TIMEWISE: Temporal Dynamics for Urban Resilience

Theoretical insights and empirical reflections from Amsterdam and Mumbai

Krishnan, S.; Aydin, N.Y.; Comes, M.

DOI
10.1038/s42949-024-00140-5

Publication date
2024

Document Version
Final published version

Published in
npj Urban Sustainability

ARTICLE OPEN

Check for updates

TIMEWISE: Temporal Dynamics for Urban Resilience - theoretical insights and empirical reflections from Amsterdam and Mumbai

Supriya Krishnan[1]✉, Nazli Yonca Aydin[1] and Tina Comes[1]

Increasing frequency of climate-related disruptions requires transformational responses over the lifecycles of interconnected urban systems with short- and long-term change dynamics. However, the aftermath of disruptions is often characterised by short-sighted decision-making, neglecting long-term urban shifts. In this study, we present a first attempt to develop the theoretical foundation for temporal dynamics for increasingly disrupted yet "connecting and moving" cities that can be used in planning for urban resilience. Using the lens of climate urbanism, we conceptualise the interplay of temporal dynamics to empirically examine how planning practice perceives and addresses temporality in two regions - Amsterdam, the Netherlands, and Mumbai, India. Our findings reinforce that disruptions do not inform long-term planning. Endogenous and exogenous dynamics of change are not viewed together nor used to embed short-term planning goals within long-term resilience visions. To address the lack of systematic planning approaches that can leverage temporal dynamics, we propose two options for temporally flexible urban planning processes.

npj Urban Sustainability (2024)4:4 ; https://doi.org/10.1038/s42949-024-00140-5

INTRODUCTION

The IPCC's 6th Assessment Report emphasises the urgent need for cities to adapt to climate change and prepare for extreme events, especially in developing regions[1]. Hence, urban environments have become the focus of climate policy and implementation of resilience goals[2]. In this study, we refer to urban resilience as[3,4] "the ability of an urban system to maintain or rapidly return to desired functions in the face of disruptions, shocks or stresses". Currently, resilience research has two main streams: (1) emphasising urban transformation and adaptation through substantial changes of infrastructure systems and services[5]; (2) focusing on rapid recovery from disruptions[6]. Despite interest in leveraging disasters for long-term transformation[7], evidence suggests that they do not lead to policy change[8]. We hypothesize that the inability to leverage disaster response for adaptation and urban resilience transition is due to the disconnect between the associated timescapes/ temporal dynamics in the urban environment.

The need for urban transformation under climate change is uncontested. For instance, addressing the IPCC's warnings to limit global warming within a decade[9] requires transformational responses over the lifecycles of interconnected urban systems[10]. Planning for urban resilience becomes challenging as cities must reconcile changes and disruptions across the short-, medium- and long-term[11]. While the field of urban studies has made progress in understanding the temporal dynamics of cities[12–14] it is primarily focused on the lifecycles of urban (infrastructure) systems that impact their design, implementation, maintenance and renewal. Although urban lifecycles span several decades, planning theory has remained conservative, wherein formal decision-making timeframes are short-term (around 20 years), linear and fixed. Pressing urban issues tend to be quick-fixed by planning authorities using interventions[15] that inadequately account for long-term change dynamics and disruptions[12].

Given the short-term focus of urban planning, responses to disruptions mainly prioritize rapidly restoring the status quo ante, ignoring the need for a broader transformative agenda. This is because urban systems are influenced by temporal path dependencies or regimes that are predetermined by planning authorities (such as regional governments and municipalities), which are often resistant to changes and focus on "bouncing back"[16,13,17]. As a result, short-sighted and siloed planning interventions lead to lock-ins that jeopardize long-term goals. Failure to grasp these dynamics leads to fragmented planning and undesirable investments that could result in cascading risks[18] and become a roadblock to achieving resilience and sustainability goals[19,20].

For cities to manage resilience and sustainability transitions while responding to intensifying disruptions[9], urban planning must be considered a function of multiple timescapes of change. Understanding the inherent temporal dynamics of urban systems is key to leveraging disruptions to transform short-term planning responses into long-term solutions. However, currently, a disconnect exists between literature on disaster recovery and the field of adaptation and transition, resulting in a lack of systematic planning approaches to leverage and integrate the time dimension into decision-making[21,5].

To address this gap, the objective of this research is to make the first attempt to develop the theoretical foundation to conceptualise major temporal dynamics for increasingly disrupted, yet "connecting and moving" cities such that it can be used in planning for urban resilience. Our three research questions are: (1) How can we synthesise diverse temporal urban dynamics to plan for urban resilience? (2) How do existing urban planning approaches account for the different temporal dynamics? (3) How can we design temporally flexible planning processes that consolidate an understanding of the different urban timescapes? By addressing these questions, ultimately, this study aims to

[1]Resilience Lab, Faculty of Technology, Policy and Management, TU Delft, Jaffalaan 5, Delft 2628BX, Netherlands. ✉email: s.krishnan@tudelft.nl

provide arguments supporting a shift in urban planning and policy-making to account for multi-level temporal dynamics.

We follow a three-step qualitative process. First, we provide the theoretical background using three lines of inquiry. We follow it up by conceptualising the interplay between two dimensions of temporal dynamics in urban planning (endogenous lifecycles and exogenous drivers). Finally, we investigate planning approaches against the backdrop of these two dynamics.

Second, we use multi-case analysis[22] to examine the associated dynamics within the context of urban planning in two contrasting case studies. The research acknowledges that urban resilience research has focused on cases from the Global North[23,24], resulting in limited approaches tailored for the fast-growing cities in the Global South. To provide a more balanced perspective, we work with the following cases: the Metropolitan Region of Amsterdam (MRA) and the Mumbai Metropolitan Region (MMR). The resulting insights can subsequently inform the design of theory and approaches that can be tested, validated, and applied in a broader range of settings in the Global South and North. As such, even though the findings are grounded in the contexts of Amsterdam and Mumbai, they aim to contribute to a broader understanding of urban temporality.

Third, we design vignettes of temporally flexible urban planning processes that consider major temporal dynamics of urban systems. We demonstrate how planning timeframes could be adjusted to align with different timescapes and facilitate forward-looking decisions under climate disruptions.

Urban systems are driven by two major dimensions of temporal dynamics: Endogenous lifecycles (such as speed and duration of change, rhythms of urban systems including their renewal and decay) and Exogenous drivers (extreme climate events, disasters, and economic shifts). Understanding the two dynamics with very different timescapes for decisions requires approaches to harmonise both within the formal timeframes of urban planning (typically spanning up to 20 years).

To understand Endogenous Lifecycles, we first assess the speed and duration of urban change. The theoretical starting point for endogenous dynamics is Wegener's theory of urban change[25]. It characterises temporal dynamics based on the Speed and Duration of change[26]. 'Time geography' concept describes human activity, using geometries such as cubes and prisms representing the scale and speed of change[27]. Urban DNA[28,29] deciphers or shapes cities based on spatial form, growth speed[30], as well as velocities of infrastructure flows, lifespans, ageing, and seasonal demands[14]. Next, Blumenfeld's theory of spatiotemporal dynamics was one of the earliest contributions that described urban growth as waves[31] - vital to understanding rhythms and lifecycles in urban expansion. Social scientists further built upon the notion of rhythms[32] to conceptualise spatiotemporal cycles of change using *Chronotopes* that link places to recognizable dynamics[33]. Next, Lefebvre's *Rhythmanalysis* focused on repetitive rhythms in cities[34] and described three modalities of rhythms: Repetition of periodic tasks, Cycles of decay, and Periods of "birth, growth, peak, decline, and end."

Finally, an urban environment is polyrhythmic, it consists of nested fast-changing behavioural rhythms resulting from live-work patterns[35] and slow-changing physical rhythms[36]. Importantly, as is true for other social or social-ecological systems[37], urban systems that change slowly set the conditions within which faster and smaller behavioural rhythms emerge. Yet, research suggests that over 90% of urban investments are incremental and often overlooked in research[38], which hinders the consideration of mid-cycle corrections and changes crucial for long-term resilience[39].

Exogenous drivers include climate change disruptions and disasters that accelerate or impede the speed of urban change[38]. The low points of resilience created by disruptions reveal windows to bring in abrupt but transformative changes in urban systems[5,39,40]. Yet, especially in the aftermath of disruptions, planning and policy conventionally become trapped in the '*tyranny of urgency*'[41], focusing on rapidly re-establishing the status quo ante instead of pursuing long-term agendas. Exogenous drivers also come in the form of disruptive technologies (like electric vehicles, sharing economy, ICT) which drive rapid reconfiguration of conventionally slow-changing urban systems. Catastrophe theory[42,43], explains non-standard urban changes such as rapid emergence of places, real estate bubbles, depopulation of cores, and rebuilding cities post disasters. However, no systematic planning approach has leveraged disruptions as intervention points that can be consolidated ex-post with long-term transformative goals.

Planning approaches under climate change requires combining incremental and transformative responses[44] across the short-, medium- and long-term. Currently, planners use formal planning timeframes spanning between 5-20 years. Within this timeframe, planners identify changing insights and align them with decision-making windows for different urban systems[44,45]. The timescapes for formal planning and decision-making for urban systems are often conflict ('arrhythmia'), leading to deadlocks in decisions[46]. The disjuncture in dynamics is further reinforced by capacity and knowledge gaps.

Figure 1 illustrates the interplay of two major temporal dynamics in urban planning that must be aligned and harmonised for achieving long-term resilience goals. The X-axis is Time representing Urban planning timeframes of up to 20 years in which decisions must be made for multiple urban systems. Y-Axis represents Endogenous lifecycles of five major urban systems, i.e., the period over which an urban system decays or can be renewed. It also illustrates Exogenous drivers and disruptions that impact urban systems (red). To account for the temporal heterogeneity of urban systems, we use the Urban Layers Approach (ULA), which classifies urban systems into five groups based on their lifecycles[47,48]:

1. Layer 1: Unplanned/Open spaces: retention parks, traffic intersections, parking lots (1–10 years).
2. Layer 2: Occupation: buildings, neighborhoods (3– 50 years).
3. Layer 3: Focal Points: multi-model hubs, train stations, airports (5–50 years).
4. Layer 4: Networks: highways, railways (10–100 years).
5. Layer 5: Natural Resources: wetlands, national parks (20–100+years).

Figure 1 also shows that urban systems are in different stages of their lifecycles at any given time. However, conventional planning decisions are focused at the beginning or endpoint of the lifecycles of urban systems where they have decayed or fulfilled their functions[49]. Mid-course corrections or modifications are challenging to account for within planning timeframes, where such decisions have to be made for multiple systems with different temporal dynamics. Hence, they remain disconnected from the overall plan. For instance, Planning Timeframe A (black) includes the beginning or ends of lifecycles of several urban systems (both short and long-lived). The lifecycles present windows to integrate new insights. Whereas Planning Timeframe B (grey) includes the beginning or ends of only a few short-lived urban systems, subsequently offering few opportunities for change. Further, restrictive formal planning timeframes (up to 20 years) hinder adapting to abrupt disruptions crucial for transitioning to long-term climate-resilient futures, even if these disruptions affect all urban systems (red in Fig. 1).

RESULTS

Across both cases, participants acknowledge the need to formulate and implement long-term visions and align the dynamics of different urban systems to plan for resilience. They

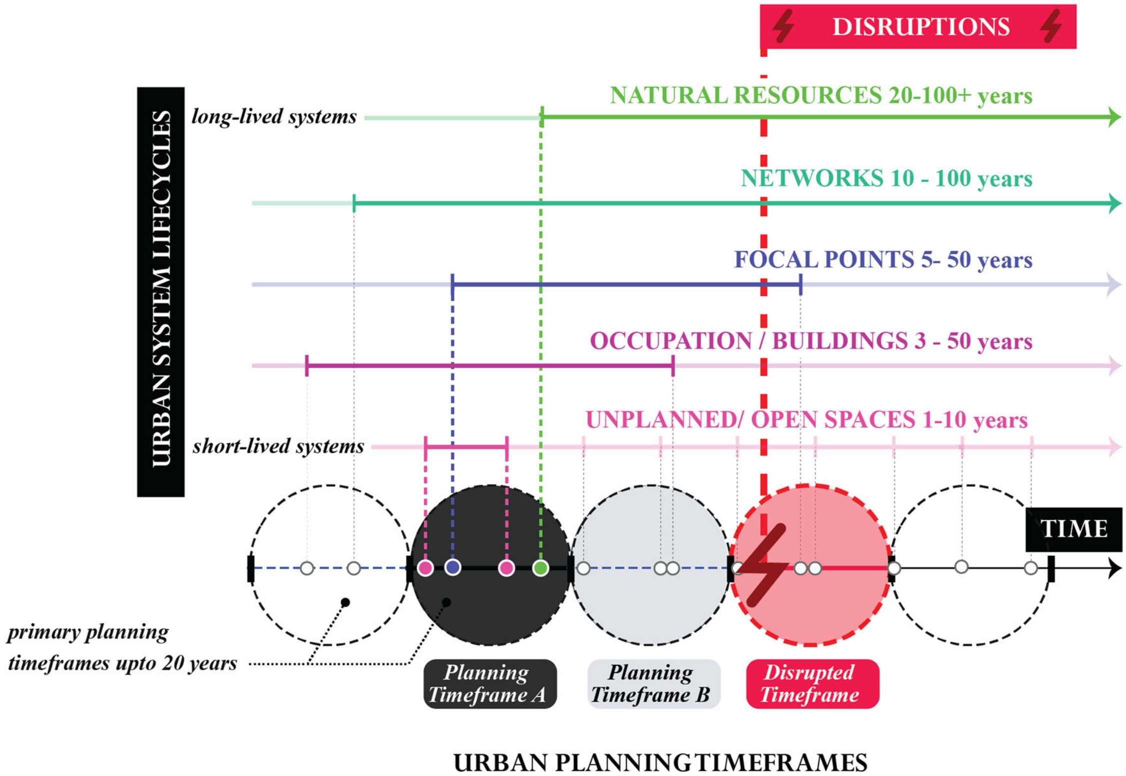

Fig. 1 Conceptualising the interplay of two major temporal dynamics in urban planning that must be aligned and harmonised for achieving long-term resilience goals. (1) X-axis: TIME - representing urban planning timeframes of up to 20 years in which decisions must be made for multiple urban systems. (2) Y-Axis: Endogenous lifecycles of five major urban systems, i.e. their lifecycles of renewal and decay (various colours); and Exogenous drivers and Disruptions that impact urban systems (red). Urban systems include short-lived systems that can be renewed every 3-10 years (unplanned spaces) to long-lived systems that last beyond 100 years (natural resources). Within a single planning timeframe, different urban systems are at different stages of their lifecycles, which must be harmonised or realigned to manage climate stresses and shocks. However, mid-course corrections or modifications in urban systems are often not accounted for in planning timeframes. *Planning Timeframe A* (black) includes the beginning or ends of lifecycles of several urban systems (both short and long-lived). The lifecycles present windows to integrate new insights, thus becoming a critical juncture in managing urban change. *Planning Timeframe B* (grey) includes the beginning or ends of only a few short-lived urban systems, which offer fewer windows to integrate long-term change. *Disrupted Timeframe* (red) are a result of exogenous drivers and climate-change-related disruptions. This timeframe must be leveraged to bring long-term systemic transformation?. However, empirical evidence has shown that disasters do not lead to policy change.

highlight the role of exogenous drivers in bringing about transformative change. For planning approaches, participants spoke both to the possible enablers of considering temporal dynamics such as scenarios, storylines, and high-level strategies as well as the barriers that prevent long-term planning in practice. In the following, we formulate three main findings reflecting the three lines of enquiry of temporal urban dynamics outlined above, reflecting upon the specific context of MMR and MRA. Table 1 synthesizes and summarizes commonalities and differences between the findings for the two cases. In addition, Tables 3 and 4 present a clear overview of the frequency of themes and quotations from the interviews.

Finding 1 (Endogenous lifecycles): short-lived urban rhythms and tactical urbanism dominate in the face of lock-ins - rendering long-term planning futile

Endogenous lifecycles illustrate the speed & duration of change in different urban systems, including their renewal and decay.

In the MMR, while participants emphasized the importance of interventions in long-lived urban systems, concrete climate strategies predominantly focus on bottom-up approaches in short-lived systems, such as plot-level adaptation and rooftop rainwater harvesting. Long-term thinking is sporadic, mainly observed in systems like transport, which provide the spatial structure for urban expansion. Planning discussions focus on "solving urgent problems rather than central ideas" [P22] or "alternatives for future development" [P23]. [P36] clarified that "India's planning is stuck in a 10-year time step" forced by financial and political processes that align to this temporal frame. Mega-infrastructure projects are viewed as catalysts for urban transformation. However, planning beyond 20 years is considered counterproductive "given the speed of technology and climate change"[P36]. P29 cites the "shortsightedness of planners as obstacles to resilience thinking. As MMR experiences rapid growth and invests in long-lived systems, it needs to adopt a risk-informed approach to planning. However, P21 confirms that "MMR hasn't been able to actively integrate risk or climate projections in long-range planning decisions or visions.". Delays in the acceptance and implementation of plans render the original assumptions and projections outdated, leading to asynchronicity with the lifecycles of urban systems [P35].

The MRA has developed programs to consolidate tactical local-level responses for climate adaptation, exemplified by initiatives like Amsterdam Rainproof[50]. The initiative aims to capture and channel excess rainwater into planned and unplanned spaces, buildings, and neighbourhoods - largely short-lived systems. Having said that, we observe that MRA still acknowledged endogenous lifecycles better than MMR, as it must conserve and renew older infrastructure systems while meeting resilience and sustainability goals. P7 explicitly stated that "planning and policies must account for multiple and nested temporal frames within a

Table 1. Synthesizing and summarizing commonalities and differences between the findings for the two cases: Metropolitan Region of Amsterdam (MRA) and Mumbai Metropolitan Region (MMR).

Results	Commonalities	Differences
Finding 1: short-lived urban rhythms and tactical urbanism dominate in the face of lock-ins, rendering long-term planning futile.	Both regions prioritize alleged "quick wins" through incremental responses in urban systems with short lifecycles. Both have fixed timeframes for planning.	MRA recognizes the long-term transformation process and the importance of incorporating multiple nested temporal frames within a single planning timeframe. However, the underlying master plan remains static, limiting its adaptability to change. MMR participants do not discuss long-term strategies, as there is a lack of adherence as well as significant delays in the implementation of master plans.
Finding 2: disasters fail to inform transformative urban change.	Both cases acknowledge the role of disasters as catalysts for change.	MRA's approach to planning for resilience after disasters and outlier events remain erratic and abstract. MMR develops concrete interventions for disaster management, but is highly reactive, and not aligned with risk-informed plans or policies.
Finding 3: overtly structured planning approach in MRA and the prescriptive approach in MMR are restricting temporal flexibility in planning.	Both cases discuss the dynamics of urban renewal, maintenance and transformation as temporal windows to integrate resilience.	A history of structured planning in the MRA has created inertia in existing planning and policy-making, hindering their ability to adapt or respond effectively to disruptions despite ample future projections. MRA engages in concrete planning approaches incorporating urban layers, enabling tangible strategies. MMR's approach is conservative, prescriptive, and mechanical, relying on past metrics and market forces and exhibiting limited flexibility to change.

single planning timeframe.". However, the underlying masterplan or urbanization concept that ties systems together is static. P1 explained that there is "an overarching resistance to change" and, P3 confirmed this by stating that "We need to try to not make very big investments, where they are locked-in."

While participants in both cases acknowledge the importance of long-term thinking in theory, the high densities and existing lock-ins in MMR and previous locked-in investments in MRA limit the scope for spatial readjustment necessary for transformative change. Hence, climate-related strategies tend to be tactical, targeting fast-changing urban systems and immediate returns, with limited examples of long-term investments. This results in a prevailing belief that long-term planning is futile and counter-productive in meeting resilience goals.

Further, MMR and MRA develop formal urban plans with fixed timeframes of 20–30 years, aligning with the definition of 'short-term' provided by the IPCC. Participants in both cases endorse the need for flexibility in plans, suggesting modifications every 1–5 years [P7,P27,P31] or every 10–20 years [P14]. However, multi-scalar temporal planning is neither explicitly discussed nor fully understood. Instead of embracing and planning for complexity, P1 & P34 recommended that "interconnected (urban) rhythms must be cut loose from each other". However, in a complex environment, this is not feasible.

Finding 2 (Exogenous drivers): disasters fail to inform transformative urban change

Exogenous drivers include climate change disruptions, disasters and shocks that may accelerate or impede the speed of urban change.

The MMR experiences recurrent flooding disruptions, including the 1-in-100-year mega-flood (2005). While the event led to a surge of reactive interventions such as weather stations and floodwater pumping facilities[51], it did not lead to risk-informed urban policies. P25 endorsed that "In consultations on climate and disasters, they [the city] will always discuss traffic, parking, and waste management issues." Despite recurrent flooding, land continues to be reclaimed for development in low-lying areas [P39]. P33 stated the urgent need for courageous trade-offs and to accept trial-and-error planning mechanisms to use disasters as an opportunity for building region-wide resilience. Current strategies are deemed insufficient to effectively manage extreme events [P21,P35,P36,P38].

In the Netherlands, the 1953 flooding disaster catalysed a shift in flood management from relying on historical metrics to focusing on future probability[52]. The Western Europe flood (2021) also renewed interest in resilience planning, especially for outlier events[53]. However, risk management in the Netherlands is driven by a 'protection' approach, where "people trust the national government and high dikes to protect them". [P5]. Systems shocks and disruptions are low points of resilience that break, shift or reset temporal dynamics, revealing windows for transformations. In line with that, MRA & MMR participants expressly acknowledge the role of disasters as catalysts for change. However, planning practice treats disasters as 'episodic events' [P30] and does not use them to bring in long-term, systemic change. Integration of disruptions or disasters as temporal windows in urban planning, especially under climate change, remains abstract and is not implemented systematically [P2].

Finding 3 (Planning approaches): overtly structured planning in MRA and prescriptive planning in MMR restricts temporal flexibility

Urban systems are influenced by temporal dependencies and tools utilised by conventional planning institutions such as regional governments and municipalities, which are often resistant to change.

MMR's planning approach is broadly characterised as "conservative, prescriptive & mechanical", where decisions rely on past metrics and market forces and are largely inflexible to temporal changes [P29, P30, P35, P36, P38]. Physical planning is done at the level of land parcels using mathematical restrictions [P21, P37], leaving little flexibility to integrate additional climate goals. MMR does not have an official repository of land- use changes, nor do participants discuss tools or approaches to utilise temporal dynamics. A critical factor hampering well-coordinated, flexible responses is the lack of a vision or 'attractor', which is essential to attaining alternative development trajectories[5]. In addition, proper implementation of original plans in MMR is weak, further exacerbating the gap between planning timeframes and the lifecycles of urban systems [P29,P37]. Hence, project implementation routinely deviates from the original plan [P29, P33], resulting in ineffective channelling of positive path dependencies required to meet long-term goals.

Although the Netherlands is exploring the dynamics of individual systems using the 'urban layers approach'[48], its planning approach is characterised as 'too structured' by participants. The plan's inertia to change [P1] extends to planning policies and climate adaptation strategies that use fixed scenarios despite the uncertainties acknowledged [P7, P9]. MRA's urban planners discuss flexibility by keeping several options open and avoiding negative path dependencies, even if the system is inflexible [P3, P4]. To some extent, participants discuss concrete planning approaches identified in literature, notably urban landscape dynamics[54], as MRA benefits from a national record of historical land-use changes. Participants propose the development of abstract visions [P1], storylines [P8], and scenarios for changing dynamics. While scenarios are developed nationally, they are not yet downscaled to the metropolitan region scale where plan implementation happens [P3, P13].

Reflecting the need to consolidate lifecycles of old and new infrastructures in a complex environment, MRA participants discussed the dynamics of urban renewal and transformation as a path to meet resilience goals [P5]. Similarly, MMR emphasised renewal and maintenance as the sole temporal windows that offered flexibility in a hyper-dense region. However, such approaches are time-consuming and focused on one fixed point in time. Given the relatively short time available in the aftermath of disruptions, visions and storylines would need to be (re-) developed continuously to ensure they are available and ready for use when (climate) disaster strikes.

A critical outfall of not accounting for temporal dynamics is that plans and policies become outdated earlier than expected. For instance, Amsterdam's Structure Vision (2012) for 2040 became outdated within a few years as the city grew faster than expected [P3, P4]. Similarly, MMR's Regional Plan 2014-2034 was sanctioned only in 2021 [P37].

The barriers to incorporating temporal thinking

Participants across MRA and MMR acknowledge the necessity of reconciling multi-temporal goals in planning. However, interviews in both regions indicated no systematic consideration of temporal aspects in urban planning. Processes are based on a fixed point in time and consider urban systems to be in temporal equilibrium.

Figure 2 presents the status quo of urban planning processes (representative of both cases), which follow a fixed sequence of 20-year periods (which may have shorter time steps within to update plans). Hence, cities are stuck with small- scale tactical planning where they continue to promote incremental interventions in urban systems with short lifecycles. Harmonization of nested lifecycles is discarded as too complex as there are no clear mechanisms, processes or incentives to enable long-term planning. Hence, policies are often outdated, and the relevance of thinking across temporal scales is not valued.

Under disruptions, the planning timeframe is reset, cf. Figure 2. Cities fall back on re-establishing the status quo soon after disruptions due to the shortsighted and restrictive nature of planning. Processes of recovery and re-calibration of development goals extend into future timeframes, impeding long-term resilience goals. Finally, both cases demonstrate an aversion to non-confirmative planning processes, with a fear of failure and strong inertia to change. They promote the perception that long-term planning is futile and further discourage planners from pushing longer-term temporal boundaries, essential to manage climate disruptions. P17 warns that *"the climate crisis has bypassed us as even an issue that needs to be considered politically"*.

DISCUSSION

The starting point of this research is to develop the empirical and theoretical foundation to conceptualise major temporal dynamics for "connecting and moving" cities planning for urban resilience. It argues that planning must be rooted in understanding temporal dynamics for transitioning to urban resilience under climate disruptions and supporting progress towards the SDGs. Our main finding is that even though the need for understanding and utilising different timescapes of urban planning is recognized, there is a noticeable absence of planning theories and approaches to put this concept into action. As a result, current planning overlooks the complexities of preparing for a long-term future impacted by climate disruptions.

We synthesise existing literature along three lines of enquiry channelling endogenous lifecycles, exogenous drivers of change, and planning approaches towards climate change. We complement this with empirical interviews in two climate ambition case studies to explore real-world planning approaches and their temporal dynamics.

We find that practitioners' perspectives [P5, P10, P29] are largely consistent with literature that emphasises embedding resilience in urban systems with long lifecycles[55–57]. This is, however, in sharp contrast to *Finding 1*, where climate-related interventions focus on 'quick wins' in systems with short lifecycles. Tactical urbanism measures are adopted when institutional gaps or resource scarcity hinder sustained, long-term responses to risks[58]. Both cases acknowledge disruptions from disasters and climate that shift urban rhythms drastically and open up intervention windows. While literature endorses the role of disruptions as opportunities for planners to implement transformative adaptation measures and enable mid-course corrections in systems to extend or revise their lifecycles, our interviews indicate that planning remains fixed and unresponsive. Despite disruptions, the focus is primarily on building back the status quo ante. The overarching vision or 'attractor' required to implement transformative resilience goals is missing and cannot be developed in the few weeks or months available to plan for the recovery from disruptions.

Utilising temporal dynamics requires explicit consideration of short-, medium- and long-term interventions, aligning, realigning, and negotiating them into formal planning timeframes. A critical challenge is the integration of uncertainties. The lack of flexibility in planning approaches leads to lock-ins resulting from undesirable investments. Overall, only 3-4 participants, notably in the MRA, explicitly discuss flexibility in planning when drafting new development plans and urbanization strategies [P1, P2, P6, P22]. Overall, the findings reflect the stark contrast between the perception and practicalities of temporal dynamics. They highlight the methodological gaps in why current urban planning cannot utilise temporal flexibility. Enhanced understanding of temporal dynamics will require existing planning theory to acknowledge the limitations of practice, increasing the emphasis on adapting planning policies over time as well as better monitoring systems to deal with anticipated and unanticipated changes.

To leverage temporal dynamics in urban planning, we design vignettes of temporally flexible urban planning processes that

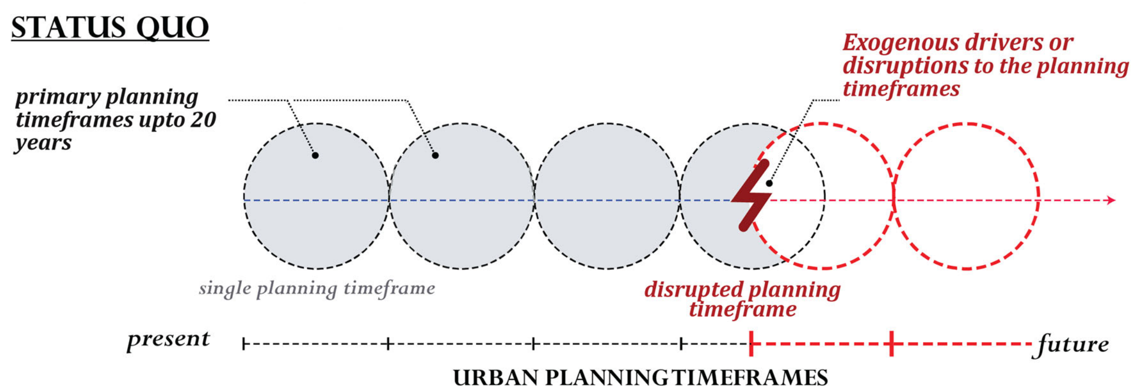

Fig. 2 Illustrating the current status quo of urban planning. Planning is myopic to the long-term implications of urban change. It follows a fixed, linear sequence of around 20-year periods (grey circles). It may have smaller incremental time steps within to update plans due to exogenous drivers such as politics, industrial lobbies or technology. Under disruptions (in red), the planning timeframe is reset, and cities fall back on re-establishing the status quo. Due to the restrictive nature of planning, recovery processes extend into future timeframes, impeding long-term resilience goals. Hence, cities are stuck with tactical, small-scale technical planning where they continue to promote incremental alleged 'quick wins' in urban systems with short lifecycles. Harmonization of nested temporal frames is discarded as it is too complex.

consider endogenous lifecycles and exogenous drivers in Fig. 3. We contrast them with the status quo of urban planning (Fig. 2) to highlight how planning timeframes could be adjusted to leverage disruptions to enable forward-looking decisions. The options are prototypical vignettes whose advantages, drawbacks, and implementation requirements are discussed below.

Both options feature a primary (grey) and secondary (green) timeframe (Fig. 3). The primary timeframe* serves as the primary window for decision-making and serves as the key temporal unit for exploring flexibility and variations. The influence of exogenous factors and disruptions is depicted in red. Option 1 (Nested Timeframes) introduces two timeframes: 20 years (primary) and 100 years (secondary). Typically, a two-tier planning process involves a national strategy and a regional strategy (like in MRA). The secondary timeframe (green) allows for monitoring slower-changing systems like water or transport. It offers flexibility under disruptions to adapt to changes and facilitate abrupt transformations by guiding adjustments in primary timeframes. This enables the derivation of explicit requirements and goals for *each* primary planning timeframe, which can be translated into planning visions for short-lived systems. Option 1 may work well in regions like MRA with well-established spatial planning and the capacity to create multiple strategies, given that the urban fabric is also not changing dramatically. MRA already integrates long-term sectoral visions into its national adaptation strategy. However, in rapidly evolving regions like MMR, heavily investing in new urban systems, a fixed long-term vision may hinder adaptation to the dynamics of emerging urban systems.

Option 2 (Flexible timeframes), similar to Option 1, presents a short-term primary planning timeframe (grey) guided by a long-term secondary timeframe (green). Both timeframes are flexible and can adapt to changing planning variables. Option 2 goes beyond Option 1 as the secondary timeframe can acknowledge dynamics of short- and long-lived urban systems and guide incremental decisions within primary timeframes. Decisions could range from major projects to consolidating measures in local rainwater harvesting interventions, developing amphibious neighbourhoods or re-hauling the water or energy systems.

Both timeframes can adapt during disruptions, aligning with shifting short-term goals and long-term vision, promoting harmonisation. It offers flexibility to add extra planning layers (shorter or longer than the primary timeframes) after significant disruptions for rapid recovery without compromising long-term resilience. This approach demands a highly responsive planning and governance system to monitor, understand and capture the right variables to bounce forward after a disruption. Clear markers and monitoring are crucial to initiate new responses; without them, the plan becomes vulnerable to political powerplay and urgent development agendas and may fall back to the status quo.

This option could potentially become effective when regions review their development objectives every few years due to accelerating climate change, paving the path for newer insights. It enables a two-way knowledge exchange between the primary plan and the long-term vision. A downside of offering high flexibility for planning a region like MMR with significant capacity gaps is that it might not effectively regulate interventions between the two timeframes.

This paper investigates the synthesis of major temporal dynamics (endogenous and exogenous) of urban change for resilience. It uses the synthesis to propose two options for temporally flexible urban planning processes to manage climate disruptions. While understanding and implementing temporally flexible planning processes is already challenging for planners, doing so under climate disruptions compounds the problem. Leveraging disruptions to achieve urban resilience requires moving away from decision-making solely at the end of the planning timeframe or an urban systems' lifecycle towards making changes mid-cycle or in moving time intervals where insights can be continuously integrated and harmonized. Several participants recommend updating plans every few years, which allows the opportunity to implement new insights, provided there are policies for it [P5, P7, P14, P27, P31, P36]. Currently, in the absence of such temporal considerations, P3 expressed aversion to making big investments, whereas participants in both cases recommend formalising renewal and maintenance of infrastructures as temporal windows for updating insights [P5, P6, P14, P32], which is a key area for further research.

Introducing mid-cycle changes in urban systems also requires a reliable knowledge base on their condition, accessible to planners. Lack of data or outdated data are cited as a major roadblock to planning in the MMR [P35]. The Netherlands however has a publicly available repository of building construction and age. A similar system may be scaled up for other urban systems. This also allows for finding couplings between urban systems to capitalise on resilience opportunities.

This study expands on primary research on temporality in less-studied and rapidly changing urban contexts of the Global South. MMR exhibits different perspectives and resistance levels for achieving urban resilience. As an emerging region, it benefits from relatively fewer structural lock-ins to adopt newer temporal planning processes[59]. However, theoretical findings indicate resistance to

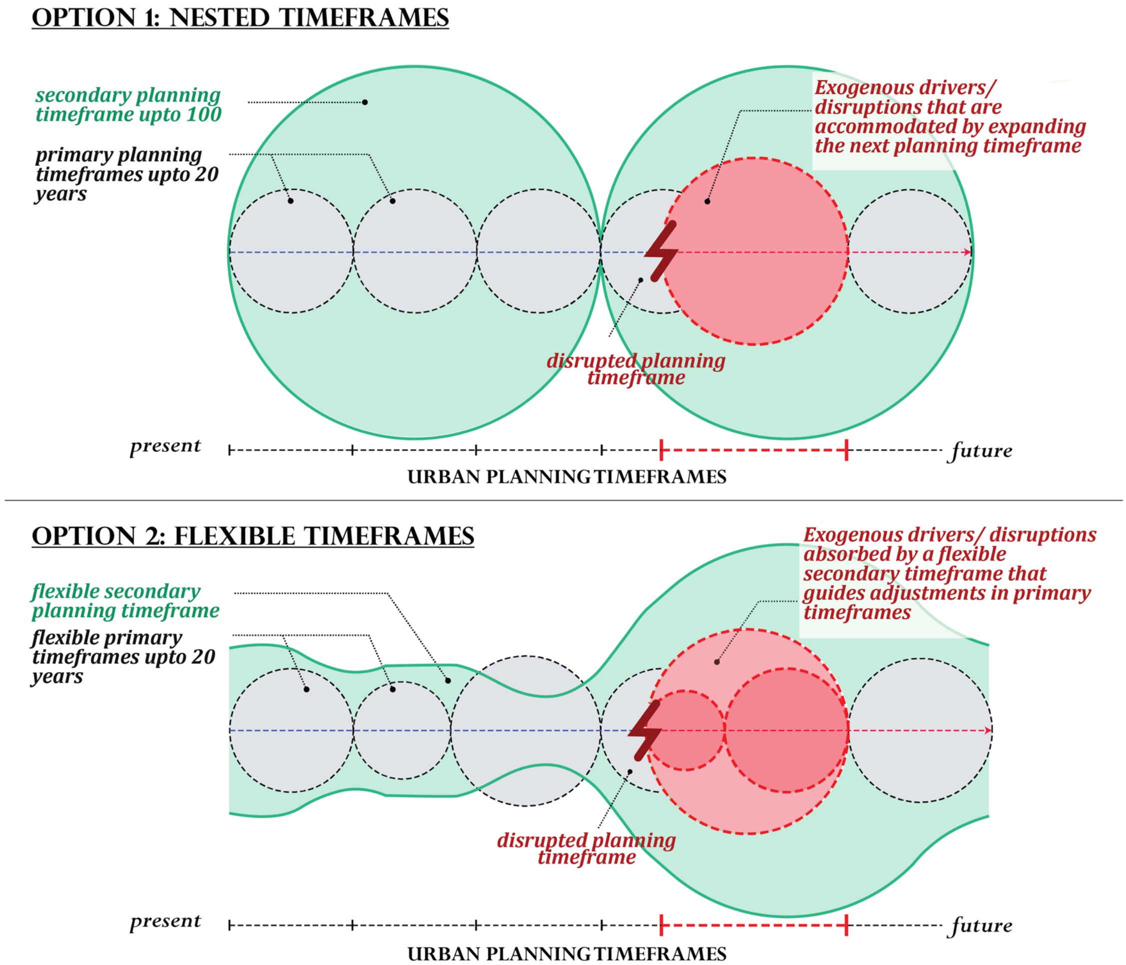

Fig. 3 Exploring prototypical vignettes of temporally flexible urban planning processes. We demonstrate how current planning timeframes (in grey circles) could be adjusted to leverage disruptions (in red), harmonize lifecycles of urban systems and enable forward-looking decisions for urban resilience. (a) In Option 1 (nested timeframes), we propose two nested plans for the same spatial scale. Under disruptions, the secondary timeframe (in green) offers the room to absorb changes or enable transformations by guiding adjustments in primary timeframes (in grey). It allows monitoring changes in systems with longer lifecycles, such as water or transport networks. (b) In Option 2 (Flexible timeframes), both timeframes are flexible and can evolve due to changing planning variables. The secondary timeframe (in green) allows consideration of the impacts of major endogenous lifecycles of long-lived urban systems and guides incremental decisions within each primary timeframe. Under possible disruptions (in red), both timeframes can adjust and re-align with changing objectives.

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.

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

'X' indicates that we did not receive responses from the right participants from that domain (Table 1 borrowed from a preceding study[63] by the authors of this study focusing on resilience in urban planning for climate uncertainty).

respond to changes due to rigid and unresponsive planning regimes and negative path dependencies embedded due to past investments[13,17]. Our interview findings suggest no strategies or thinking in that direction, making it essential for future research.

This study recognizes the distinctiveness of various planning contexts and emphasises that these case studies do not represent the only city 'types' in the Global North and South. The theoretical foundations developed in this can be expanded by researching other

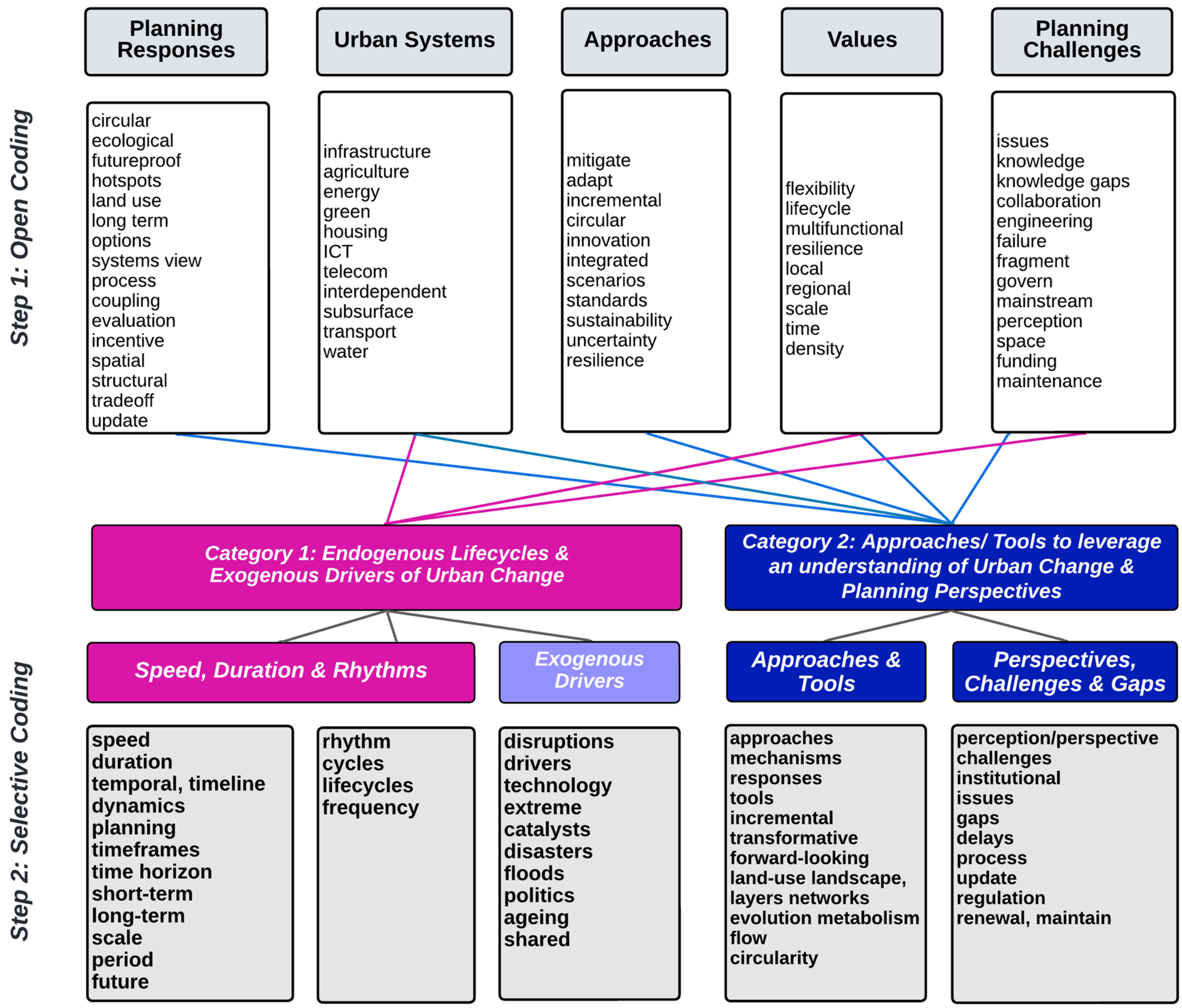

Fig. 4 Two-step qualitative coding scheme used for the analysis of interviews for MRA and MMR. Findings are organized under two main coding categories: Category-1: Endogenous Lifecycles/ Rhythms & Exogenous Drivers of Urban Change (in pink). Category-2: Planning Approaches: Tools to leverage an understanding of Urban Change & Planning Perspectives on Urban Change (in blue).

cases. Nonetheless, the significant urbanization characteristics displayed by our case studies offer the necessary diversity for this research.

The planning vignettes (Fig. 3) are initial steps to reorganize planning processes for leveraging temporal dynamics. They must be adapted for specific regions. Planners have access to tools like scenario thinking, visioning, model-based decision-making, climate projections, and improved data availability. Understanding temporal dynamics in the Global South also requires examining emerging, non-standard growth patterns, such as informal settlements [P32,35,36]. Ultimately, this study urges a methodological shift in urban planning and policy-making processes to account for multi-level temporal dynamics.

METHODS

This section discusses the research approach, case study selection, data collection, and analysis. In this study, we make the first attempt to develop the theoretical foundation for major temporal dynamics "connecting and moving" cities that can be used in planning for urban resilience. The objective is to understand, through empirical insights from contrasting case studies in the Global North and Global South, how urban planning deals with temporal dynamics.

Case studies

We use multi-case analysis to assess contextual variability in the case studies and combine it with the conceptual lines of enquiry derived from the literature. Amsterdam and Mumbai, located in the Global North and Global South, respectively, were selected due to the contextual and cultural variation they offer to examine planning processes, perspectives, and institutional characteristics of decision-making. Both regions have solid financial and cultural functions and are undergoing urban regeneration, ranging from massive infrastructure renewal and maintenance to investments in new infrastructure and adaptive reuse. Their dual ambitions to meet development goals while tackling climate disruptions frame the opportunity to derive diverse insights.

Table 3. Overview of discussions under Coding Category 1: endogenous lifecycles/ rhythms and exogenous drivers of urban change.

S.no.	Coding sub-category and terms	Mentions	Participants	Example quotes
1	Speed &duration: speed, duration, temporal, dynamics, planning, timeframes, time horizon, short-term, long-term, scale, period, future	112	P3, P6, P7, P29, P30, P34, P36, P38	P7: "Planning and policies must account for multiple and nested temporal frames within a single planning timeline." P30: "When you do a city as large as Mumbai, obviously, you cannot make short-term plans." P38: "The speed of the temporal and statutory cycles is a mismatch."
2	Rhythms: rhythm, cycles, lifecycles, frequency	9	P1, P7, P9, P14, P30, P36	P1: "MRA acknowledges different elements with different frequencies and rhythms. Cut these rhythms loose from each other." P7: "Planning and policies must account for multiple and nested temporal frames within a single planning timeline." P14: "Is it future-proof?" Is it able to absorb changes? Can it be easily replaced in 10-20 years? you should make that in such a way that it can be easily replaced in 10-20 years." P36: "India's planning is stuck into a 10-year time step because the census is a ten-year time step."
3	Exogenous drivers of urban change: drivers, technology, extreme, disruptions, catalysts, disasters, floods, politics, ageing, shared	94	P1, P11, P13, P25, P27, P29, P30, P34, P36	P1: "Only when there is a big event like an earthquake or flood or a bombarding, then we change the layout of the city." P11: "Political roadblocks in planning approaches and horizons might be preventing effective climate adaptation." P29: "MMR acknowledges the role of system-shocks and disasters in driving urban transformation." P36: "For a rapidly urbanizing region, a vision for 20 years is too long given the speed of technology and climate change."

It highlights concepts discussed by participants in both cases including frequency of codes and example quotes. [Amsterdam participants (MRA): P1 to P20; Mumbai participants (MMR): P21 to P39].

Case study 1: Metropolitan Region of Amsterdam, Netherlands (MRA). The MRA is an advanced urban economy with robust formal planning structures, well-coordinated investments, consensus-driven political processes, and[60]. It is an agglomeration of 32 municipalities housing 2.48 million people spread over 2580 sqkm. Its urbanization strategy includes climate ambitions for 2050 and identifies vital urban systems that must become resilient under climate change. Future growth involves consolidating and streamlining temporal dynamics of renewing ageing infrastructure, building a large volume of housing, and transitioning to a fossil-fuel-free economy[61]. 70% of MRA is vulnerable to one or more risks, such as extreme heat, rainfall, prolonged droughts, and sea-level rise.

Case study 2: Mumbai Metropolitan Region, India (MMR). The MMR is a developing economy where planning is a mix of formal and informal processes. It is an agglomeration of 9 major municipal corporations housing 26 million people spread over 6355 sqkm, making it amongst the most populous metropolitan areas in the world[62]. Its regional planning strategy includes high-level actions for climate change, but they are not integrated with infrastructure and land-use aspects. MMR's future growth involves capitalising on temporal dynamics to invest mindfully in a large volume of long-lived new infrastructure, including metros, industrial corridors, airports, high-speed rail, and coastal roads. MMR was originally built on reclaimed land, and large portions along the coast lie below the high tide level. Hence, planning must respond to chronic disruptions from flooding and heat waves coupled with inadequate infrastructure.

Data collection and interview design

We conducted 39 semi-structured interviews with senior practitioners who work on four critical domains in urban planning: (a) Urban Planners; (b) Strategic/ Policy Advisors/ Bureaucrats; (c) Academic Researchers; and (d) Specialists in Sustainability/ Engineering. The interviews were conducted over one year (2020-21) online using Zoom/Teams calls due to travel restrictions during the Covid-19 pandemic. Each interview was approximately 60 min long.

To select interview participants, we used a combination of snowball sampling, personal referrals, and social media (LinkedIn) to shortlist 200 participants, of which 20 were selected for MRA [participants P1-P20] and 19 for MMR [participants P21-P39] (see Table 2).

The interview questions were structured into three main sections (derived from the three lines of enquiry from the literature) to derive insights into Endogenous dynamics, Exogenous drivers, and Planning approaches. Using findings from the literature review, the questions investigated the characteristics and associated gaps for each line of inquiry through participants' accounts of how they understand and work with temporality, such as planning duration/ timeframes, urban infrastructure lifecycles, the role of disruptions and their integration into planning processes. Supplementary Material presents an indicative semi-structured interview protocol with full documents disclosed under https://doi.org/10.4121/6952ac97-2753-4f4b-b9bc-8e65968d81e6[63].

We conducted a systematic qualitative data analysis of interviews to interpret the text and derive insights along the three lines of inquiry to extend theoretical insights. We developed a corpus of interviews by transcribing the voice recordings and memos written during the interviewing process. Each case was analysed separately using two-step uniform qualitative coding.

In Step 1, we used open coding to extract broad findings on experiences in urban planning responses and climate change, urban systems, broad approaches, planning values, and challenges. In Step-2, we used selective coding to extract findings under two main coding categories to investigate the lines of enquiry and gaps derived from the literature (Fig. 4).

Category-1: Endogenous lifecycles (pink) and Exogenous drivers of urban change (violet). Characterising urban change (speed, duration, & rhythms, planning timeframes); external drivers (extreme events, disruptive technologies, and political shifts).

Category-2: Approaches/tools to leverage an understanding of urban change and Planning perspectives on urban change (blue). Specific approaches and tools to assess temporal dynamics of the urban landscape, networks, and flows; participants' perspectives and challenges in long-term thinking (institutional issues, delays).

Open coding was conducted by four student researchers. The heterogeneous participants used different terminologies to describe similar concepts of planning and temporality. Hence, to

Table 4. Overview of discussions under Coding Category 2: approaches/tools to leverage an understanding of urban change and planning perspectives on urban change.

S.no.	Coding category and terms	Mentions	Participants	Example quotes
1	Approaches and tools: approaches, mechanisms, responses, tools incremental, transformative, forward-looking, land-use, landscape, layers, networks, evolution, metabolism, flow, circularity (pertaining to urban metabolism studies)	95	P1, P2, P3, P5, P6, P7, P8, P10, P24, P29, P30, P33, P34, P35, P36, P38	P2: "Make an abstract vision for the future. Then it works out in different programs that can change so you can be flexible." P8: "There are techniques to link (flood) return periods to planning storylines, but the future will evolve differently, but at least think of some catastrophic storylines." P33: "The more you are in reactive response mode, the lesser time and resources to devote for strategic thinking." P34: "We need a multilevel framework for assessing (long-term) trade-offs for coastal roads, overhauling the drainage systems…" P35: "Temporality of the informal landscape cannot be assessed using existing approaches as they cannot be fully regulated." P36: "Development could be controlled using transit networks which offer a spatial structure for future growth…with long lifecycles".
2	Perspectives, challenges and gaps: perception, challenges, institutional, issues, gaps, delays, process, update, regulation, renewal, maintain	119	P2, P3, P5, P7, P8, P21, P29, P30, P33, P35, P37	P3: "Amsterdam's Structurevision (2012) became outdated soon after its release as the city grew faster than expected." P5: "Policies to implement climate norms will always be dated. How do you allow the policy design to respond and go beyond what is set in stone?" P29: "Projects with long gestation periods are hard to implement as planners can't even see beyond three years." P37: "This lag in planning and implementation timelines cascades to day-to-day decision-making which then stretches to several months."

It highlights concepts discussed by participants in both cases including frequency of codes and example quotes: Amsterdam participants (MRA): P1 to P20; Mumbai participants (MMR): P21 to P39.

keep the coding consistent, the researchers were provided with an exhaustive list of 77 codes encompassing various aspects of the interview responses, which were double-checked by the authors with the support of one student assistant. Next, selective coding was conducted by the authors to investigate the themes relevant to this study. Detailed documents on the interview process, including the detailed interview protocol, consent forms, list of questions and codebooks, are available at https://doi.org/10.4121/6952ac97-2753-4f4b-b9bc-8e65968d81e6[63].

Tables 3 and 4 enlists the coding categories, terms included under each category, and example quotations. We quantified the codes, dived into the associated quotations, and went back to the interviews to position them in the broader context of this research. We conduct a cross-case assessment to observe the similarities and differences between the cases.

Reporting summary

Further information on research design is available in the Nature Research Reporting Summary linked to this article.

DATA AVAILABILITY

All interview data in this study were collected through a GDPR-compliant framework and with approval from the Human Research Ethics Committee (HREC) at the Delft University of Technology, the Netherlands. The publicly available datasets supporting the study's findings may be accessed at https://doi.org/10.4121/6952ac97-2753-4f4b-b9bc-8e65968d81e6[64]. Restrictions apply to the availability of the interview participants' personal data per the consent received by all participants. Datasets containing personally identifiable information are for verification and validation only; they may not be used for further research and are available upon request until March 2025, after which they will be deleted.

CODE AVAILABILITY

Qualitative data coding and analysis of interviews were conducted using software *Atlas TI* (Version 9).

Received: 5 April 2023; Accepted: 9 January 2024;
Published online: 26 January 2024

REFERENCES

1. Po¨rtner, H. O. et al. IPCC, 2022: Summary for policymakers (In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change). *Clim. Change*, 3–33 (Cambridge University Press, 2022).
2. Espey, J., Parnell, S. & Revi, A. The transformative potential of a global urban agenda and its lessons in a time of crisis. *npj Urban Sustain.* **3**(1), 15 (2023).
3. Meerow, S., Newell, J. P. & Stults, M. Defining urban resilience: a review. *Landsc. Urban Plan.* **147**, 38–49 (2016).
4. Amirzadeh, M., Sobhaninia, S. & Sharifi, A. Urban resilience: a vague or an evolutionary concept? *Sustain. Cities Soc.* **81**, 103853 (2022).
5. Elmqvist, T. et al. Sustainability and resilience for transformation in the urban century. *Nat. Sustain.* **2**(4), 267–273 (2019).
6. Cariolet, J.-M., Vuillet, M. & Diab, Y. Mapping urban resilience to disasters–a review. *Sustain. Cities Soc.* **51**, 101746 (2019).
7. Davoudi, S. et al. Resilience: a bridging concept or a dead end? "reframing" resilience: challenges for planning theory and practice interacting traps: resilience assessment of a pasture management system in northern afghanistan urban resilience: what does it mean in planning practice? resilience as a useful

concept for climate change adaptation? the politics of resilience for planning: a cautionary note: edited by simin davoudi and libby porter. *Plan. Theory Pract.* **13**, 299–333 (2012).
8. Nohrstedt, D., Mazzoleni, M., Parker, C. F. & Di Baldassarre, G. Exposure to natural hazard events unassociated with policy change for improved disaster risk reduction. *Nature Communications* **12**(1), 193, (2021).
9. Lwasa, S. et al. Urban systems and other settlements. in IPCC, 2022: Climate change 2022: Mitigation of climate change. *Contribution Of Working Group Iii To The Sixth Assessment Report Of The Intergovernmental Panel On Climate Change*. (IPCC, 2022).
10. Batty, M. Modelling cities as dynamic systems. *Nature* **231**, 425–428 (1971).
11. Karen, O'.B., Mark, P., & Anand, P. *Toward A Sustainable And Resilient Future* (Cambridge University Press, 2012).
12. Henri, L. *Rhythmanalysis: Space, Time And Everyday Life* (Bloomsbury Publishing, 2013).
13. Natalia, B., Fritz-Julius, G., Hanna, H., & Hannes, L. *Time As Infrastructure: For An Analysis Of Contemporary Urbanization* (Taylor & Francis, 2019).
14. Monstadt, J. Urban and infrastructural rhythms and the politics of temporal alignment. *J. Urban Technol.* **29**, 69–77 (2022).
15. Chelleri, L. From the resilient city to urban resilience. a review essay on understanding and integrating the resilience perspective for urban systems. *Doc. d'ana'lisi Geogr.* **58**(2), 287–306, (2012).
16. Meerow, S. & Stults, M. Comparing conceptualizations of urban climate resilience in theory and practice. *Sustainability* **8**, 701 (2016).
17. Mun˜oz-Erickson, T. A. et al. Beyond bouncing back? comparing and contesting urban resilience frames in us and latin american contexts. *Landsc. Urban Plan.* **214**, 104173 (2021).
18. McPhearson, T. et al. Radical changes are needed for transformations to a good anthropocene. *Npj Urban Sustain.* **1**, 5 (2021).
19. Fouquet, R. Path dependence in energy systems and economic development. *Nat. Energy* **1**, 1–5 (2016).
20. Mikhail, V. C. & Allenby, B. Toward adaptive infrastructure: flexibility and agility in a non-stationarity age. *Sustain. Resilient Infrastructure* **4**, 173–191 (2019).
21. Yeowon Kim, D. A. et al. Fail-safe and safe-to-fail adaptation: decision- making for urban flooding under climate change. *Clim. Change* **145**, 397–412 (2017).
22. Eisenhardt, K. M. What is the eisenhardt method, really? *Strateg. Organ.* **19**, 147–160 (2021).
23. McPhearson, T. et al. Scientists must have a say in the future of cities. *Nature* **538**, 165–166 (2016).
24. Thomas, E. & David, M. *The Urban Planet: Knowledge Towards Sustainable Cities* (Cambridge University Press, 2018).
25. Michael, W., Friedrich, G., & Michael, V. *The Time Scale Of Urban Change* (IRPUD, 1983).
26. Simmonds, D., Waddell, P. & Wegener, M. Equilibrium versus dynamics in urban modelling. *Environ. Plan. B: Plan. Des.* **40**, 1051–1070 (2013).
27. Torsten, H. & Allan, P. *Space and time in geography: Essays dedicated to Torsten Ha¨gerstrand* (Liber Läromedel, 1981).
28. Elisabete, A. S. The dna of our regions: artificial intelligence in regional planning. *Futures* **36**, 1077–1094 (2004).
29. Mahdi, M., Yones, G. & Seyed, A. H. Urban growth dynamics modeling through urban dna in tehran metropolitan region. *Ann. GIS* **29**, 55–74 (2022).
30. Votsis, A. & Haavisto, R. Urban dna and sustainable cities: a multi-city comparison. *Front. Environ. Sci.* **7**, 4 (2019).
31. Blumenfeld, H. The tidal wave of metropolitan expansion. *J. Am. Plan. Assoc.* **20**, 3–14 (1954).
32. Dietzel, C., Herold, M., Hemphill, J. J. & Clarke, K. C. Spatio-temporal dynamics in california's central valley: empirical links to urban theory. *Int. J. Geogr. Inf. Sci.* **19**, 175–195 (2005).
33. Mike, C. *Spaces of Geographical Thought*. p. 199–220 (Sage Publications, 2005).
34. Smith, R. J. & Hetherington, K. Urban rhythms: mobilities, space and interaction in the contemporary city. *Sociol. Rev.* **61**, 4–16 (2013).
35. Brelsford, C. et al. Spatial and temporal characterization of activity in public space, 2019–2020. *Sci. Data* **9**, 1–11 (2022).
36. Mul´ıcˇek, O., Osman, R. & Seidenglanz, D. Time–space rhythms of the city—the industrial and postindus- trial brno. *Environ. Plan. A* **48**, 115–131 (2016).
37. Holling, C. S. Understanding the complexity of economic, ecological, and social systems. *Ecosystems* **4**, 390–405 (2001).
38. Micheal, B. *Urban Change* (1996).
39. Egerer, M. et al. Urban change as an untapped opportunity for climate adaptation. *Npj Urban Sustain.* **1**, 1–9 (2021).
40. David Ta'bara, J. et al. Positive tipping points in a rapidly warming world. *Curr. Opin. Environ. Sustain.* **31**, 120–129 (2018).
41. Nohrstedt, D. When do disasters spark transformative policy change and why? *Policy Politics* **50**, 425–441 (2022).
42. John, C. & Harry, S. *IFIP Technical Conference on Optimization Techniques*. p. 388–406 (Springer, 1975).
43. Alan, W. *Catastrophe Theory And Bifurcation: Applications To Urban And Regional Systems* (Routledge, 2011).
44. Supriya, K., Nazli Y. A. & Tina, C. *Urban Informatics and Future Cities, The Urban Book Series*, 465–498 (Springer, Cham., 2021).
45. Jimena, C. Clock/lived. *Time: A vocabulary of the present,* 113–128 (NYU Press, 2016).
46. Daniel, G., John, H., & Mark, T.-J. *Metropolitan Regions, Planning And Governance*, p. 237–256 (Springer, 2020).
47. Rob, R. *Adaptation To Climate Change: A Spatial Challenge* (Springer, 2010).
48. Rob, R. Towards A Spatial Planning Framework For Climate Adaptation. *Swarm Planning: The Development of a Planning Methodology to Deal with Climate Adaptation.* 31–65 (2014).
49. Byrne, D. M., Lohman, H. A. C., Cook, S. M., Peters, G. M. & Guest, J. S. Life cycle assessment (lca) of urban water infrastructure: emerging approaches to balance objectives and inform comprehensive decision-making. *Environ. Sci.: Water Res. Technol.y* **3**, 1002–1014 (2017).
50. Gemeente Amsterdam. *Amsterdam Rainproof* (2014).
51. Kapil, G. & Vinay, N. *Disaster Recovery*, p. 287–297 (Springer, 2014).
52. Elco, K., Kees, VanG., Margreet, VanM., & Anne, L. *Natural Hazards and Earth System Sciences*, 1–11 (European Geosciences Union, 2021).
53. de Bruijn, K. M. et al. Flood risk management through a resilience lens. *Commun. Earth Environ.* **3**, 1–4 (2022).
54. Dirk, F. S. The hull concept: an approach to landscape planning, 24. *Information and Knowledge Center/NBLF* (1991).
55. Dhar, T. K. & Khirfan, L. A multi-scale and multi-dimensional framework for enhancing the resilience of urban form to climate change. *Urban Clim.* **19**, 72–91 (2017).
56. Zevenbergen, C., Veerbeek, W., Gersonius, B. & Van Herk, S. Challenges in urban flood management: travelling across spatial and temporal scales. *J. Flood Risk Manag.* **1**, 81–88 (2008).
57. Tim, D. & Malcolm, E. *Scaling Up: The Challenges Of Urban Retrofit* (2013).
58. Silva, P. Tactical urbanism: towards an evolutionary cities' approach? *Environ. Plan. B: Plan. Des.* **43**(6), 1040–1051 (2016).
59. Nagendra, H., Bai, X., Brondizio, E. S. & Lwasa, S. The urban south and the predicament of global sustainability. *Nat. Sustain.* **1**(7), 341–349 (2018).
60. Patsy, H. *Urban Complexity And Spatial Strategies: Towards A Relational Planning For Our Times* (Routledge, 2006).
61. Chauvin, J. P., Glaeser, E., Ma, Y. & Tobio, K. What is different about urbanization in rich and poor countries? Cities in Brazil, China, India and the United States. *J. Urban Econ.* **98**, 17–49 (2017).
62. Yu, S., Zhang, Z., Liu, F., Wang, X. & Hu, S. Urban expansion in the megacity since 1970s: a case study in mumbai. *Geocarto Int.* **36**(6), 603–621 (2021).
63. Krishnan, S.; Aydin, N.Y., & Comes, T. *Data Underlying The Publication: Timewise: Temporal Dynamics For Urban Resilience - Theoretical Insights And Empirical Reflections From Amsterdam And Mumbai* (2023).
64. Krishnan, S., Aydin, N. Y. & Comes, T. RISE-UP: resilience in urban planning for climate uncertainty-empirical insights and theoretical reflections from case studies in Amsterdam and Mumbai. *Cities* **141**, 104464 (2023).

ACKNOWLEDGEMENTS

This research emerges from the project 'The Future Ground' at the Resilience Lab, TU Delft. We want to thank the interview participants who devoted their time and shared their insights online during the challenging Covid-19 pandemic. The views expressed in this paper are in the authors' capacity and do not represent the views of participants' institutions.

AUTHOR CONTRIBUTIONS

All authors contributed equally to conceptualising the study and drafting the manuscript. S.K.: conceptualisation, conducting interviews, methodology, software, formal analysis, writing, original draft, review & editing, and visualization. N.Y.A.: conceptualisation, methodology, supervision, review & editing, and project administration. T.C.: conceptualisation, methodology, supervision, review & editing, project administration, and funding acquisition.

COMPETING INTERESTS

The authors declare no competing interests.

ADDITIONAL INFORMATION

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s42949-024-00140-5.

Correspondence and requests for materials should be addressed to Supriya Krishnan.

Reprints and permission information is available at http://www.nature.com/reprints

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.