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Transformational Adaptation in the Context of Coastal Cities

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Abstract

Coastal settlements, home to more than three billion people and growing rapidly, are highly vulnerable to climate change. Increasingly, there are calls for climate adaptation that goes beyond business-as-usual approaches, transforms socioeconomic systems, and addresses underlying drivers of vulnerability. Although calls for transformational adaptation are growing, greater clarity is needed on what transformation means in context in order to bridge the gap between theory and practice. This article reviews the theoretical literature on transformational adaptation, as well as practitioner frameworks and case studies of urban coastal adaptation. The article discusses specific challenges for transformational adaptation and its governance in coastal cities. In doing so, this review contributes to the growing debate about operationalizing the concept of transformational adaptation in the context of coastal cities and offers insights to ensure that transformation processes are inclusive and equitable.

Contents

1. INTRODUCTION

1.1. Coastal Cities and Climate Change

Risk: the probability of an event or trend, multiplied by associated impacts resulting from the interaction of vulnerability, exposure, and hazard

Exposure: physical proximity to a place that could be adversely affected by a hazard

Hazard: the (potential) occurrence of a natural or human-induced physical event or trend that may cause reversible or irreversible impacts

An estimated 40% of the world's population lives within 100 km of a coastline (1). These approximately 3.12 billion people live in settlements of various sizes, from megacities to small urban centers. Globally, the influx into dense urban clusters in the past 200 years has been fueled by transitions from agrarian to industrial economies and by promises of opportunity. Coastal areas have been favored throughout the history of human settlement, with water providing essential functions for defense, industry, agriculture, and trade (2). Together these push and pull factors driving urbanization and coastal settlement have contributed to the current number of individuals exposed to the unique suite of climate-related risks that characterize coastal cities.

Rapidly urbanizing coastal areas are at particularly high risk due to their exposure to extreme climate hazards, vulnerability, and dependence on climate-sensitive resources (3, 4). Historically, coastal cities have suffered heavy losses due to their location and exposure to extreme natural events (5, 6). A range of natural phenomena including tides, currents and waves, runoff, storms, sediment flow, and erosion continually shape coastal zones, rendering them extremely dynamic, and increase exposure to climate hazards. As temperatures and sea levels rise, climate change contributes to flash floods, salinization of water sources, and more intense storm surges associated with severe cyclones. Coastal cities also face climate hazards that are not specific to the coast, including heat waves, snowstorms, heavy rainfall, flooding, storms, and landslides. Large events have the potential to destroy assets, lives, and livelihoods, but even smaller impacts, such as nuisance flooding or small-scale droughts, have the potential to erode resources and adaptive capacity through processes of risk accumulation (7). These dynamics are particularly devastating for poor

urban residents, whose livelihoods are often precarious (8). Over time, however, even better-off urban residents are likely to be impacted (8).

The social construction of risk is particularly important in urban contexts (9–12). Cities are often centers of enormous wealth, but large numbers of poor people also live in cities. Through government neglect of existing vulnerabilities, lack of institutional capacity, and historical development patterns, risk is unevenly distributed (8, 13–15) and disasters are not equal opportunity events (16). Women in Lagos, Nigeria, experienced greater hardship than men during a flooding event in 2011 and with recovery post-disaster. This was particularly true for low-income women, due to their limited economic resources and social support (17). In New Orleans, USA, Black-majority neighborhoods were more exposed to flooding during Hurricane Katrina and were more vulnerable in terms of income and health. Discriminatory recovery programs also made it harder for Black families to return to the city (18). In New York City, after Hurricane Sandy, marginalized communities located on the industrial fringe were exposed to effluent, increasing repair costs and adding new health risks (19). In Khulna, Bangladesh—ranked one of the top 20 cities in terms of people projected to be exposed to coastal flooding by 2070 (20)—the underlying social and political marginalization of low-income communities and informal settlements has been argued to be the single most important factor contributing to their vulnerability (21). Many of these informal settlements, which are also the likely destination of Khulna's growing low-income migrants displaced by disasters, are not covered by municipal services such as drinking water, roads, drains, and solid waste management, as the municipal authority does not officially acknowledge that these settlements exist (21). Despite its relevance, urban poverty, including informality, is often sidelined from national poverty reduction policies as well as climate policies (21, 22). Climate impacts on low-income urban households in this context must be contextualized within the broader perspective of their poverty, as their response to climatic risks are shaped by other difficulties and priorities (22). For example, in Supraghat, an informal settlement on public land in Khulna, the threat of eviction was recognized as the primary concern of residents (23). Because of the social nature of risk, huge disparities in access to resources and adaptive capacity can exist in close proximity in urban areas, creating unique challenges for designing equitable adaptation strategies.

Vulnerability: propensity or predisposition to be adversely affected, encompassing sensitivity/susceptibility to harm and lack of adaptive capacity/resilience

Adaptive capacity: the ability to cope with and respond to the challenges created by climate change

Informal settlement: residential area with insecure tenure and insufficient basic services that does not comply with formal planning regulations

Urban development has been a critical driver of coastal environmental change, increasing the exposure and sensitivity of humans and ecosystems to hazards (24). Pollution, coastal erosion, habitat fragmentation, extraction of resources like clay and oysters, and ecosystem destabilization negatively impact cities by altering the ecosystem services and environmental quality that their inhabitants depend on. For example, in Jakarta, land conversion has increased the built-up area by a factor of 31 over the past forty years (25). Uncontrolled groundwater extraction for private and industrial uses, loss of sedimentation due to interruption of natural replenishment processes, and land compaction due to buildings and other infrastructure have led to rapid subsidence, with rates up to 25 cm per year. In some areas, up to 4 m have been lost since 1974 (25). The lack of sustainability of these practices necessitates new forms of urban development and changes to the relationship between the city and its coastal environment.

Coastal cities are dynamic places. Globally, the number of urban dwellers has increased from 751 million in 1950 to more than 4.2 billion today (26). Urbanization in coastal areas is even faster than in other areas (27), and this urbanization is often informal. It is estimated 1 billion people live in informal settlements in developing countries (28), many in coastal zones and flood plains. In these places, densities are high, houses are often constructed illegally and without adherence to building codes, and critical infrastructure, including piped water, sanitation, drainage, solid waste collection, and roads are often inadequate or absent, increasing risk (12, 29).

Patterns of rural to urban migration, along with population growth, could add another 2.5 million people to urban areas by 2050 (26), increasing the number of people exposed to

climate hazards. Already, urban populations face migratory pressures due to climate changes: pressures predicted to increase, with an expectation of migration inward from the coasts under various models of sea level rise (30). Indeed, globally it is projected that approximately 800 million people in 570 cities will be exposed to the risks related to rising seas and storm surges by 2050 (31). These dynamics raise questions of how cities will live with water, where urban coastal populations will go, and who and how many will be affected (32).

Transformational adaptation: a qualitative shift in the fundamental attributes of natural and human systems to enable adaptation, often including structural change

1.2. The Call for Transformational Adaptation in Coastal Cities

Coastal cities have—in most cases—developed without consideration of climate change (33). Adapting cities to climate change will be expensive, with current estimates of approximately $64–80 billion annually (34). Costs are often cited as a barrier to adaptation, yet they pale in comparison to the costs of inaction, estimated to be 10 times higher (e.g., $640–800 billion annually) (34, 35). Of course, the importance of adaptation cannot be measured in economic terms alone; millions of lives and livelihoods, as well as the ecosystems and natural resources that sustain these, will be lost without action.

Calls for transformation point to the urgency of adaptation, the need to reconfigure social institutions and economic structures, including questioning the models of economic development that have driven growth to date, and the challenge of doing so under unprecedented uncertainty (36–40). The lack of progress in reducing climate-related risks globally and the increasing number of people facing these risks suggest that incremental improvements and business-as-usual approaches are insufficient and may even create lock-ins to problematic patterns, systems, or institutions (8, 41–43).

The concentration of people, economic activities, and financial assets within coastal cities make them particularly dynamic places in terms of demographics, cultural development, urban form, economic growth, and governance. Significant growth in urbanization in low- and middle-income nations will take place over the next few decades, primarily along the coast, providing opportunities for urbanization to be planned and managed to accommodate climate risks. Cities are sites of enormous innovation and on the forefront of social movements and societal change. At the same time, as cities grow, inequality and vulnerability often rise concurrently. The challenge is to ensure that as coastal cities evolve, adaptation strategies that match the scale and breadth of the challenges, and include visions that enable true transformation, are at the center of these dynamics.

Despite the growing attention paid to transformational adaptation in scholarship and practice, the term still lacks conceptual clarity and risks becoming an empty buzzword (44–48). Lack of consensus on the goals of transformational adaptation, what transformational adaptation looks like on the ground, and criteria for pursuing transformational adaptation make it difficult to assess progress (49–53). Transformational adaptation must be understood in context: What transformational adaptation looks like in a coastal city will necessarily be different from transformational adaptation in an arid rural community. This contextualization is essential to bridge the gap between the conceptualization of transformational adaptation in theory and practice.

The overall objective of this article is to review transformational adaptation in coastal cities. We seek to underscore the ways in which coastal urban transformational adaptation is unique and identify specific challenges in coastal cities. In doing so, this review contributes to the widening debate about operationalizing the concept of transformational adaptation.

2. METHODOLOGY

To conduct the literature review, we used the database Web of Science and the following search terms: (*a*) "urban" OR "cities" AND (*b*) "transformational adaptation" OR "transformative" OR

"transformational" AND (*c*) "adaptation" OR "climate change adaptation" AND (*d*) "sea level rise" OR "climate change." No time limit was placed on the search, although the majority of the papers returned were from the past 30 years, with a strong majority within the past 10 years. From the results, papers were selectively included in our review based on the expert judgment of the authors. Further references were identified based on papers reviewed.

Publications were reviewed for definition of and approach to transformation, examples of transformational adaptation, key findings and trends in the literature, and tensions and/or contradictions between papers. Our review considered both theoretical and empirical studies. The focus of this review was on transformational adaptation in coastal cities. Broader theoretical literature identified as foundational to the field was also included. Due to our emphasis on the translation of transformation concepts from theory to practice, relevant policy documents and practitioner frameworks were also reviewed. These were selected based on expert judgement. Papers reviewed can be grouped as follows: urban dynamics and transformations, coastal urban climate impacts, transformational adaptation theory, specific literature looking at topics of urban adaptation strategies and governance, and case studies on adaptation in coastal cities.

Resilience: a system's ability to persist, adapt, or transform when faced with a disturbance or shock

Climate adaptation: the process of adjustment to actual or expected climate change and its effects in order to avoid harm and unlock opportunities

3. UNDERSTANDING TRANSFORMATIONAL ADAPTATION IN THEORY AND PRACTICE

This section reviews the theoretical literature on transformational adaptation and highlights some of the key debates in the literature. It also addresses how transformational adaptation has been operationalized in practical frameworks and applied to adaptation projects. This conceptual literature then informs our review of transformational adaptation in coastal cities in the following section.

3.1. Adaptation

In the context of climate change, the Intergovernmental Panel on Climate Change (IPCC) defines adaptation as "the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities" (54, p. 785). This definition emphasizes proactively responding to risks before they occur by addressing exposure and vulnerability (55). Vulnerability is the propensity or predisposition to be adversely affected and consists of two components: sensitivity (or susceptibility to harm) and lack of adaptive capacity or resilience (54, 56). For low-probability, high-intensity events, such as hurricanes or cyclones, exposure tends to be the most important factor explaining disaster losses, but for higher-probability, lower-intensity events, such as coastal flooding, vulnerability plays a more important role (54).

Adaptive capacity can be understood as the preconditions that enable adaptation (57, 58). At an individual, organizational, or system level, adaptive capacity is characterized as the ability to live with uncertainty, to foster diversity and experimentation with different types of knowledge, and learning (59), and is determined (at least in part) by access to human (e.g., knowledge/expertise), financial, and technological resources (60). Adaptive capacity can be eroded over time through repeated coping mechanisms and risk accumulation processes (7, 8). Whereas climate adaptation is framed in response to exposures and vulnerabilities, adaptation in a more general sense can be defined as the response to new information or changing conditions and is ultimately a process of change or innovation (58, 61), connecting closely to concepts of transformation.

3.2. Transformation

Although transformation has a long history in climate mitigation discourse, its role in adaptation is more recent. The IPCC first defined transformation in the context of adaptation in 2012 as

"fundamental qualitative change. . .that often involves a change in paradigm and may include shifts in perception and meaning, changes in underlying norms and values, reconfiguration of social networks and patterns of interaction, changes in power structures, and the introduction of new institutional arrangements and regulatory frameworks" (55, p. 465). This is consistent with other conceptions of transformational adaptation that characterize it as "a fundamental reconsideration of human-environment relations" resulting in the long-term sustainability of the system being transformed (44, 62) and that see transformation as a reinvention of systems and people with new relationships, modes of organization, and networks (39, 40, 47).

Other characteristics of transformational adaptation include adoption of a (new) technique or technology at a larger scale and intensity than in the past, novelty to a particular region or system, transformation of places, or shifts in locations (39). A fundamental change to the political economy and addressing root causes of vulnerability in a given system (25, 63), development pathway (64), or urban governance itself (13) have also been identified as qualities of transformational adaptation.

3.3. Debates Within Transformation Scholarship

This section discusses several key debates within the transformational adaptation literature. These debates concern the definition of transformation, its relationship to other central concepts in adaptation, and the transformation process. A plurality of perspectives is expected given the interdisciplinary nature of the field, but explicit acknowledgement of the diversity of perspectives will help advance these discussions.

3.3.1. Relationship between resilience, adaptation, and transformation. Early discussions distinguished adaptation from transformation and used the term adaptation to refer to changes necessary to protect or safeguard a system from climate impacts and the term transformation to refer to system change, when adaptation was not possible or desirable (38, 40). More recently, scholars have begun to broaden conceptions of adaptation to include transformation, categorizing adaptation as incremental or transformational (39) (see Section 3.3.3). These distinctions, which can appear rhetorical, have important implications for the ways that adaptation policies and programs are designed and implemented, and thus it is important to pay attention to the evolution of concepts and their application (52).

These debates link closely to framings of transformation in relation to resilience. Research on resilience in socio-ecological systems (SES) has long explored "how to enable SES to anticipate and cope with (external) changes that could undermine their structure, identity, and functions" (43, p. 438). Resilience proponents argue that resilience thinking goes beyond a narrow framing of resilience as the ability to withstand shocks and looks at both adaptability and transformability as properties that influence resilience at different scales and levels of governance (65). Advantages of such approaches are that they (*a*) acknowledge the relationship between changes in ecological and social systems; (*b*) account for the dynamic nature of SES and provide frameworks for safeguarding or improving social development and well-being within planetary boundaries (66); and (*c*) enable the distinction between capacities to maintain a system in its current state (adaptability) and deliberately create a new and more desirable system (transformability), which can help identify parts of a particular SES where transformation is preferable to the status quo (67, 68).

Other scholars argue that resilience frameworks are counterproductive for transformation. They position resilience and transformation on either ends of a continuum (see 62). In this conception, transformation occurs when the limits of resilience, as well as a system's adaptive capacity and the sustainability of the status quo, are surpassed (62, 69). Scholars point to the tendency of resilience approaches to reinforce existing social, economic, and technological structures, leading

to unsustainable and inequitable adaptation strategies (62, 70–72) and decreasing the potential for transformation.

3.3.2. Process versus outcome. Another debate within the literature is whether transformation is viewed as a process or an outcome (73). Some see transformation as a "process that involves interacting units at multiple levels operating as a larger whole or system" (74, p. 24) and characterize it as a cycle of continuous learning (39, 41). In this line of thinking, principles of adaptive management are foregrounded based on the understanding that it is not possible to predict the outcomes of complex nonlinear processes. Scholars also note that transformation may not always be intentional and can be triggered by emergent processes or forced by an external actor (43), making it difficult to define outcomes a priori. However, many of the characteristics used to describe transformation focus on outcomes (see Section 3.2).

The terms transformational adaptation and transformative adaptation both appear in the literature. Although these are often used interchangeably, scholars identify a distinction with transformative referring to the actions (process) leading to a transformation (outcomes) (75). Few et al. (53, p. 5) suggest that "using 'transformative' as an adjective to 'adaptation' implies an adaptation activity that can change other things, as opposed to the adjective 'transformational' which implies an adaptation that itself constitutes a step-change." Scholars point to a lack of methods to assess progress toward transformation as a critical challenge, but the extent to which transformation is viewed as a process or an outcome leads to different potential indicators of success (76). For the purposes of this article, we chose to use the term transformational adaptation but acknowledge the importance of considering both process and outcome aspects of transformation.

Similarly, the terms transition and transformation are frequently used interchangeably. Although the goals appear similar, the terms emerge from different scholarly traditions (47, 62, 63, 77, 78). Scholars of sustainability transitions employ transition to refer to "fundamental social, technological, institutional and economic change from one societal regime or dynamic equilibrium to another" (79), whereas transformation has been used by the researchers of global environmental change to describe "fundamental shifts in human and environmental interactions and feedbacks" (80, p. 1; see also 40, 81). Some scholars see transformation as a building block or particular type of transition (82); others consider transition the process of change and transformation, the outcome (73).

3.3.3. Incremental versus transformational change. Incremental adaptation actions have been defined as "extensions of actions and behaviors that already reduce the losses or enhance the benefits of natural variations in climate and extreme events" (39, p. 7156). Incremental adaptation and transformational adaptation are frequently conceptualized to be at two opposite ends of the spectrum (39, 52, 53, 83). However, many authors have questioned this incremental-transformational dichotomy and argue that incremental adaptations can accumulate in the long run to become transformational (39, 84–86). The strong tradition within socio-technical transitions literature exploring the roles of niche and regime dynamics addresses this tension between truly novel innovations (occurring in niches) and the accumulation of these changes at the system level (regime change) (87, 88). There is, therefore, growing support for acknowledging incremental adaptation as potentially productive for transformational adaptation.

3.3.4. Capacities approaches and agency. A lack of attention to the agency of individuals and organizations to influence outcomes has been a consistent critique of both SES frameworks and socio-technical transitions frameworks because of their emphasis on system structure and function rather than the agency of individuals to change these systems (43, 63, 77). Frameworks

that emphasize adaptive capacity have been identified as an approach to overcome these limitations, but whether such approaches are appropriate for analyzing transformation is debated. Advocates claim that transformative capacity can allow different actors or organizations to "create a fundamentally new system when ecological, economic, or social (including political) conditions make the existing system untenable" (67, p. 3). This school of thought holds that transformative capacity expands beyond adaptive capacity to include the capacity to (*a*) actively disrupt and dismantle existing systems and simultaneously to (*b*) create and build up viable alternatives (43, 89). A significant danger with frameworks that focus on capacity is the potential to transfer responsibility for resilience and transformation to individuals rather than the state (62, 90–92).

3.4. Transformational Adaptation in Practice

This section reviews key practitioner frameworks for assessing transformational adaptation, contributing to the goal of this article to bridge the divide between theory and practice in understanding transformational adaptation in the context of coastal cities. Transformational adaptation has become the "mantra" for multilateral organizations and a significant investment criterion for many international climate funds (52, 93, 94). Donors now expect that adaptation projects and programs will go beyond direct impacts and facilitate transformation or a shift in paradigm.

The Green Climate Fund (GCF), the largest financial mechanism of the United Nations Framework Convention on Climate Change, considers transformation through paradigm shifts, defined as the "degree to which the proposed activity can catalyze impact beyond a one-off project or program investment," (52, p. 5). Scalability and replicability are presented as the key components of a paradigm shift (52). Similarly, the Climate Investment Funds' (CIF) mission is "to support transformational change towards low-carbon, climate-resilient development" (95, p. 15). The CIF employs four dimensions of transformational change: (*a*) relevance, (*b*) systemic change, (*c*) scale, and (*d*) sustainability that can be achieved through nine implementation pathways: institutions, governance and empowerment, markets, technologies and infrastructure, policies, natural capital, knowledge and information, practices and mindsets, and financing (95).

Funding criteria and guidance on transformation necessarily influence project design and the discourses employed by projects. **Table 1** presents transformational attributes of two urban coastal adaptation projects as described in the project proposals against the attributes of transformational adaptation identified in the literature. In these projects, transformational adaptation narratives primarily focused on quantitative indicators of transformation such as scale and replication, with less attention to qualitative characteristics, particularly those related to social change. For example, the GCF project includes a resettlement component, but the transformational potential (positive or negative) of resettlement was not addressed.

Initiatives aiming to influence policy and practice have also employed transformational adaptation as a guiding concept. In the Building Resilience and Adaptation to Climate Extremes and Disasters Program, one of the world's largest community-based resilience initiatives comprised of 15 projects across 10 countries in Asia and Africa, each project reported annually on the likelihood of their interventions demonstrating transformational change using a self-reporting scorecard (97). According to this scorecard, there are three essential characteristics of transformation: (*a*) catalytic impact (where interventions influence processes beyond direct project activities), (*b*) scale (outcomes that are achieved in relation to the magnitude of resource inputs), and (*c*) sustainability (processes of resilience-building must be sustained after the project) (97). These are accompanied by three pillars of transformation: (*a*) planning and policy, (*b*) empowerment, and (*c*) decision-making and innovation.

Similarly, the Action on Climate Today initiative, a large technical assistance program working with governments in Afghanistan, Pakistan, India, Nepal, and Bangladesh, assesses its work

Table 1 Climate finance and transformational adaptation[a]

Criteria/attribute	C40 Cities Finance Facility (CFF)	Green Climate Fund (GCF)
Treatment of transformation in mission statement/vision	"The CFF seeks transformation through large-scale, sustained and catalytic GHG emissions reductions and enhanced resilience within cities, by supporting shifts in the systems of cities that remove critical barriers around access to finance and thus enable further action on climate change. The CFF achieves this by strengthening the capacity of cities to develop and finance climate change projects, working directly with specific projects in its partner cities, and by informing the thinking and practice of other cities, practitioners, and national and international policy-makers" (94, p. 3).	"[The GCF] seeks to promote a paradigm shift to low-emission and climate-resilient development, taking into account the needs of nations that are particularly vulnerable to climate change impacts" (93, p. 3). Paradigm shift is a core investment criteria for GCF and is defined as "degree to which the proposed activity can catalyze impact beyond a one-off project investment" (96, p. 24)
Sample funded project	**Durban Transformative Riverine Management Program**	**Senegal Integrated Urban Flood Management Project**
Brief description	In response to frequent summer floods and storms and their impacts on city life in Durban, the Sihlanzimvelo Program was established to reduce the amount of damage to municipal infrastructure and homes, as well as human casualty. The program also intends to enhance resilience of the local population through employment opportunities, improved water quality, and enhanced social cohesion through the establishment of community cooperatives.	The project intends to lower the vulnerability of urban communities in Senegal to flood risks through the creation of an enabling environment for cost-efficient public expenditure in drainage infrastructure and flood risk management. It will assist the Government of Senegal in flood management policy-making by "(i) building knowledge on the actual and projected risk, (ii) recommending alternative solutions to costly hard-engineered solutions and integrating flood risk to urban planning, (iii) optimizing management of existing and future infrastructure and (iv) ensuring mainstreaming of integrated flood management in the governance of the sector" (96, p. 39).
Transformational attributes		
Temporality	The program is expected to utilize USD $1 billion over 10 years to achieve the intended goals. Partnerships are emerging between the city, communities, local businesses, and industry to invest in the project and water management more generally, suggesting that the project's potential for transformation may be realized.	A total of 71 million Euros (with 15 million Euros from GCF) has been allocated for the five-year project.
Scale	The project aims for increased resilience across 4,000 km of waterways in the city. There is potential to increase this, as other municipalities around Durban have expressed an interest in replicating the project.	The local-scale knowledge base on flood risk that will be developed for six pilot urban areas could be scaled-up to cover at least another 25 flood-prone urban centers. The envisaged integrated urban flood management in Senegal, if successful, could be replicated in other countries in the region.

(*Continued*)

Table 1 (*Continued*)

Criteria/attribute	C40 Cities Finance Facility (CFF)	Green Climate Fund (GCF)
Nonincremental change	Not applicable (NA)	Limited data and knowledge base on local level risks and vulnerability of the Senegalese territory limit risk management and investment planning for managing floods. Through the creation of such knowledge, the project will enable operational decision-making as well as facilitate better understanding of the flood risk dynamics linked to climate change in the short, medium, and long term.
Shift in norms/ perceptions	The project promotes a shift from an extractive and segregated view of water, treated as a disposable resource by municipal departments, to a circular and holistic view of water as a resource, key to achieving economic, social, environmental, and climate change benefits. The project promotes the consideration of water and waterways as an economic asset that provides a range of ecosystem services and as such are analogous to built infrastructure. This may fundamentally alter city officials' viewpoints of water and how they should consider it as an economic asset (like the city's built infrastructure) to be protected and maintained routinely. Through ecosystems-based adaptation, the project will create jobs and assets for communities, benefit urban spaces, and rejuvenate linkages between communities and water.	The project aims to initiate the shift from an infrastructure-oriented policy to an integrated and transversal national policy of flood risk management. Adequate integration of flood risk in urban planning will limit public and private investment in risk-prone areas and thereby create an enabling environment for efficient public investment in urban drainage infrastructure.
Innovation	NA	NA
Nonlinear	NA	NA

[a]Example transformational adaptation attributes are identified in two funded coastal urban flood management projects. Attributes are identified from Reference 52.

using a transformation framework (98). The framework has three levels: (*a*) the enabling environment (political will, policy mandate, awareness, capacity, evidence and information), (*b*) the domains of transformation (policies and governance, innovation and social/behavior change), and (*c*) indicators measuring systemic approach, catalytic impact, operating scale, and inclusive and sustainable outcomes.

This constellation of transformation frameworks spanning financing mechanisms and policy and practice initiatives suggests a convergence on the key components of transformation. There is emerging consensus that transformational initiatives are different from business as usual in their scale, sustainability, and replicability: (*a*) They have to benefit large numbers of people (either directly or by influencing policies and institutions) (scale); (*b*) results should endure beyond the immediate duration of a project (for example, by enhancing the capacity of individuals and institutions to carry on the work) (sustainability); and (*c*) a project or initiative must influence wider processes and catalyze change beyond the immediate area of intervention (replicability). Although there appears to be convergence on these fundamental or essential tenets of transformation, initiatives conceptualize them differently and interpretation of each aspect is still broad.

4. TRANSFORMATIONAL ADAPTATION IN COASTAL CITIES

In this section, we apply the concepts of transformational adaptation discussed conceptually above to better review the dynamics of transformational adaptation in coastal cities. We discuss why cities are particularly important places for transformation, as well as the transformational potential of different coastal urban adaptation strategies, and conclude with a discussion of governance of urban transformations.

4.1. Cities as Sites for Transformational Adaptation

Cities are increasingly recognized to be on the forefront of addressing adaptation (13, 74, 99). The choices made in cities can unlock new opportunities for adaptation, or they can create lock-in to problematic development pathways and institutions (43). Although it is estimated that only between 0.5 and 2–3% of the globe's surface is urban (100, 101), cities play a disproportionate role in the global economy, currently contributing more than 80% of global domestic production (102). Although there are no estimates of the percent of economic production coming from coastal cities, due to the centrality of coastal cities to multiscalar trade networks and economies, these cities play a dominant role overall, and impacts in these cities can reverberate throughout regions and nations as well as internationally.

Several factors position cities well to drive transformations. Local and small-scale initiatives are argued to be more innovative, and therefore more likely to be transformational compared to initiatives at a larger scale (74). Cities also have the potential to influence national and international levels, serving as pilots, incubators, or demonstrations of transformational approaches (74). For example, small-scale greening projects have been argued to induce broader transformation toward green infrastructure than top-down planning processes (103, 104).

The void created by a lack of national leadership in many places has shifted the emphasis to cities (69, 99, 105–107). Given that more than 50% of the global population lives in cities and, by 2030, 70% of the population is projected to live in a city (26), their "people power" alone wields influence over the global climate policy agenda. Numerous UN policies, including the 2030 Agenda and Sustainable Development Goals (with Goal 11: Sustainable Cities and Communities focusing specifically on cities), the New Urban Agenda, and the Marrakech Partnership for Global Climate Action (74), highlight the important role of cities. There is momentum at all scales, as evidenced by the range of city-driven or city-targeted initiatives, such as C40 cities, Carbon Neutral Cities Alliance, 100 Resilient Cities, Covenant of Mayors, and WWF One Planet Cities. It is clear that "diverse actors are demanding or already developing capacity and actions that target urban sustainability transformations" (43, p. 437).

Although much of the focus on cities has been on their potential contributions to mitigation, cities are particularly key for adaptation because climatic hazards and policy implementation unfold at the local level (108). Due to their responsibility for ensuring safe and sustainable conditions for their residents, local governments are well-positioned to identify local adaptation needs and develop adaptation policy responses (74).

4.2. Urban Adaptation Strategies with Transformative Potential

Adaptation can come in many forms and occurs over many spatial and temporal scales. Spatial scales of relevance for urban adaptation include the neighborhood, the ecosystem, the city, and the urban region or the bioregion in which a city is embedded. In this section, we review key adaptation strategies with strong transformational potential that are of particular relevance for coastal cities. Rather than being comprehensive, this section focuses on factors that contribute to transformational adaptation in urban coastal contexts.

There are many ways to categorize adaptation strategies. For example, coastal adaptation strategies have often been categorized as protect, accommodate, and retreat (41, 60). Infrastructural adaptation strategies have been variously described as hard and soft (34) and as gray (e.g., building a dam or reservoir), green (e.g., protecting a forest or restoring a floodplain), and blue (e.g., remeandering of rivers or waterways) (43, 109–111). The strategies highlighted below cut across these different typologies. For instance, land use planning can include protection, accommodation and retreat, as well as policy decisions that encourage a combination of gray, green, and blue infrastructure. As discussed, each of these strategies has the potential to, but does not necessarily, contribute to transformational adaptation.

4.2.1. Land use management and planning. Land use shapes the direction of development in the short and long term, making it a critical tool for transformation (74, 112). Land use planning can enable transformation, lock in systems that are potentially maladaptive, or create barriers for transformational adaptation (see the sidebar titled Transformational Adaptation and Urban Informality in Jakarta). Subsidies and tax incentives for risky land use practices (e.g., coastal and floodplain development or second home incentives) encourage risk accumulation (19). Post-disaster funds can alter a land use regime by funneling investment into vulnerable areas, without necessarily changing design or planning (114). Existing institutions governing access to land, (secure) ownership over it, and access to basic services and critical infrastructure can also stimulate or reinforce maladaptive practices (12).

Wolfram et al. (43) argue that urban planning should be reinvented to allow for transformational change and observe that currently it "necessarily still relies on existing (i.e., path-dependent) rules and practices that tend to conform with and become instrumentalized for the currently prevailing political-economic growth paradigm, and/or remain largely confined to physical and technical dimensions of planning" (p. 444). To unlock transformational urban planning, they point toward the need to (*a*) expand multilevel, cross-scale, and cross-sector/cross-issue connections; (*b*) learn from transformative actions and capacity development; and (*c*) foster synergies between implementation capability and innovation capability (43). Other scholars suggest that participatory planning, scenario planning, and collaborative planning can enable transformation by allowing new voices and perspectives to come to the table.

TRANSFORMATIONAL ADAPTATION AND URBAN INFORMALITY IN JAKARTA

Jakarta, Indonesia, is a coastal megacity that faces a high risk of flooding and alarming rates of land subsidence. Current adaptation measures focus heavily on traditional engineering solutions. Informal settlements have been identified as one of the causes of flooding, as they take up space that is needed for water retention and the installation of flood protection infrastructure (113). The National Capital Integrated Coastal Development Masterplan proposes the development of what would be the world's largest flood wall and would turn Jakarta Bay into a sealed reservoir. This plan envisions a transformation in the city's hydrology and morphology, including the reclamation of artificial islands and the development of a new sea front for commercial and residential purposes (25). Such an approach meets the criteria of large-scale adaptation (see Section 3.2) but has significant social and ecological side effects, including the resettlement of low-income households, that reinforce rather than transform the existing social-ecological system, thereby perpetuating marginalization and vulnerability (25). This case demonstrates the challenge of relying on engineering approaches to transformation: Widespread protests have led to moratoriums on the construction of the sea wall due to social unrest associated with resettlement necessitated by the construction of the sea wall (25). This reinforces the importance of considering political and social components of socio-technical transformations and the centrality of governance for urban transformations.

4.2.2. Infrastructure. Infrastructure is often constructed to manage and harness natural environmental processes. Structural interventions, in addition to impacting urban form, can influence and alter coastal zones, often with unintended consequences (115). As long-lived assets, infrastructure choices and investments made today have the potential to shape transformation options or constrain transformational pathways in the future (116, 117).

Urban infrastructure is often on the front line for climate impacts (118). Water resources, transportation, housing, electricity, coastal defenses, communication, and waste management are among the infrastructural staples of urban systems, placing infrastructure at the center of the urban experience. Trillions of dollars need to be spent on buildings, houses, roads, bridges, sea walls, piers, and sewage treatment plants in developing and emerging economies (69, 119), as well as the replacement of aging infrastructure across the Global North, offering huge potential for transformational adaptation.

Nature-based solutions (NBS): the use of natural processes and structures to address environmental challenges and provide both economic and social benefits

As Torabi et al. (41) argue, there is significant scope for a "paradigm shift in infrastructure planning." This can be supported by promoting resilience attributes such as redundancy, decentralization, and diversity (83). Existing urban infrastructure systems have been built using risk-based fail-safe concepts, designed to withstand infrequent yet extreme events (120). However, the consequences of failure are catastrophic, as the failure of levees following Hurricane Katrina demonstrated. Moreover, infrastructure is often designed to be permanent and not amenable to easy upgrades (121).

The alternative safe-to-fail design approach originates from green infrastructure and safety science research (120, 122, 123) and is built on the premise that unprecedented events are inevitable; the goal, therefore, is to minimize the consequences. Thus, safe-to-fail infrastructure is "designed to lose function in controlled ways" (120). Such infrastructure systems remain adaptable and provide new services more readily than fail-safe designs. If the adoption of these approaches fundamentally shifts the way that coastal cities conceptualize their relationship with the coast and ways of managing risk, these strategies may be transformational. However, if this is viewed as simply a technical issue, exchanging one way of calculating failure and building infrastructure for another, it is not likely to lead to transformational change.

Adopting a safe-to-fail approach may also help coastal cities assess their institutional capacity to manage extreme events and future risks (120). The many trade-offs at hand in safe-to-fail approaches, decisions about the consequences of infrastructure failure and priorities for protection, and inherent uncertainty associated with such planning necessitate negotiation and consensus-building (120). Although the case study of the Room for the River program in the Netherlands (see the sidebar titled Room for the River Progamme in the Netherlands) shows the potential of a safe-to-fail approach, the specific approach is not necessarily transferable across contexts. As a point of comparison, in the Dutch example, only 150 households were affected, whereas in developing country cities, large shares of informal settlements along rivers and canals with hundreds, if not thousands, of households would need to be moved to accommodate such a strategy. In such contexts, residents are often not recognized as having legal rights, and their customary land claims are easily dismissed, as they are seen as violating laws and regulations. Thus, the transformational potential of such strategies is highly dependent on the governance capacity in the local context. Strategies that are transformational in one context may reinforce existing inequalities and vulnerabilities in other contexts, the antithesis of the goals of transformational adaptation.

4.2.3. Nature-based solutions and ecosystem-based adaptation. There is significant interest in nature-based solutions (NBS) as part of transformational adaptation. Urban settlements rely heavily on the ecosystems around them for functions like heat reduction and air quality regulation, energy availability, food provision and water purification, aesthetic enjoyment, and

ROOM FOR THE RIVER PROGRAMME IN THE NETHERLANDS

Climate projections in the Netherlands indicate increased incidence of high river discharges, but instead of increasing the strength or raising the height of the embankments (protection), the Dutch government implemented an alternative approach known as the Room for the River Programme (a form of accommodation) (124). The approach consists of a range of measures to enable more room for rivers to flow, increase the disposal and storage capacity of rivers, and improve the quality of the landscape along the river (124, 125). As part of the program, a dike was moved inland by 350 m to create enough room to make a secondary channel that could reduce the water levels by up to 35 cm during high tides. In doing so, the program intentionally transformed nearby farmlands and recreational parks into a vegetated flood buffer during high water events (120). This is an example of a safe-to-fail approach: The implemented measures intentionally compromise the economic and recreational values of the parks, but reduce the risks of catastrophic damages incurred by the local population (120). Moving the dike meant that nearly 150 houses had to be relocated, which created opposition by the affected people (125, p. 52). However, the conflicts were resolved through consultations with residents and experts in spatial design, engineers, and policymakers. Stakeholders and the local community were kept engaged and informed through newsletters, information meetings, and interactive planning workshops, resulting in broad overall support for the project.

spiritual fulfilment. Scholars recognize that as natural and agricultural lands are converted with the expansion of cities, there is greater pressure for green spaces within cities to provide the ecological and cultural services previously offered by less modified ecosystems (126).

NBS have been defined as "living solutions underpinned by natural processes and structures that are designed to address various environmental challenges while simultaneously providing multiple benefits to economy, society and ecological systems" (104, p. 101; see also 127). NBS can help restore ecological flows and serve as alternatives to traditional infrastructure (104). Commonly cited examples of NBS initiatives include increasing greenspaces or tree cover for benefits like heat protection, air quality improvement, carbon sequestration, increased water retention, and temperature regulation, increasing permeability of urban surfaces for benefits like rainwater retention and stormwater control and protecting mangroves or wetlands for the benefit of coastline protection (34, 110, 128). Historically, coastal cities have responded to their proximity to the coast by constructing barriers to protect the city and its residents from nature, but scholars and practitioners working on NBS question the adaptive limitations of such traditional approaches and offer an alternative.

Enthusiasm for NBS in urban settings draws on a long tradition of landscape architecture and urban ecology (126). As such, it is hard to argue that categorically all NBS interventions in an urban context are transformational, in the sense of being new, or unconstrained by path dependencies in thought or practice. Rather, proponents argue that the focus on using nature and ecosystems to adapt is in itself a paradigm shift in the relationship between the built environment and nature.

As the Room for the River Programme in the Netherlands sidebar depicts, NBS strategies can include a reconceptualization of paradigms of risk management and protection. Although many analyses of the transformational potential of NBS focus on the physical form of cities, NBS also has potential to catalyze social transformations (104). In an analysis of lessons learned from experiments in 15 European cities, Frantzeskaki (104) found that NBS create new relations between people and between people and their environment. She argues that through the creation of urban commons, NBS transform people's sense of place and belonging.

NBS have also drawn criticism, particularly in terms of the potential equity impacts of such strategies. Questions of who designs NBS, who benefits from these strategies, and the risks of gentrification have been raised (129, 130). Again, unless these equity considerations are addressed, the transformational potential of NBS will be limited.

4.2.4. Retreat and resettlement. Urban adaptation strategies often call for the relocation of vulnerable populations, particularly informal settlements located in the flood zone. In the Global South, the combination of coastal cities' exposure to climate impacts and high levels of poverty and informality compounds into situations of great risk and generates a particularly difficult set of tasks for policymakers who need to address an array of social and urban development challenges. Resettlement represents a radical change for those being moved, transforming their lives, but the extent to which it can be considered a transformational adaptation strategy depends on how transformation is defined, as well as on who makes the decision (see the sidebar titled Transformational Adaptation and Urban Informality in Jakarta and Section 4.2.2).

Low-income and informal settlements are more often affected by resettlement following a disaster compared to wealthier areas (131). For example, urban greening programs may end up displacing informal settlements or low-income neighborhoods, and sea walls may displace fishing communities or transfer flood risks to other coastal regions (34, 132). Transformational adaptation in these contexts is often based on the construction of large-scale flood protection infrastructure as well as the restoration of rivers and upgrading of canals and informal settlements to increase runoff and retention capacities (see the sidebar titled Room for the River Programme in the Netherlands). In this process, informal settlements are often relocated to make way for embankments and provide households with better living conditions outside the flood zone. Resettlement disrupts livelihoods and often creates new risks for the affected households who struggle to adjust to the new environment. Although it solves the problem of flood exposure, research shows that resettlement can perpetuate or even increase vulnerability when it fails to meet people's needs and deprives them of their income-earning opportunities (113). In contrast, the term retreat is often used to refer to a process over which homeowners, businesses, and communities have a greater sense of agency, and in which there is more purposeful planning. When resettlement or retreat is necessary, it has been observed that both homeowners and municipalities can benefit when homeowners are incentivized to resettle nearby (133). Incentives for resettlement can include taxes, payments, or developing new areas for housing.

In recent years, community-based adaptation and participatory slum upgrading approaches that better recognize and address the needs and strengths of slum dwellers have gained prominence (15, 17). These measures are usually implemented at a small scale and prioritize in situ upgrading rather than relocation in order to minimize livelihood disruptions. In Ho Chi Minh City, Viet Nam, a participatory project to upgrade a stretch of Tan Hoa-Lo Gom canal was implemented with support from the Belgian Development Agency (134). The project engaged social workers and prioritized social support and the consultation of affected households throughout the entire process. People were able to influence the design of the apartment block and decrease the size of apartments to make them more affordable. As a result, a much higher share of the original inhabitants still lived in the apartment building ten years after its completion compared to conventional resettlement schemes that often witness extremely high rates of turnover as people struggle to pay rent or repay their loans. Although such participatory and community-based approaches can be considered transformational as they reduce poverty and vulnerability and contribute to social inclusion and overall development (see Section 3.3.2), numerous challenges remain. The focus on specific communities and the relatively small-scale nature of these projects are at odds

with the scale of the challenges that coastal cities face, and it is not clear how they could be scaled up to become transformational. The project-based nature of community-based interventions can also create situations in which upgrading or resettlement experience differs markedly for different communities within the same municipality, which points to the importance of effective and transparent governance mechanisms (see Section 4.3).

Blue economy: the sustainable use of ocean and other water resources for economic growth, improved livelihoods, and job creation

4.2.5. Blue economy. The blue economy is a concept that emerged from the UN Conference on Sustainable Development (Rio+20) referring to the "sustainable use of ocean and other water resources for economic growth, improved livelihoods, and job creation" (135) and offers potential for better stewardship of ocean and other water resources, including lakes, rivers, and wetlands (136). The concept is particularly relevant for coastal cities as they play a crucial role in sustainably harnessing ocean and coastal ecosystems and improving the living standards of coastal communities (136). Due to coastal cities' central role in global tourism and shipping, planning for coastal waterbodies is also crucial for enhancing sustainable development, and reducing the negative footprint on natural resources and ecosystems. Focusing on the blue economy may foster transformative adaptation by allowing decision-makers to "reorient the long-standing conventional wisdom that largely focuses on estimating the costs and benefits of protecting our ocean to estimating the true potential of the ocean as an economic space and engine for growth, while developing associated policies to better manage their sustainable use" (135, p. 15). A focus on the blue economy could also lead to transformative changes for women and youth. Despite marketing as much as 60% of seafood in Asia and West Africa, women's contribution to fisheries remains invisible (137). Effective labor force participation for women and youth harnessed through access to credit, training, education, and job opportunities could drive the development of a transformational blue economy in coastal cities (136).

4.3. Governance of Urban Transformations

Effective multilevel urban risk governance, alignment of policies and incentives, and building adaptive capacity are all critical to ensuring transformational adaptation (138, 139). A diverse set of actors including government, civil society, the private sector, and academia can steer societal outcomes toward transformation (140, 141). There are multiple levels of governance, including the neighborhood, district, city, region, nation, and transnational, each with different roles to play in urban adaptation. City governments may act as "policy entrepreneurs," advocating for innovative solutions to new or established problems (74), and are critical for agenda setting of local priorities as well as implementation of adaptation strategies. Other actors including local communities, businesses, and research institutes may contribute to urban transformations through experimentation, service provision, and the generation and integration of knowledge—including data—capable of advancing different policy agendas (142).

The literature often points toward entrenched interests as a hurdle to transformations (133). In cities, private developers and real estate entrepreneurs are often construed as oppositional to transformational change. Private developers often have strong influence on the spatial use of a city (74), and their influence is expanding in many cities as responsibility for public services is relegated to the private sector through public-private partnerships, deregulation, and privatization (143). In these instances, the power of local governments to shape urban transformations is increasingly constrained and the need to engage the private sector effectively may be critical.

Although cities may be the sites at which transformational adaptation unfolds, there is widespread acknowledgment that success at the urban scale depends on alignment and support

TRANSFORMATIVE GOVERNANCE IN ROTTERDAM

The city of Rotterdam in the Netherlands is often presented as a model for transformative governance, and its experience illustrates four types of governance capacities that can enhance transformation. Stewarding capacity is the ability to anticipate and respond to disturbances (13). The KvK Knowledge for Climate, a research collaboration between the government, the business community, and research institutes that aims to ensure the integration of climate change in long-term decision-making, is an example of an effort to enhance stewarding capacity. In addition, the province of South Holland requires municipalities to conduct risk assessments, further enhancing this capacity (13). Political and economic interests focused on short-term gains and investments stand in the way of transformation, and support networks of political and civil society are vital to unlocking capacity—the ability to recognize and dismantle drivers of unsustainable path dependencies and maladaptation. The Rotterdam Climate Initiative brings together actors from different spheres, including local energy cooperatives and homeowners associations, and serves as an example of the potential of unlocking capacity. Integration of innovative strategic goals into operational processes and replication and upscaling of novel adaptation solutions such as Benthemplein water square manifest transformative capacity, the ability to create and embed novelties, developed in Rotterdam. Finally, mainstreaming long-term strategic directions for adaptation into policy, the formulation of which was done in a collaborative manner involving citizens, different departments, and the public and private sector; new ways of designing and implementing solutions; and the changing narrative around climate solutions demonstrate the orchestrating capacity, the ability to coordinate multi-actor processes, in Rotterdam (13).

beyond the urban boundary (133, 143). Indeed, local institutions are more likely to be effective in mobilizing change if their values and priorities align with higher levels of governance (74). Collaboration across different levels of government can create a mutually reinforcing network of policies capable of unlocking multiscalar and multisectoral systems change (133). See the sidebar titled Transformative Governance in Rotterdam.

An integrated decision-making approach that (*a*) takes into account multiple policy concerns and (*b*) embeds climate change into urban planning and development discourses is frequently highlighted as an enabling condition for transformational adaptation (74, 112). Integrated decision-making can identify and address potential conflicts or trade-offs between different policy objectives (34) and allows policymakers to identify adaptation strategies with mutual benefits for health, housing, and safety. Conceptualizing adaptation as a central cross-cutting issue rather than a standalone issue, to be dealt with through measures like zoning or land use policy alone, demands a cognitive shift, which in itself may bring about transformational change (13, 41). Uncertainty is a key defining feature of adaptation planning, and understanding and preparing for different climate scenarios has the potential to transform current governance practices (13, 41, 75). Incorporating this uncertainty and the systemic linkages across scales and issue areas can increase citizens' and decision makers' ability to anticipate and manage emergent risks (13).

Transformational adaptation requires experimentation with untested approaches where success is not guaranteed, making learning central to transformational governance (105, 107, 144). Monitoring and self-assessment can generate knowledge about a city's current climate adaptation practices and vulnerabilities so that these can be transformed (13, 43, 145). Monitoring can provide cities with relevant data to manage climate change effectively. Ongoing self-assessment provides a consistent flow of information to decision makers and an opportunity for learning about what works and doesn't, allowing plans to be updated and adaptive management of success (13). See the sidebar titled Big Data for Transformational Adaptation.

BIG DATA FOR TRANSFORMATIONAL ADAPTATION

There is a growing consensus that existing approaches for acquiring and analyzing risk information suffer from lack of certainty, granularity, and veracity. For example, a granular understanding of air temperature is crucial to respond to growing incidence of heat waves, but acquiring this information is difficult due to urban microclimates where temperatures can vary block by block (146). As a result, there is growing interest in big data. One initiative has overcome this challenge by crowdsourcing air temperature data from mobile phones (147). Using an app, they crowdsource battery temperature data and run this data through an algorithm that converts them into air temperature readings, providing accurate data that can, over time, be employed to model heat waves and predict extreme heat events with greater accuracy. To measure exposure, call detail records (the unique, georeferenced signature created by mobile phone calls) have been used to accurately map the number of people exposed to extreme events in South Asia, Europe, and Latin America (148, 149). One initiative used anonymized datasets from six million mobile phone users in cyclone-affected areas over a three-month period in Bangladesh and, in addition to identifying the number of people exposed, also identified high-risk behaviors such as evacuation delays and suboptimal use of cyclone shelters (148). To measure vulnerability, one initiative employed data from 25,000 anonymized ATM and point of sales transactions in hurricane-affected urban areas of Mexico to determine gender-disaggregated preparedness patterns (e.g., by analyzing individual spending on stockpiling) and the time it took various groups to recover (e.g., by analyzing return to pre-disaster transaction patterns) (150). These effectively people-powered approaches permit the acquisition and analysis of data at great velocity, volume, and variety. When good data are in the right hands, they can empower action and help overcome barriers to transformation.

Who is involved in adaptation influences both the ability to disrupt existing systems and the sustainability of change. Participatory processes, however, present challenges. Although adaptation planning often requires technical and local environmental expertise, transformational adaptation needs broader participation. Drawing on evidence from New Orleans, scholars argue that despite awareness about the disproportionate impact of disasters, "emergency managers collectively are still not competent in the design and implementation of planning programs that engage especially vulnerable populations in assessing their needs and identifying strategies to address those needs in ways that are equitable and compatible with science" (132, p. 386). Addressing disproportionate climate impacts requires conscientious consideration of a range of perspectives, knowledge, and experiences. Without this effort, the needs of poor and marginal groups may be overlooked or eclipsed by interests of more politically and economically powerful groups (see the sidebar titled Transformational Adaptation and Urban Informality in Jakarta and Section 4.2.4). Many city and national governments as well as planners and other stakeholders "either look the other way or are complicit in accepting the negative consequences" (151, p. 27).

Marginal communities are often not "visible" to decision-makers and the exclusive and unequal power dynamics that define local politics and policymaking may discourage meaningful engagement—by both the governed and governing parties in question. Factors such as power imbalances, cultural differences, and discrimination of women and minorities make inclusive participation extremely difficult. The Know Your City study conducted by Slum Dwellers International observed that universal indicators failed to capture the complex local realities of slums, leading to policies and programs that do not respond to the most pressing needs of the urban poor (151, p. 31). Participation of these groups is often reduced to identifying vulnerabilities, exchanges of information, and box-ticking exercises. A shift in perspective where "the poor are recognized as assets and partners, not problems" and effective partnerships with local grassroots organizations are developed "to deliver inclusive, resilient, and sustainable urban development" (151, p. 31) is needed for transformation that is beneficial to all.

5. DISCUSSION

5.1. The Normative Nature of Transformation: Calls for Attention to the Politics of Transformation

Transformation is frequently presented as a normative good, but scholars caution that transformation is inherently political and there are winners and losers associated with transformational change (40, 46, 51). Attention needs to be paid to transformation of what, for whom, and for what purpose (why) (40). Attention to how transformation happens—the governance mechanisms, including the multiscalar and multistakeholder dynamics at play—is also essential.

Transformations, particularly in urban contexts, are often described in terms of changes in technical systems, including transportation, buildings, and infrastructure, but the role of technology in transformational adaptation is debated. Frequently cited characterizations of transformational adaptation highlight the novelty of technology as a key indicator of transformation (39), and modeling approaches emphasize changes in technical systems as drivers of change. This focus on technology and technical systems overlooks the process of change itself, which is a social process. Changes in technologies and technical systems contribute to transformational adaptation to the extent that they interact with the human dimension of SES (143). Unless governance is addressed, models of technical change are unlikely to capture the feasibility or inclusivity aspect of transformation.

The literature on sponge cities in China provides an interesting case: Some scholars focus primarily on the technological solutions to flood risk (152). Other authors are increasingly attending to other dimensions of transformation (e.g., equity and governance) in relation to new technologies, such as the extent to which local populations are able to influence how a new technology such as permeable surfaces is used (153), as well as the ways in which sociocultural practices interact with technological interventions to enable and amplify success (154). There is also growing attention to urban development strategies more broadly as a basis for fundamental changes in the drivers of urban flood risk (128).

Critical scholars highlight that transformations are inherently political, reflecting the priorities and values of different stakeholders and contingent on power dynamics in the system (38, 40, 46, 143). These power dynamics can play out at all scales. For example, research in Papua New Guinea found that households that had agency over the management of marine resources were more likely to adapt but less likely to transform, suggesting those with power had a greater interest in maintaining the existing system rather than transforming it (155).

Strategies that emphasize technological novelty may come at the expense of strategies that address underlying social and political structures or root causes of vulnerabilities (13, 25, 46, 52, 63, 64). Scholars of socio-technological systems emphasize that innovation and transformation are the result of interactions between technology and socio-political systems (156), and as such, low-tech or non-tech strategies also have potential to be transformational depending on the socio-political context and the way that they interact in specific contexts (156, 157).

Scholars call for greater attention to ethics when designing and implementing transformational adaptation strategies (46, 158). Chu et al. (34, p. 43) suggest "without fundamental shifts that disrupt existing socio-political dynamics and the balance of power, climate adaptation may perpetuate unequal development patterns and norms." This places justice and equity concerns at the core of transformational adaptation initiatives in cities and emphasizes the importance of avoiding interventions that merely repackage development as usual. Because transformational change can challenge current power structures, there can be significant resistance to this change, for instance from coastal developers (70, 159, 160).

Business-as-usual thinking that informs many large-scale adaptation measures currently under consideration can lock cities into unsustainable development pathways and maladaptation in the long run, and ultimately reinforce or exacerbate socio-spatial inequalities. In order to contribute to transformation, urban adaptation planners have to confront injustices and "critically consider the distribution of adaptation benefits, costs, and responsibilities across society, address unsustainable and inequitable development patterns, and apply interventions that, at a minimum, treat groups equally regardless of socioeconomic status or, better yet, actively prioritize beneficial outcomes for disadvantaged and vulnerable groups" (131, p. 345). Without attention to the ethical aspects of transformational adaptation, adaptation strategies will not address the root causes of vulnerability, including structural inequality, and will risk reinforcing power dynamics under the guise of transformation.

Attention to power dynamics must extend to the international level. Many transnational city networks (Section 4.1), as well as large-scale adaptation projects such as the giant sea wall in Jakarta (see the sidebar titled Transformational Adaptation and Urban Informality in Jakarta), are driven by ideas and assumptions of the Global North, and a global elite of technical experts are shaping what transformation occurs. Ownership over visions of transformation are also of concern in climate finance (Section 3.4). Scholars have raised concerns that calls for transformational change have the potential to perpetuate neocolonial relations through climate finance by superseding the needs of developing countries with the international community's goals for transformation (161–163). Concerted efforts are needed to transform our learning networks, funding mechanisms, and capacity-building in order to give those with the most at stake a position to influence approaches to adaptation.

5.2. Challenges of Urban Coastal Transformation

Urban adaptation has been described as a patchwork due to the voluntary nature of many adaptation strategies, the range of sectors and associated actors involved in urban transformations, the multiplicity of hazards and their distribution throughout cities, and demographic characteristics of residents (76, 142, 164). Each of these elements need to be incorporated into the governance of transformational adaptation.

Because coastal cities are complex SES, misalignments between natural and human boundaries can serve as a further challenge for transformation (65, 165). Adaptation requires alignment with features of the environment that may not correspond with governance structures, necessitating unprecedented collaboration between different communities and levels of governance. Water resources are particularly unlikely to conform to urban jurisdictions, and alternative governance structures such as riparian partnerships may be needed to coordinate transformation (144, 166).

Although municipal departments traditionally have primary responsibility for most planning, sector-specific strategies are insufficient to deal with the complexity and uncertainty associated with climate change (13), issues that are particularly heightened in coastal urban contexts due to the tight coupling of SES, diversity of coastal cities and their residents, and the high levels of economic, political, and social activity in these dense areas. Transformation may occur in single subsystems, while other subsystems remain stable, potentially creating misalignments for the urban system as a whole (69).

Added to these coordination issues is the tripartite political, ethical, and logistical challenge that transformational adaptation in coastal cities likely involves resettlement and displacement of urban residents. Identifying ways to avoid increasing harm and displacing already vulnerable populations while also adapting to climate impacts such as sea level rise is a critical challenge for transformation.

Addressing all of these challenges will not only rely on transformations of socio-technical systems but also fundamentally calls into question our existing systems of urban governance and necessitates a transformation of urban governance itself.

5.3. Coronavirus Disease 2019 and Its Impact on Transformational Adaptation

The still-evolving coronavirus disease 2019 (COVID-19) pandemic has profound impacts on transformational adaptation in coastal cities. The pandemic has created a transformational moment: Although it serves as a window of opportunity for structural change, it also undeniably exacerbates existing challenges and creates new challenges. As scholars of sustainability transitions acknowledge, it is often in moments of disruption that change can occur and focusing events can be powerful drivers for transformation (167, 168). In this moment, there are opportunities to think about green recovery and address long-delayed updates to coastal infrastructure. The importance of social protection for adaptation and creating an enabling environment for transformation has also been demonstrated in the contours of this crisis (169, 170).

Ensuring transformation toward sustainability and resilience, however, requires mobilization. Policy entrepreneurs and mobilized publics will need to ensure that this moment of crisis does not become an excuse for retrenchment and more conservative approaches (46, 90). The social and economic impacts of the COVID-19 pandemic have revealed again how existing inequalities can disproportionately affect the urban poor in the event of disasters. The case of Mongla, a small coastal town in Bangladesh, serves as a case study for this dynamic (169).

The economic costs of the pandemic are staggering and will constrain budgets for years to come. This will have significant implications for the resources available for public policy priorities, including adaptation. The pandemic has revealed the urgency and need for transformational adaptation. Yet, it remains to be seen if positive change can emerge from this crisis, or if there will be greater retrenchment toward the status quo.

6. CONCLUSION

Transformational adaptation is occurring in many sectors and locations, but as this review has demonstrated, the process of transformational adaptation in cities is particularly unique. Geographic, political, and social factors combine to make urban coastal transformational adaptation challenging, but they also position coastal cities to be on the forefront of transformational adaptation.

One of the greatest challenges for transformational adaptation is the translation from theory to practice. Kasdan et al. (52) identify several potential tensions in how characteristics of transformational adaptation may play out in practice: (*a*) A focus on scalability may privilege large-scale changes and more well-tested approaches, precluding more innovative strategies and experimentation; (*b*) replication has the potential to reinforce existing dynamics and power dynamics as well as promote the homogenization of adaptation interventions and discourage experimentation; (*c*) a push for results in short time spans (i.e., observable outcomes) may be in tension with the long-term nature of behavior change; (*d*) incremental change may lead to transformation over time, so positioning these in opposition may be counterproductive; and (*e*) transformational change may not be appropriate in all contexts.

As urban adaptation moves from agenda setting and goal creation toward implementation, the gap between theory and practice becomes more salient, and strategies to ensure coherence between theoretical understandings of transformational adaptation and the experience on the ground become more needed. Although a multiplicity of views is likely to persist and is a sign of healthy debate and discussion, this should not hinder or preclude action on adaptation.

SUMMARY POINTS

1. Hundreds of millions of people living in coastal cities face risks related to climate change.
2. Calls for transformational adaptation are growing, and clarity on what transformation means in context is needed to bridge the gap between theory and practice.
3. Justice and equity should be at the core of transformational adaptation in coastal cities; to address underlying drivers of vulnerability and unequitable social structures, transformation processes must be participatory, inclusive, and attentive to the most vulnerable, including the urban poor.
4. Transformational adaptation in cities is inevitably influenced by other transformations—e.g., demographic, economic, cultural, digital—unfolding simultaneously.
5. High levels of informality in coastal cities in the Global South pose unique challenges for transformation.
6. Shifts in perspective about the relationship between cities, their physical assets, and their coastal environment, including natural assets, such as considering coastal waters and wetland ecosystems as assets capable of generating economic, social, and cultural benefits or increasing the flow of such benefits, are transformative.
7. The COVID-19 pandemic has revealed the urgency and need for transformational adaptation; however, it remains uncertain if positive change or greater retrenchment will emerge.

FUTURE ISSUES

1. Both social and technical infrastructure are essential to transformations, but more research is needed on how to combine these effectively and equitably to allow for transformational adaptation in coastal cities.
2. As interest in nature-based solutions and the blue economy continues to grow, practitioners and researchers should consider the potential opportunities these approaches unlock for transformational adaptation, as well as the trade-offs between these approaches and alternatives.
3. There continues to be a need for research, including research that engages practitioners, on the enabling conditions for effective participation of grassroots organizations and local communities in the planning, design, and implementation of transformational adaptation in coastal cities.
4. A current gap in the literature, but with high potential relevance, is the role of innovations in environmental and urban data systems (for data collection and monitoring) and how these could enable transformational adaptation in cities.
5. As the number of individuals displaced by climate change, conflicts, and other factors continues to grow, there is a need for more analysis of the ways in which migration patterns and resettlement interact with transformational adaptation in coastal cities, including both how migration influences transformational adaptation and how transformation influences migration.

6. A key area for further inquiry is how sustainable finance and particularly innovative financial mechanisms that extend beyond the public sector can facilitate (or stifle) transformational adaptation in coastal cities.
7. Despite recognition of the importance of evaluation, methods to evaluate transformation are still in their infancy, and more work is needed to identify potential indicators that adequately capture the complexity of transformation processes in coastal cities.
8. As the impacts of COVID-19 continue to play out around the world, researchers should track the ways in which the pandemic has shaped adaptation agendas of coastal cities, including new adaptation responses gaining traction or new barriers to adaptation, changes in coalitions of actors, and new ways of framing issues.

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