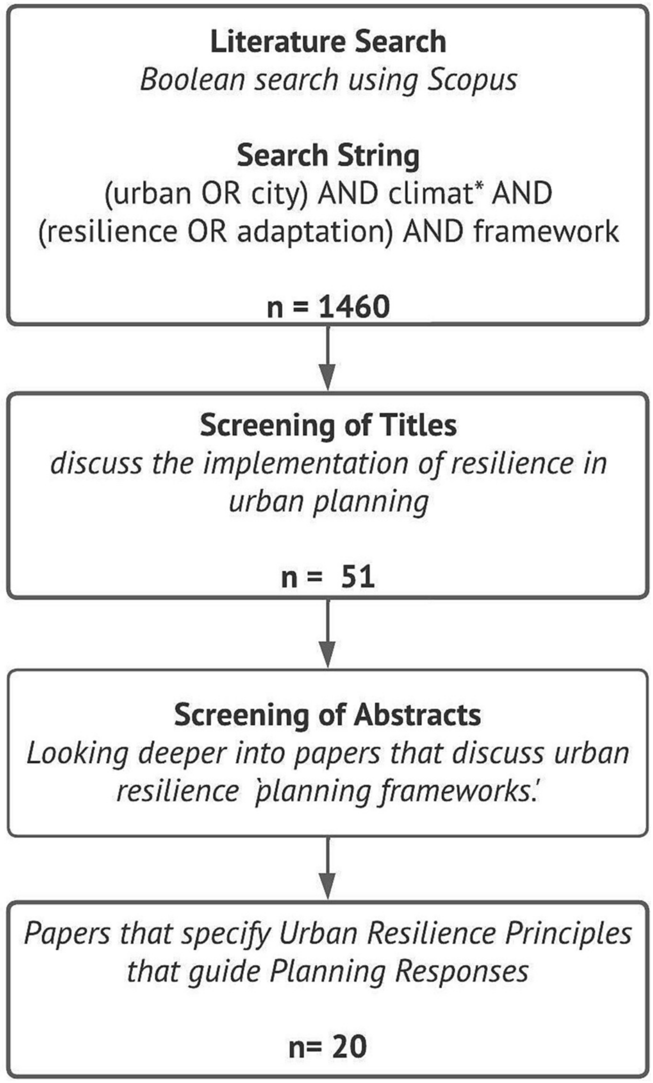

Fig. 9. Process of literature review to identify papers on urban resilience ‘planning’ frameworks that provide guiding knowledge (such as resilience principles), which must be translated into appropriate planning responses. The search string is expanded to include *‘urban climate adaptation’* as it is sometimes used interchangeably with *‘urban resilience’*.

Appendix B. List of selected academic papers on Urban Resilience Planning frameworks and the Resilience Principles they discuss

S.no	Year	Document Ref.	Urban Resilience Principles mentioned in relation to urban planning						
			Adaptivity	Buffer	Connectivity	Diversity	Efficiency	Flexibility	Innovation
1	2003	(Godschalk, 2003)	Y			Y	Y		
2	2011	(Leichenko, 2011)	Y			Y		Y	
3	2011	(Chelleri, 2012)				Y			
4	2012	(Wilkinson, 2012)	Y	Y	Y	Y			
5	2012	(Tyler & Moench, 2012)				Y		Y	
6	2012	(Liao, 2012)	Y			Y			
7	2013	(Davoudi et al., 2013)	Y					Y	
8	2013	(Desouza & Flanery, 2013)	Y			Y		Y	
9	2013	(Collier et al., 2013)						Y	
10	2013	(Jabareen, 2013)	Y	Y		Y			
11	2014	(Galderisi, 2014)	Y		Y	Y	Y	Y	
12	2014	(Marcus & Colding, 2014)	Y			Y			
13	2016	(Tabibian & Movahed, 2016)				Y		Y	
14	2016	(Meerow et al., 2016)	Y			Y	Y	Y	
15	2016	(Kim & Lim, 2016)	Y	Y	Y	Y		Y	
16	2016	(Dhar & Khirfan, 2017)	Y	Y	Y	Y		Y	
17	2018	(Sharifi & Yamagata, 2018)			Y	Y	Y	Y	Y

(*continued on next page*)

(*continued*)

S.no	Year	Document Ref.	Urban Resilience Principles mentioned in relation to urban planning						
			Adaptivity	Buffer	Connectivity	Diversity	Efficiency	Flexibility	Innovation
18	2018	(Wardekker, 2018)	Y	Y	Y	Y		Y	
19	2019	(Ribeiro and Gon, 2019)	Y		Y	Y	Y		Y
20	2020	(Lak et al., 2020)	Y	Y	Y	Y		Y	
			Modular	Multiscalar	Multifunc.	Redundancy	Robust	Self org	
1	2003	(Godschalk, 2003)				Y	Y	Y	
2	2011	(Leichenko, 2011)							
3	2011	(Chelleri, 2012)		Y		Y	Y	Y	
4	2012	(Wilkinson, 2012)	Y	Y		Y		Y	
5	2012	(Tyler & Moench, 2012)	Y			Y	Y		
6	2012	(Liao, 2012)				Y		Y	
7	2013	(Davoudi et al., 2013)					Y		
8	2013	(Desouza & Flanery, 2013)					Y		
9	2013	(Collier et al., 2013)				Y			
10	2013	(Jabareen, 2013)				Y			
11	2014	(Galderisi, 2014)				Y	Y		
12	2014	(Marcus & Colding, 2014)				Y		Y	
13	2016	(Tabibian & Movahed, 2016)							
14	2016	(Meerow et al., 2016)				Y	Y		
15	2016	(Kim & Lim, 2016)	Y			Y			
16	2016	(Dhar & Khirfan, 2017)	Y						
17	2018	(Sharifi & Yamagata, 2018)	Y	Y	Y	Y			
18	2018	(Wardekker, 2018)	Y			Y	Y		
19	2019	(Ribeiro & Gonçalves, 2019)				Y	Y		
20	2020	(Lak et al., 2020)			Y		Y		

Appendix C. List of Planning Documents assessed for each case study as explained in Section 3.2 and Fig. 5 (Date of Access: 15 January 2022)

Case Study 1: Metropolitan Region of Amsterdam (MRA)

(a) Strategie Klimaatadaptatie Amsterdam (Feb 2020)/https://bit.ly/3AId2sO
(b) Structuurvisie Amsterdam 2040 (Feb 2011)/https://bit.ly/3obNkbb
(c) MRA Urbanization Concept, Metropolitan Region of Amsterdam (Nov 2011)/https://bit.ly/33XsKVk
(d) Metropoolregio Amsterdam Klimaatbestendig/(Action Plan) (2020)/https://bit.ly/3o9vq9d

Case Study 2: Mumbai Metropolitan Region (MMR)

(a) Regional Plan for the Mumbai Metropolitan Region (Apr 2021) & https://bit.ly/34dZpWh
(b) Development Plan for Greater Mumbai 2014-34 (2014)/https://bit.ly/3G9cpcZ
(c) Maharashtra State Adaptation Action Plan on Climate Change (2014)/https://bit.ly/3Gh6h2q
(d) Disaster Risk Management Master Plan Mumbai (2009)/https://bit.ly/3IMthYF

Appendix D. Interview protocol

1. Introduction [5′]

(a) Introductions and overview of the research.
(b) Major climate-related projects and the participants' role in it.

2. Climate-related planning responses and sectoral focus (selection from the following questions based on the participant's background) [15′]

(a) Perception and integration of climate in urban planning over the years.
(b) Regions in focus for planning and renewal projects.
(c) Knowledge sources and scenarios used.
(d) How to spur urban reforms that are climate resilient?
(e) At what spatial scale can these be translated as projects?

3. Long-term thinking (beyond the current planning timelines [5]

(a) Time horizons for planning.
(b) Adopting an uncertainty perspective in a complex context.

4. Planning variables and values [10′]

(a) Key drivers of growth.
(b) Institutional preferences and biases.
(c) Reflections from leading and implementing key projects.

5. Knowledge gaps and institutional challenges [10′]

(a) Issues with the current master planning process.
(b) Big knowledge gaps in long-term planning decisions for land use and infrastructure.
(c) Regulatory and policy challenges.
(d) Requirements and constraints for planners.

6. Looking ahead [10′]

(a) Future vision and issues not addressed.
(b) Successful and unsuccessful examples.

7. Wrapping up [5′]

(a) Room for additional questions and comments.
(b) Anything off the record? (not included in the analysis).
(c) Other experts to connect with.

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