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# Urban Resilience in relation to climate changes: Lessons from New York, Rotterdam, and Singapore

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**ABSTRACT**

Urban resilience has become crucial in urban planning as cities face increasing challenges from climate change and rapid urbanization. This research examines two main urban resilience frameworks “equilibrium resilience and non-equilibrium resilience” by analysing their application in three cities: New York, Rotterdam, and Singapore. The aim is to evaluate the strengths and limitations of these frameworks in different urban contexts and provide insights for improving resilience in Egyptian cities, addressing environmental, social, and economic challenges. The methodology employs descriptive, analytical, and comparative approaches. New York illustrates an equilibrium resilience model (engineering), focusing on rapid disaster recovery. Rotterdam demonstrates an equilibrium resilience model (ecological), emphasizing long-term adaptation, particularly in water management. Singapore presents an evolutionary resilience model, blending immediate response with long-term sustainability. The study underscores the importance of crafting resilience strategies tailored to specific urban contexts, balancing immediate recovery with long-term adaptation to address emerging and unpredictable risks. Results show that equilibrium resilience effectively facilitates rapid recovery and system stability but lacks the flexibility needed for sustained adaptation over time. In contrast, non-equilibrium resilience promotes transformation and adaptability but demands substantial resources and strong governance coordination. To address these challenges, the study introduces a Hybrid Resilience Model, which merges the strengths of both frameworks. This model enables Egyptian cities to recover quickly while building sustainable, long-term adaptability to climate risks.

## 1. Introduction

Urban resilience has arisen as a critical idea in urban planning and development debates, particularly in light of the 21st century's dual concerns of growing urbanization and climate change [1]. The term "resilience" has its roots in various disciplines, including ecology, engineering, psychology, physics, and economics, and over time, it has been adapted to the unique dynamics of urban environments [2]. Holling's work in the field of ecology during the

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1970s was the most significant in developing the idea of urban resilience. Holling distinguished between resilience and stability, stating that stability "is the ability of a system to return to an equilibrium state" following a shock [3].

Even though the 1980s saw the first mentions of the idea of resilience in urban [4], urban planning has long been predicated on the key notion that cities must be able to adapt to both internal and external shocks and disturbances, such as natural disasters [5]. Urban studies outline resilience as a city's ability to tolerate, bounce back from, and react to a variety of shocks and stressors, such as social disruptions, natural disasters, and economic recessions [6].

Unquestionably, urban resilience is vital for cities, particularly in this day and age of expanding metropolitan areas and escalating environmental risks. Cities are at the forefront of addressing global concerns like climate change, rising sea levels, and extreme weather events since they are home to the majority of the world's population. To ensure that cities can handle these difficulties, safeguard their citizens, and preserve vital infrastructure, urban resilience is crucial. Without resilience, cities are likely to take longer to recover from disasters, which can lead to economic losses, social disturbance, and lower living standards for local residents [4].

In addition, resilience has an invaluable role to play even in the long-term sustainability of the city as per the present direction. It envisions that once a decent recovery takes place, a given city is able to function well, and also safe, and healthy for coming generations by the capacity to sustain and to cope with any catastrophe. Eventually, as urban inhabitants will grow, resilience becomes increasingly important for the protection of the urban habitat including the business activities and the population. It equips the cities with a mechanism that will not only ensure recovery to any shocks caused by adverse events but also enhance their ability to withstand other shocks in the future as well [3].

Though urban resilience has become a buzz word of increasing significance, it is still disputed with numerous frameworks providing different meanings of resilience. This paper will examine two frameworks: the equilibrium resilience framework and the non-equilibrium “evolutionary” resilience frameworks. The first is the equilibrium resilience approach which stresses that urban systems are able to bounce back from shocks to more or less their pre-disturbance state, hence it implies stability and return to normal [7]. The notion of Urban Systems Resilience on the other hand does not treat urban systems as static and unchanging per se but rather as complex evolving systems that are subject to significant regime change under pressures from within and outside the system. This approach emphasizes change, education, and adaptability as key components of resilience [8].

This is fundamental to understanding how cities can build resilience to climate change, as it effectively is two different approaches. Equilibrium model provide a precise and quantitative method to build the resistance front against ranges of threads yet may not fulfil all the multi- layered problems that cities coping today. Evolutionary models are much more adaptable and fluid, but may be harder to apply in a real-world scenario given their oversimplified perspective on change. The research aims to elucidate these conceptual frameworks and explore the synergy of short-term and long-term approaches to enhancing urban resilience.

### *1.1. Research problem*

The problem of this research in theory lies in the limited understanding of the issue of urban resilience in cities against climate changes, and the problem lies in practice in how to apply and operate different patterns and frameworks of resilience in real urban contexts, i.e. how to apply them in real cities with different geographical, demographic and environmental conditions and challenges, as well as in knowing the different impacts and results of the application of each of these patterns and frameworks. On the other hand, the problem lies in the lack of specific visions or guidelines in Egyptian cities that enable them to maintain acceptable levels of urban resilience against of their growing environmental challenges.

### *1.2. Research aim*

This research mainly aims to shed light on the different aspects related to the issue of urban resilience in cities against climate change, and to explore the different frameworks and patterns of this resilience and the fundamental differences between them, the strategies of action and application of each of them and the expected results of each. This is done through the study and analysis of three case studies, namely the cities of New York, Rotterdam and Singapore, with the aim of extracting a number of lessons learned that can be guided by them to raise the efficiency of urban resilience levels in Egyptian cities against the increasing environmental, social, and economic challenges and constraints.

### *1.3. Research Methodology*

The research methodology relied on combining several different research methods, the most important of which are the descriptive approach and the analytical method, in addition to the comparative method and the deductive method. The descriptive approach was used in reviewing the various literature to provide a clear theoretical basis for the topic of urban resilience and its associated concepts and foundations. The analytical approach was used to study and analyze urban resilience strategies and mechanisms that were practically applied in three different cities as case studies. The comparative approach was also used to compare the results of the application of these strategies and mechanisms in the three cities.

As for the deductive approach, it was used to derive and draw lessons learned that can guide the development of the resilience of Egyptian cities against climate change. The process of selecting the study cases "study cities" relied on several criteria. The key criteria included:

- Diversity in Geography and City Size: Cities were selected to represent diverse geographic locations and urban scales.
- Quality and Type of Resilience Plans: Selected cities demonstrated distinct approaches to resilience planning, incorporating frameworks like engineering, ecological or evolutionary resilience.
- Pioneering Role in Urban Resilience: Cities were required to have a globally recognized role in resilience, including active participation in initiatives like the 100 Resilient Cities program, highlighting their leadership and influence in resilience planning.
- Demonstrated Impact of Resilience Strategies: Each city needed a track record of measurable resilience outcomes.
- Multi-Sectoral Integration: Selected cities implemented resilience strategies that integrate multiple sectors.

Based on these criteria, three cities were selected as case studies: New York City, USA, which used equilibrium resilience in the aftermath of Hurricane Sandy with a focus on infrastructure reconstruction and disaster preparedness, Rotterdam, Netherlands, which used ecological resilience with a focus on long-term adaptation and change with innovative approaches to water management and climate adaptation, and Singapore, which successfully blended cutting-edge technology with strict planning laws to deliver Integrated insights into equilibrium and evolutionary resilience in the urban environment.

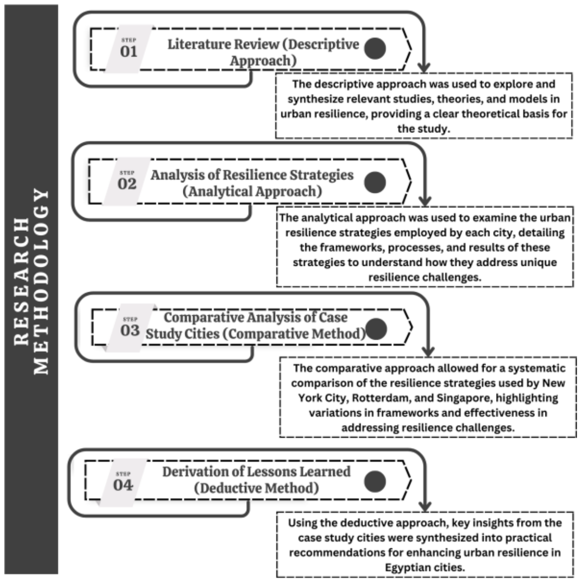



Figure 1 Research methodology [Author]

## 2. Urban resilience: A Theoretical Concept

### *2.1. Definitions of Urban Resilience*

As mentioned earlier, the concept of resilience originates from multiple disciplines, including ecology, engineering, and psychology, and has been adapted to urban environments to address the diverse challenges cities face. Urban resilience, as defined by UN-Habitat Urban Resilience Hub, is "the measurable capacity of an urban system, with its inhabitants, to maintain continuity in the face of shocks and stresses while adapting positively and transforming towards sustainability" [9]. This definition emphasizes the dual function of resilience: the ability to recover from shocks and the ability to evolve and transform in response to changing circumstances.

Another widely cited definition comes from the Rockefeller Foundation's 100 Resilient Cities initiative, which highlights resilience as "the capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow no matter what kinds of chronic stresses and acute shocks they experience" [10]. This definition expands the scope of resilience beyond physical infrastructure, recognizing the social, economic, and institutional dimensions that contribute to a city's overall capacity to cope with disruptions.

Urban ecological resilience, urban hazards and catastrophe risk reduction, the resilience of urban and regional economies, and urban governance and institutions that support resilience are the four research topics that scholars have recognized as being used to develop resilience in urban design [11].

However, "urban resilience" as a novel idea is primarily developed to environmental risks, with an emphasis on disasters, communities, and most recently, the effects of climate change, particularly disasters related to it. As a result, the literature on community resilience and disaster resilience primarily interacts with the literature on urban resilience [12]. In this part, we briefly overview one major area of planning literature that has addressed resilience.

The detrimental effects of climate change are becoming more visible, as evidenced by rising sea levels and large-scale shifts in weather patterns. Cities are at the center of climate change mitigation, facing enormous challenges. As a result of recent climate-related hazards, such as extreme weather and natural disasters, the idea of resilience has gained popularity throughout the world as a fresh approach to urban risk management and emergency management [13]. Urban systems should be resilient to the risks posed by climate change, retain a certain level of functionality, and quickly restore the system's intended level of efficiency after a hazard. [11].

Resilience is concerned with how cities may continue to grow and develop in the face of climate change. Cities must not only reduce the danger of frequent disasters in the short term but also enhance their capacity to respond effectively to a systemic transformation [12]. The discussion about urban climate resilience emphases on future uncertainties, unpredictability, and the city's complexity [14]. The capacity of a city to withstand the direct and indirect effects of climate change and natural disasters is particularly stressed. Urban climate resilience and related challenges must therefore play a significant role in policy planning, and urban climate resilience must be understood as the extent to which cities can tolerate stress before being compelled to reorganize and change [6].

### *2.2. Urban resilience frames against climate change*

Framing happens when individuals with various backgrounds, knowledge, and experiences consider a shared problem and try to understand it from their own or their organization's point of view. The resulting frames can be viewed as intentional "sense-making tools" that let group members recognize and categorize the activities they are involved in and place those processes inside a certain paradigm of beliefs, ideologies, or political goals [14]. Due to urban resilience's conceptual malleability, various people will have varied visions of what a "resilient urban future" may include. In other words, various people will frame urban resilience in different ways [15].

Cities and regions need to adjust to the complex and highly transdisciplinary topic of climate change. For the world to become less vulnerable to shocks and surprises brought on by climate change, cities must become more resilient. This will allow for quick and adaptable solutions to short-term problems as well as long-term challenges, and it will ensure that cities continue to thrive for years to come [16]. Instead than emphasizing reducing the effects of climate change and averting the threat, resilience shifts the narrative to concentrate on how to build a "good" city [15]. Examining the fundamental decisions that must be made, or are implicitly made, in resilience thinking is helpful when examining several potential urban resilience frameworks.

According to Meerow et al., decision-makers must specifically consider the resilience of who, what, when, where, and why in order to achieve urban resilience. They result in various decisions, considerations, and trade-offs [17]. When thinking about urban resilience, Chelleri et al. point out that there are significant trade-offs to be made when considering both temporal and spatial scales [18]. Cities also differ in whether they prioritize short-term or long-term components of urban resilience development and climate change.

The evolution of resilience thinking has influenced how urban resilience is approached. With time, the resilience models changed from striving for a stable equilibrium to recognizing the need for and importance of change and transformation. Initially, the concept of resilience in urban studies was rooted in engineering resilience in the early of 1990s, which emphasized stability and rapid recovery. then ecological resilience in the mid of 1990s, which introduced the idea of multiple stable states emerged.

More recently, evolutionary resilience has emerged in 2000s, emphasizing continuous adaptation and transformation [19]. The time evolution is shown in figure 2.

Below we will explore two main conceptual frames related to short or long-term resilience equilibrium (engineering- ecological) and non-equilibrium (evolutionary resilience).

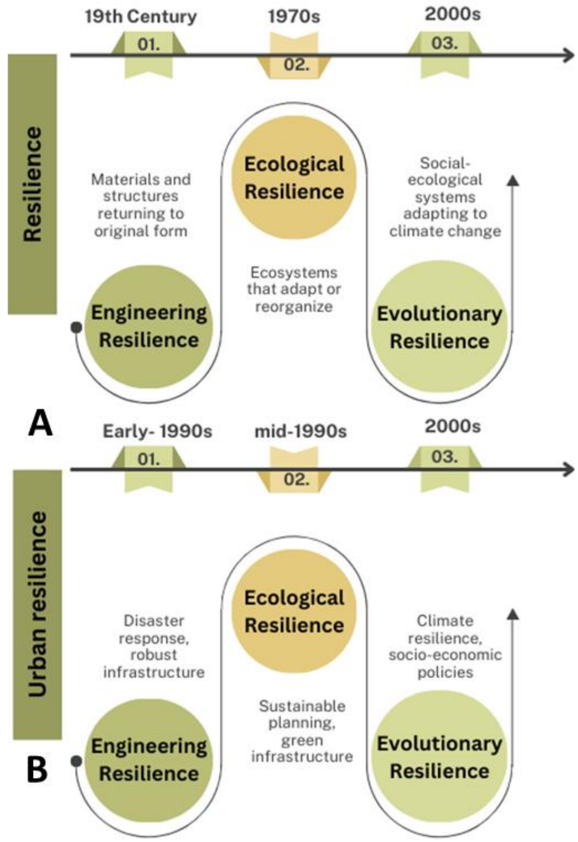



Figure 2 A) Evolution of resilience approaches with time. B) Evolution of resilience approaches with time. [Author]

### 2.2.1 *Equilibrium resilience*

Equilibrium resilience is concerned with maintaining the status quo [4]. There are two kinds of equilibrium resilience: engineering resilience and ecological resilience. Holling distinguished between resilience and stability, characterizing stability as a system's capacity to resume equilibrium following a brief disruption [8]. This was called the "field of stability" engineering resilience. Engineering resilience is the ability of a system to stabilize or return to an equilibrium condition following a disruption. Return time, efficiency, consistency, and predictability are the main concerns [5]. This resilience is based on four qualities: toughness, which is the physical stamina to withstand disruption without functional degeneration; redundancy, which is the degree of replaceability of system components; resourcefulness, which is the capacity to recognize issues and mobilize the required resources; and adaptability. and swiftness, or the capacity to quickly restore order [19]. Engineering resilience addresses disruptions that affect the functional stability of systems, resulting in low failure probabilities and speedy recovery to normal levels of performance [1]. Although the idea of engineering resilience includes both resistance to and recovery from disturbances, the measurement only looks at recovery; the more quickly complete functionality is restored, the more resilient the system is. As shown in the figure 3.

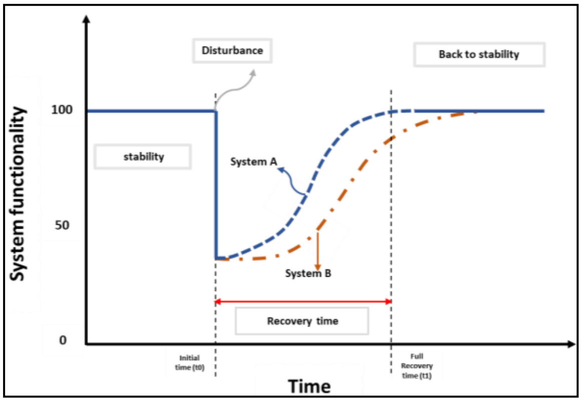



Figure 3 An illustration of engineering resilience conceptually. The time it takes for a damaged system to regain 100% of its prior functionality (t1-t0 in state A) is a measure of the system's resilience. The system becomes less resilient the longer it takes (case B), adapted from[20]

The idea of engineering resilience highlights the importance of urban environments' physical components and infrastructure as well as their ability to endure shocks. The built-in infrastructure, such as housing, utilities, communications, and power plants, as well as rivers, soils, topography, geology, and other natural systems, is the one that attracts the most attention. The physical system must be able to endure the effects of extreme stress in the case of a disaster because it is the main structure of a city [21].

However, while engineering resilience is effective for short-term recovery, it has limitations in addressing the complex, long-term challenges that cities face, such as climate change, socioeconomic shifts, and emerging technologies. The assumption in engineering resilience is that a single, optimal state exists to which the system should return. This focus on equilibrium can limit a city's ability to adapt to changes that require flexibility and transformation. In urban studies, this model has thus been critiqued for not fully accounting for the complexity and dynamism of urban systems, where multiple interconnected and evolving factors influence resilience [8].

Ecological resilience is explained as "the amount of stress that can be absorbed before a system changes structure." [22]. Therefore, ecological resilience is defined as the maximum amount of disturbance a system can tolerate without exceeding critical thresholds, as well as the time it takes for the system to recover following a shock [23]. To put it another way, ecological resilience relates to the system's ability to continue under a given condition while also allowing it to adapt into new equilibrium states. According to modern understandings of cities as complex systems, this perspective, which has its roots in ecology, focuses on strengthening urban-based ecosystems and human-environmental systems when applied to urban areas. But it ignores how dynamic and ever-changing urban systems like housing, transportation, and land use are, as well as how transformable they are [24].

Short-term shocks and immediate stressors are the main focus of this frame. Considering global warming, this encompasses severe weather events such heat waves, droughts, and floods [25]. The "prevent-prepare-respond-recover (PPRR) framework," among other pre-existing concepts from the literature on catastrophe resilience, greatly influences this framing [4].

These two equilibristic perspectives on resilience are appropriate for circumstances in which restoring a previous equilibrium or achieving a new one is the obvious goal rather than reacting to a slow variable or an ongoing process [6]. The main distinction between the two types is that ecological resilience acknowledges the existence of many equilibria and the potential for a system to flip into different domains while rejecting the concept of a single, stable equilibrium. Both viewpoints agree that systems seek an equilibrium, whether by returning to a pre-existing state (engineering) or by establishing a new one (environmental) [8].

Fundamentally, ecological resilience is the capacity to endure in any state, while engineering resilience is the capacity to preserve stability—that is, to remain constant in the system state or to fluctuate as little as possible. These two system traits are distinct and even incompatible. poor engineering resilience can introduce strong ecological resilience, while systems with high engineering resilience can have poor ecological resilience [5].

### *2.2.2. Non- Equilibrium (evolutionary) resilience*

It goes under several names, including adaptive resilience, transformational resilience, and social-ecological system resilience. The concept of equilibrium is challenged by evolutionary resilience [7]. According to evolutionary resilience, long-term shifts like urbanization, socioeconomic development,

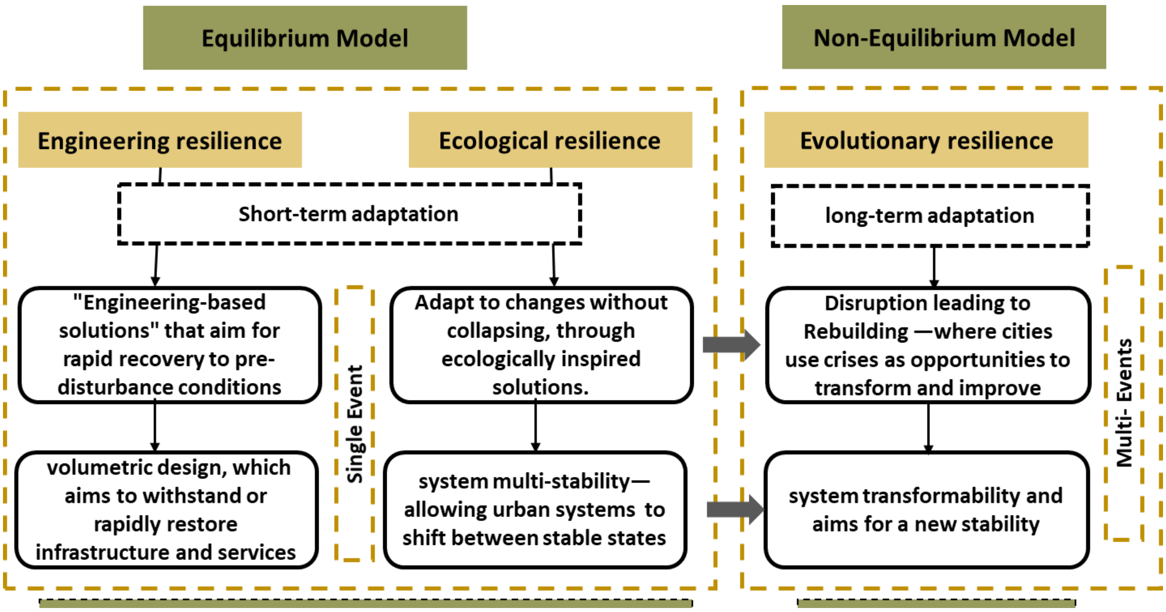



Figure 4 Contrasting Frames of Resilience: Equilibrium and Non- Equilibrium Resilience [Author].

and demographic shifts, as well as interconnections between cities, are predictable in dynamic, complex systems [4]. It recognizes that stable conditions in society or nature can suddenly change, leading to entirely new and different states [23].

This perspective views resilience as the capacity of complex socio-environmental systems to change, adapt, or transform in response to stressors and strains rather than as a "return to normality." According to this viewpoint, systems go through a four-stage process of change known as the adaptive cycle that affects both their structure and their functioning [5]. It is believed that there is a chance to "rebuild the city in an upgraded or improved system" as urban systems may be able to adapt and change in response to current or anticipated disruptions caused by climate change. It employs multi-level, linked, dynamic social, institutional, cultural, and physical objects as its reference objects, placing a greater emphasis on the sociological components of cities from balance-based views [26].

According to the idea of evolutionary resilience, cities may benefit from adapting and even reorganizing in response to disturbances rather than going back to a previous state that might not be appropriate under new circumstances because they are dynamic, complex systems with interdependent social, economic, and ecological components [5]. A central idea in evolutionary resilience is "bouncing forward" rather than "bouncing back." In an urban context, this means not just restoring services and infrastructure after a disturbance but using such events as opportunities to improve the city's social, economic, and environmental frameworks. For example, when rebuilding after a disaster, planners and policymakers might invest in green infrastructure, such as parks and rain gardens, which not only manage stormwater but also enhance community well-being [21]. The focus is on long-term climate change, slow modifications to "shock regimes," and enduring forces such rising sea levels, fluctuations in precipitation or river discharge, and modifications to climatic vulnerability [27].

Evolutionary resilience emphasizes the capacity for long-term adaptation, proactive foresight, readiness, and change while keeping shocks in mind. [28]. Consequently, the term "concept of urban resilience" describes a city's ability to:

- reverse course and return to its initial state (engineered urban resilience)
- adjust to shocks and stresses and lessen disturbance by reorganizing itself (urban ecological resilience
- acquire, adjust, and change (evolutionary urban resilience) [29].

This approach encourages urban areas to remain flexible and to invest in the capacities that allow them to respond creatively to emerging challenges. By fostering a culture of innovation, collaboration, and inclusivity, evolutionary resilience enables cities to become not only resilient to shocks but also more sustainable and adaptable over time.

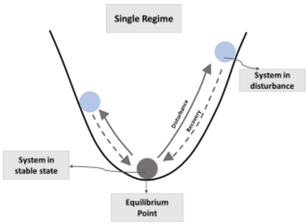
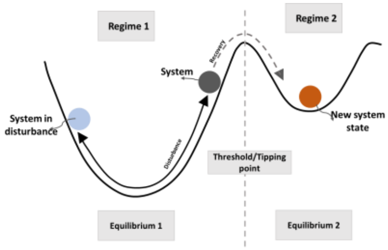
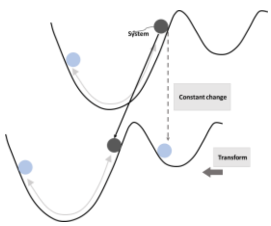
#### *2.2.3. Differences Between Equilibrium and Evolutionary Resilience*

The key difference between equilibrium resilience and evolutionary resilience lies in their approach to recovery and adaptation. Equilibrium resilience is concerned with the stability and quick restoration of a system to its pre-disruption state. It is reactive, responding to short shocks by returning to regular functions as soon as possible. When dealing with severe disasters like hurricanes or earthquakes, where the main objective is to reduce damage and get the city back to normal as soon as possible, this strategy works effectively [6].

In contrast, evolutionary resilience emphasizes learning, change, and greater adaptability. It requires a proactive approach, recognizing that urban environments are dynamic and that stress and disruption provide opportunities for growth and innovation. Evolutionary resilience enables cities to adapt to new challenges such as climate change, and thus withstand long-term threats and sudden shocks [27]. This approach improves cities' ability to cope with future shocks by promoting transformation and recovery. Table 1 shows the differences between the two frameworks.

The differing assumptions of these two frameworks create trade-offs in resilience planning. While equilibrium resilience offers stability and efficiency, it may limit a system's ability to adapt to novel or unexpected conditions. Evolutionary resilience, on the other hand, encourages adaptability and long-term transformation but may sacrifice short-term stability in favor of continuous evolution [18]. As a result, decision-makers must carefully balance these trade-offs, particularly in complex urban systems where both immediate recovery and long-term adaptability are necessary to address evolving social and environmental challenges.

Table 1 Comparison between the two frameworks

| Features | Equilibrium resilience | | Evolutionary resilience | Ref. |
|---|---|---|---|---|
| | Engineering | Ecological | | |
| Illustration |  |  |  | [30] |
| Structure | Linear, static, and simple | Non-linear | Dynamic and complex | [7] |
| State | Single equilibrium | Multi-equilibrium | Co-evolution | [30,33] |
| Means of assessment | Time | The maximum amount of disturbance that may be absorbed | Adaptive capacity | [30,44] |
| Definition | includes the notion that urban areas ought to be able to recover swiftly from both major and minor disasters. | the ability of a system to absorb disruption and adjust to change without losing its fundamental structure. | In contrast to the concept of equilibrium, evolutionary resilience highlights the idea that the nature of systems can evolve and change over time, whether or not there is an external disturbance. | [8,29,31] |
| Focus | Speed to return to the equilibrium<br>determinism<br>predictability | System evolution via various equilibria<br>system adaptability<br>Continuity of system functionality | Transformability<br>Unpredictability<br>self-regulation and learning | [30,33, 34] |
| Properties | Robustness<br>Redundancy<br>resourcefulness<br>rapidity | redundancy<br>Recovery<br>Adaptation | Renewal<br>Re-organization<br>Adaptation<br>Change | [32, 35] |
| Objectives | Return the system to its original state | Maintains efficiency of function | encourages the ability to change | [32] |

## 3.Urban resilience: applied strategies and mechanisms

This section studies the resilience strategies of three cities: New York (USA), Rotterdam (Netherlands), and Singapore (Singapore). Each city has developed unique strategies that are aligned with its specific risks, geographic vulnerabilities, and socio-economic challenges. By studying these cases, the research aims to analyze the practical applications of different resilience frameworks, such as "balanced resilience" and "evolutionary resilience," and to draw lessons that can benefit other cities facing similar challenges. The study also seeks to explore how resilience strategies can contribute to enhancing cities' long-term sustainability and resilience to future disruptions.

The selection of these cities is based on their different geographic contexts, climate risks, and resilience models. New York is a good example of equilibrium resilience, focusing on rapid recovery and rebuilding after crises. Rotterdam is a model of evolutionary resilience, focusing on continuous adaptation to long-term environmental changes. Singapore takes a hybrid approach that combines immediate recovery with long-term resilience planning. Each city will be analyzed across a number of key dimensions, including resilience strategies, tools, and actions.

### *3.1 New York (USA)*

New York City, one of the world's most densely populated and economically significant metropolitan areas. The city and metropolitan area enjoy a temperate continental climate and are situated in the eastern United States' Atlantic Ocean coastline zone. Inland (street) flooding, heat waves, extreme wind events, coastal flooding and storm surge, and more urban-related hazards such urban heat islands and primary and secondary air pollutants are currently the main climatic hazards. It is anticipated that climate change would make these dangers worse. As a financial and cultural hub, disruptions in New York's functionality have far-reaching economic consequences, not only locally but globally [36]. Hurricane Sandy in 2012 was a significant wake-up call, exposing weaknesses in the city's infrastructure and the need for a resilience strategy that could rapidly restore services and minimize disruption after extreme weather events. New York City's resilience strategy has long been grounded in the concepts of equilibrium resilience, which focuses on rapid recovery and a return to normalcy after traumatic events. This approach can be seen in the city's response to Hurricane Sandy in 2012, where the primary focus was on quickly restoring services and rebuilding infrastructure. Examples of the city's commitment to maintaining stability and minimizing disruption include implementing flood barriers, enforcing stricter building codes, and implementing emergency preparedness measures [37]. Below is a detailed look at the city's plan, building on the points mentioned above.

- Key Strategies & Actions:

Rebuilding Infrastructure: After Hurricane Sandy, New York City made rebuilding its infrastructure a top priority, including transportation and energy networks. This plan aims to minimize social and economic impacts by restoring the city's functions as quickly as possible.

1-Rebuild critical transportation and energy networks post-disaster to minimize disruptions.

2-Enhance structural resilience of buildings through enforced building codes designed for flood resistance

Zoning Updates and Regulatory Reforms: After Hurricane Sandy, New York City amended zoning laws and building requirements to improve the resilience of new buildings to flooding and severe weather. As a result, high-risk areas were required to be elevated and more flood-resistant.

1-Update zoning laws to require elevated designs in flood-prone areas, supporting resilience in new buildings.

2-Enforce the NYC Climate Resilience Design Guidelines to consider climate risks in new infrastructure

Community Preparedness Initiatives: The city also focused on increasing residents' awareness of disaster preparedness, including evacuation procedures and ways to protect their property in the event of future storms. Community engagement was essential to ensure the public was prepared for potential disasters.

1-Develop community emergency response teams that are trained in evacuation and disaster response.

2-Conduct regular public awareness campaigns on disaster preparedness, including flood risk education and emergency planning resources [38].

Strengthen Coastal Defenses: The city has invested in building levees, seawalls, and other coastal defense systems to reduce the city's vulnerability to future storms.

1-Construct levees, floodwalls, and deploy temporary barriers, as seen in projects like the East Side Coastal Resiliency.

The East Side Coastal Resiliency (ESCR) project is a comprehensive flood protection initiative designed to safeguard vulnerable neighborhoods along Manhattan's East River shoreline from the impacts of climate change. Initiated in response to the extensive flooding caused by Hurricane Sandy in 2012, the ESCR aims to enhance New York City's resilience by integrating flood protection with community amenities. This $1.45 billion project includes a series of levees, floodwalls, and green spaces spanning 2.4 miles from East 25th Street to Montgomery Street. In addition to providing essential storm surge barriers, the ESCR also revitalizes the area with park improvements, recreational spaces, and ecological restoration efforts, promoting resilience both to extreme weather events and to everyday urban needs. [36]

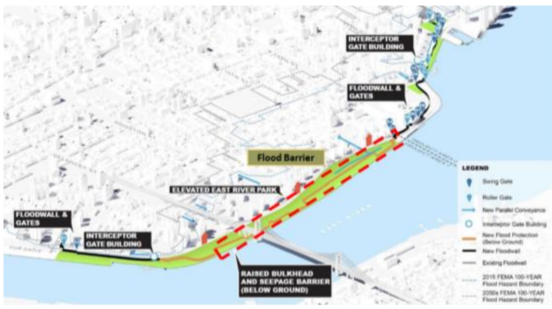



Figure 5 The East Side Coastal Resiliency project protects 110,000 residents of Manhattan's Lower East Side from potential coastal and tidal floods by constructing a continuous 2.4-mile barrier with berms, flood walls, flood gates, and raised parklands [40].

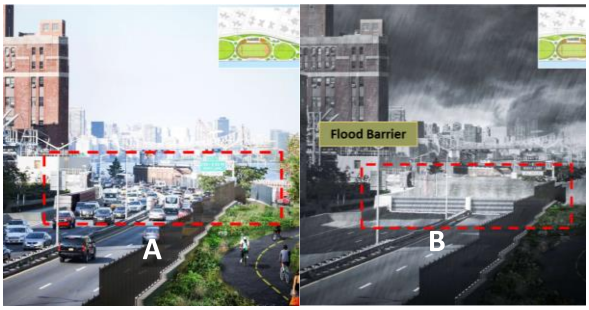



Figure 6 the ground flood barriers during floods. A) Before flood, B) During flood [40].

Though these efforts have been effective in strengthening the city's resilience to shocks, they remain essentially reactive. The focus on recovery rather than adapting to new or emerging hazards has hindered New York's ability to address the underlying vulnerabilities [39].

### *3.2 Rotterdam (Netherlands)*

Rotterdam's position in a low-lying river delta makes it one of the most flood-prone cities in Europe. As a crucial European port and transportation hub, Rotterdam cannot afford to disconnect from the water that surrounds it. Unlike New York, retreating from flood-prone areas is not an option. Rotterdam's urban fabric is closely intertwined with its waterways, creating a need for resilience strategies that incorporate water into the city's design. The geographical necessity of coexisting with high water risks has led Rotterdam to adopt an ecological resilience approach that focuses on long-term adaptation and flexible solutions [41], and as a result of its geographic fragility, it has chosen to take an evolutionary stance. Among the most notable examples of this strategy is the way the city has dealt with the growing concerns of flooding and sea level rise. Rotterdam has undertaken a number of cutting-edge infrastructure projects, such as building multifunctional water squares that double as entertainment spaces during the dry season and flood storage areas during the wet season [42]. These are illustrated in the following points:

- Key Strategies & Actions:

<u>Innovative Water Management:</u> Rotterdam has made managing water risks a long-term goal. Water plazas are used by the city as both public gathering places in the dry months and sites to contain floodwaters in the rainy ones. These multipurpose areas show how water management can be integrated into regular infrastructure through urban planning.

1- Develop multifunctional water plazas, like Benthemplein, that act as flood storage during rain and public spaces in dry periods [43].


Figure 7 A) The sports field Benthemplein water-square, which serves as a water storage area during periods of intense precipitation in (B) [44].

2- Green Roofs and Permeable Surfaces: Integrating green roofs and permeable surfaces mimics natural soil absorption processes, managing stormwater at its source. These interventions help reduce urban flooding by increasing the landscape's capacity to absorb water.

<u>Climate Adaptation Programs:</u> By 2025, the city wants to be completely climate-resilient. It incorporates adaptation to climate change into public spaces, housing, infrastructure, and other areas of urban development.

1- Rotterdam Climate Proof Program: This city-wide initiative focuses on long-term adaptability to climate risks, reflecting ecological resilience's emphasis on flexibility and preparedness for various scenarios.

2- Integration into Public Spaces and Infrastructure: By incorporating climate adaptation into everyday infrastructure, the city enhances its capacity to absorb environmental shocks [41].

<u>Adaptive Infrastructure</u>: Projects like floating homes and structures are intended to respond to rising water levels. Rather than just rebuilding after floods, the city can now adapt to the changing environment thanks to these creative ideas.

1- Maeslantkering Storm Surge Barrier: The Maeslantkering barrier is designed to protect against high-impact North Sea storms and operates only when needed, preserving the natural state of the waterway when inactive

2- Multifunctional Flood Defenses: These defenses combine protective infrastructure with community amenities, ensuring urban areas serve dual purposes [42].

### 3.3 Singapore (Singapore)

As a densely populated island city-state with limited land, Singapore faces unique resilience challenges. Surrounded by water and reliant on efficient land use, Singapore is highly exposed to climate impacts like sea level rise, extreme heat, and heavy rainfall. The high population density and limited resources increase the urgency for efficient and adaptive resilience measures. Furthermore, Singapore's economy and well-being are closely linked to its environmental stability, making resilience a crucial factor in its long-term planning. Singapore's resilience strategy exemplifies evolutionary resilience, an approach that emphasizes adaptability, continuous transformation, and long-term sustainability. This model of resilience goes beyond merely bouncing back from disruptions; it seeks to foster systems that can evolve in response to environmental and social changes over time. Given Singapore's constraints—high population density, limited natural resources, and exposure to global economic and environmental shifts—its approach to resilience is highly adaptive and forward-looking. [45]. The following points help to clarify this:

- Key Strategies:

Technological Innovation for Adaptation and Monitoring: Singapore uses cutting-edge technology to monitor environmental threats and coordinate disaster response measures. Real-time data is incorporated into these programs. The city's "Smart Nation" program serves as an example of how to use technology to improve urban resilience.

1- Launch the Smart Nation Initiative, which utilizes real-time data from sensors and analytics to monitor environmental changes, resource use, and urban activity.
2- Employ advanced systems like climate modeling and predictive analytics to identify emerging risks and enable timely responses.

Integrated Urban Planning for Climate Resilience: This long-term project aims to improve the resilience of urban infrastructure to the challenges of climate change, while reducing the city's carbon footprint. The initiative aims to prepare Singapore to respond effectively to long-term challenges such as rising temperatures and immediate threats such as flooding.

1- Implement the Singapore Green Plan 2030, which integrates sustainability across multiple sectors, including energy, waste, and transportation.
2- Develop and upgrade public infrastructure to withstand long-term climate impacts. This proactive adaptation embodies evolutionary resilience by preparing the city for future environmental conditions.

Multifunctional Projects: They are a key part of this approach, with the Marina Barrage project being a prime example of such a project in Singapore. The project demonstrates the full potential of infrastructure to accommodate multiple functions within the city's limited space. Not only is it a recreational area, it also serves as a water reservoir and a tidal barrier, helping to protect against flooding.

1-Marina Dam: Marina Dam is a vital component of Singapore's resilience strategy, providing space for public recreation, while ensuring water security and managing floods effectively. This integrated project demonstrates Singapore's ability to balance long-term water resource management with rapid emergency response.

2- Expand the use of green infrastructure, including rooftop gardens and urban greenery, to mitigate heat and manage stormwater [46].

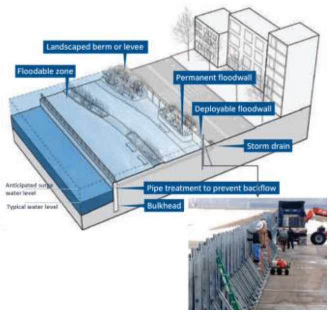
### 3.4 Cases comparative analysis

A comparative analysis of resilience strategies in New York, Rotterdam, and Singapore illustrates how these cities apply their chosen resilience frameworks—balance, evolution, and hybrid—to address the unique urban challenges they each face. By integrating these frameworks into a comprehensive comparative model, this paper highlights the benefits and drawbacks of each approach, providing valuable insights into their effectiveness in diverse urban environments, as shown in Table 2.

This study takes a holistic approach that integrates geography and economics, demonstrating that the success of resilience strategies depends largely on the specific context in which they are implemented. For example, New York City's focus on engineering resilience strategies has been shown to be particularly effective in the face of frequent and severe disruptions in dense urban areas, where any disruption to economic activity can have severe repercussions. In contrast, Rotterdam's ecological resilience strategy is highly relevant for cities that regularly face environmental challenges, particularly those related to water management [47]. On the other hand, Singapore's evolutionary resilience approach, which combines rapid disaster response with long-term strategic planning, offers tangible benefits for urban areas with diverse resilience needs, where sustainable development is essential

This study examines through a comparative analysis the importance of tailoring urban resilience strategies to the unique geographic and economic characteristics of each city. In this way, cities can enhance their resilience and respond positively to diverse challenges, ensuring rapid recovery and sustainable growth in the long term. This in-depth

Table 2 Comparison between the three cities

| Criteria | New York | Rotterdam | Singapore |
|---|---|---|---|
| Resilience Framework | Equilibrium (Engineering) resilience | Equilibrium (Ecological) resilience | Non-Equilibrium (Evolutionary) resilience |
| Focus and Objectives | Rapid recovery and restoration of urban functions post-disaster | Restoration of ecosystems and natural buffers to enhance resilience | Integration of technology with sustainability for long-term adaptive strategies |
| Key Implementation Strategies | Infrastructure reconstruction<br>Regulatory reforms and zoning updates<br>Community preparedness initiatives | Innovative water management<br>Rotterdam Climate Proof Program<br>Adaptive infrastructure (e.g., floating buildings) | Urban planning integrating technology and sustainability<br>Singapore Green Plan 2030<br>• Multifunctional projects like Marina Barrage |
| Key engineering solutions | • Strengthening of coastal defenses and seawalls | • Construction of the Maeslantkering storm surge barrier | • Building of the Marina Barrage for flood control and water supply |
| | <br>Figure8 Coastal defenses and seawalls in New York protect the city from rising sea levels [48]. | <br>Figure9 Maeslantkering: A robust flood barrier ensuring urban resilience against rising sea levels and extreme weather [49]. | <br>Figure10 Marina Barrage: A vital urban resilience solution in Singapore, integrating flood control, water management, and green space. [50]. |
| | • Implementation of zoning and building code changes post-Sandy<br>• Creation of the NYC Climate Resiliency Design Guidelines | • Development of the Rotterdam Climate Proof program<br>• Implementation of multifunctional flood defenses and adaptive building designs | • Development of innovative urban planning and integrated water management systems |
| Geographical Context | Coastal megacity, highly vulnerable to storm surges and sea level rise | Low-lying delta city with significant flood risk | Island city-state with limited land, dependent on efficient land and resource use |
| Economic Context | Global financial hub with significant economic impact from disruptions | Major European port city with critical infrastructure at risk | Highly urbanized international trade and finance center, with robust government investment in resilience |
| Applicability in Diverse Urban Contexts | cities facing frequent, high-impact disasters | cities with progressive environmental challenges | complex, urbanized environments with varied resilience needs |

understanding provides key insights into how to adapt and integrate different resilience strategies to meet the specific requirements of diverse urban environments.

## 4. Results & Discussion

The analysis of the case studies and urban resilience models highlights the challenges and opportunities faced by cities in their pursuit of resilience. While equilibrium and evolutionary resilience each offer valuable insights, their application in resource-constrained environments, such as Egypt, reveals the need for a more integrated approach. The Hybrid Resilience Approach presents a promising solution to this challenge, combining the strengths of both models to create a more adaptable and sustainable framework for urban resilience.

In the context of Egypt, cities like Cairo, Alexandria, and other rapidly urbanizing areas face unique challenges related to rapid population growth, climate change. These challenges require an innovative approach to resilience that can effectively balance immediate recovery needs with long-term sustainability. The Hybrid Resilience Approach is particularly well-suited for Egypt due to its comprehensive, adaptable nature that addresses both short-term shocks and long-term transformations.

<u>Challenges:</u>

- Balancing two models: balancing between stability and adaptation poses an obstacle when merging these models together. Equilibrium resilience focuses on recovery and stability. May overlook the necessity, for long term change and adjustment. On the hand evolutionary resilience encourages innovation and flexibility; however, it typically demands time and financial investment to ensure successful implementation [7]. The Hybrid Resilience Approach bridges these gaps by synthesizing the immediate response capabilities of equilibrium resilience with the long-term adaptability fostered by evolutionary resilience.
- Limited Resources: Implementing strategies to enhance resilience through evolution often demands commitment, to involving the community and fostering creativity and exploration in research fields like never before have been depicted as demanding for cities, with limited resources especially as they grapple with the rise of urban living and various critical social and economic dilemmas [51]. The Hybrid Resilience Approach offers a solution by emphasizing cost-effective strategies that combine technology, community-based resilience, and nature-based solutions. This approach allows cities to optimize existing resources, focusing on scalable, sustainable actions that are accessible even in resource-constrained settings.
- Governance and Coordination Issues: Urban resilience can only be achieved through action involving sectors and government bodies working together harmoniously even though merging various resilience frameworks may face challenges due, to institutional obstacles or conflicting goals. Successful implementation requires cohesive collaboration, robust leadership, and a deep understanding of complex governance structures [52]. The Hybrid Resilience Approach addresses this by promoting inclusive and collaborative governance, where diverse stakeholders, including local communities, government agencies, and private sector actors, work together toward shared resilience goals.

The Hybrid Resilience Approach focuses on short-term recovery and long-term adaptability, it provides cities with a strategic framework that balances immediate needs with future growth. This integrated approach is particularly well-suited to developing countries, as it focuses on maximizing available resources, fostering community participation, and leveraging sustainable solutions. In doing so, it paves the way for cities to become more resilient, adaptive, and equitable, ensuring they are better prepared for both the current and future challenges of urban living.

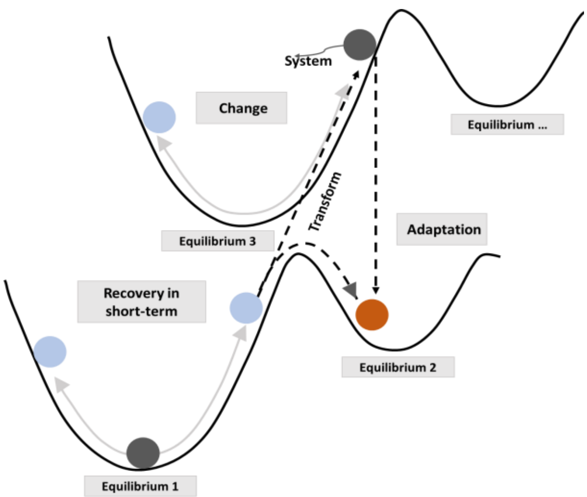



Figure 11 A hybrid resilience model that combines the equilibrium model with evolutionary resilience [Author].

The study of urban resilience strategies in case studies and the adoption of a hybrid approach as a conceptual framework provides an integrated approach that can be used to improve the resilience of Egyptian cities. Key insights from this approach include:

***Contextual Assessment of Egyptian Cities:***

- Vulnerability Analysis: The first step involves understanding the specific risks that Egyptian cities face, such as flooding from the Nile, desertification, urban heat islands, and socio-economic disparities. These vulnerabilities require both immediate and long-term resilience strategies.
- Stakeholder Consultation: Engaging local communities, government agencies, and experts in discussions ensures that resilience strategies are inclusive and reflect the needs of all stakeholders.

***Setting Dual Objectives:***

- Short-Term Recovery Goals: Focusing on immediate recovery from climate-related disasters, such as enhancing the capacity of emergency services, restoring critical infrastructure (e.g., roads, water supply), and providing short-term flood defenses.
- Long-Term Adaptation Goals: These goals include developing sustainable urban planning practices and enhancing green infrastructure to improve resilience over time, especially in light of shifting climate conditions.

***Integrated Strategies for Egyptian Urban Areas:***

- Infrastructure Development:

Equilibrium Focus: Invest in resilient infrastructure, such as levees and drainage systems, to handle immediate flood risks.

Evolutionary Focus: Integrate nature-based solutions, like wetlands and green roofs, which can evolve and adapt to changing environmental conditions, providing both short- and long-term benefits.

- Policy and Regulatory Frameworks: Update building codes to require flood-resistant designs and encourage multi-functional public spaces. These spaces will not only meet immediate needs, like shelter or emergency services, but also offer long-term ecological benefits, such as improving air quality and reducing heat island effects.

***Adaptive Management Practices:***

- Real-Time Monitoring: Establish a data-driven system to monitor and assess risks like flooding and urban heat island effects. This system will facilitate timely interventions and adjustments based on emerging challenges.
- Flexible Urban Planning: Create urban planning frameworks that can adapt to future climate scenarios, ensuring that infrastructure investments remain relevant and effective over time.

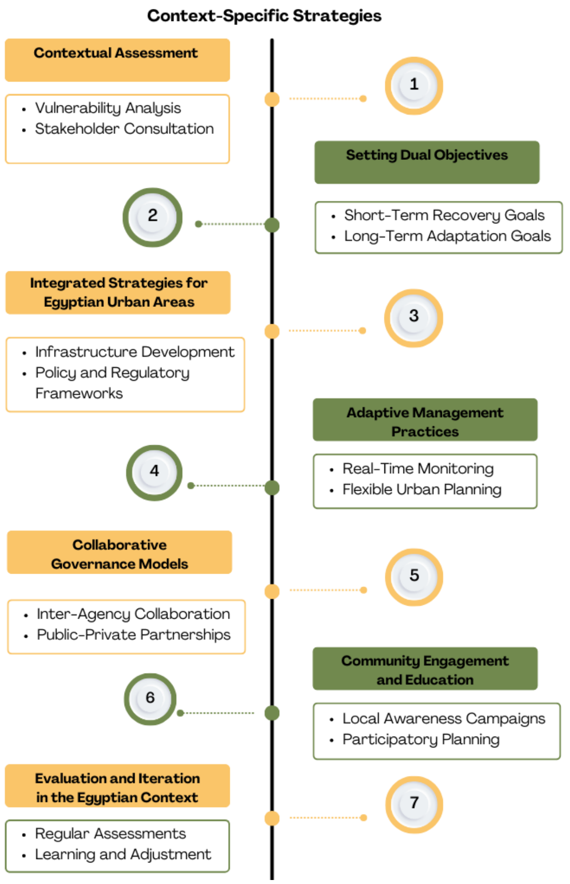



Figure 12 Integrated Approach for enhancing urban resilience [Author].

***Collaborative Governance Models:***

- Inter-Agency Collaboration: Strengthening cooperation between various governmental bodies (e.g., urban planning, environmental protection, disaster management) is essential to ensuring the success of integrated resilience strategies.
- Public-Private Partnerships: Leveraging private sector resources for infrastructure projects, especially those that combine immediate resilience measures with long-term sustainability goals, can help overcome budgetary constraints while advancing resilience objectives.

***Community Engagement and Education:***

- Local Awareness Campaigns: Raise awareness within communities about disaster preparedness, such as evacuation plans and home modifications for flood resilience. Public education is a critical component in ensuring that resilience measures are effective.

- Participatory Planning: Involve local communities in the urban planning process to ensure that resilience strategies are well-aligned with the needs and insights of the people who will be most impacted by them.

***Evaluation and Iteration in the Egyptian Context:***

- Regular Assessments: Conduct periodic evaluations of resilience strategies to measure their effectiveness. This includes tracking progress on both short-term recovery and long-term adaptation.
- Learning and Adjustment: Use the feedback from these assessments to adjust strategies as necessary, ensuring that urban resilience improves continuously over time.

## 5. Conclusion

This study highlights the importance of adopting an integrated approach to urban resilience in developing countries, such as Egypt. The Hybrid Resilience Approach, combining elements of equilibrium and evolutionary resilience, provides a comprehensive framework for addressing the challenges faced by rapidly urbanizing Egyptian cities, such as Cairo and Alexandria. This approach balances the need for immediate recovery with long-term adaptability, essential for managing both short-term shocks and long-term transformations.

The analysis of case studies from cities like New York, Rotterdam, and Singapore reveals that while equilibrium resilience focuses on stability and recovery, and evolutionary resilience fosters innovation and long-term sustainability, neither model alone is sufficient for the complexities of developing countries. The Hybrid Resilience Approach addresses these gaps by synthesizing the strengths of both models, ensuring a more adaptable and sustainable resilience framework.

Key to the approach is the vulnerability analysis of specific risks such as flooding, desertification, and urban heat islands, coupled with stakeholder consultation to ensure inclusive and context-specific strategies. The strategy's dual emphasis on immediate recovery actions (such as improving emergency services and infrastructure) and long-term adaptation measures (like green infrastructure and sustainable urban planning) guarantees that urban resilience strategies address present needs while preparing for future challenges. Additionally, the Hybrid Approach prioritizes collaborative governance, involving government entities, the private sector, and local communities to ensure coordinated and cohesive efforts.

The Hybrid Approach also emphasizes collaborative governance, involving government bodies, private sector, and local communities to ensure coordinated efforts. Adaptive management, through real-time monitoring and flexible planning, ensures that resilience strategies remain effective over time. Furthermore, community engagement and participatory planning are critical to aligning resilience measures with the needs of local populations.

In conclusion, the Hybrid Resilience Approach offers a robust, flexible, and resource-efficient model that can guide Egyptian cities toward enhanced resilience, addressing both current vulnerabilities and future uncertainties while promoting sustainability and social equity.

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