Multi-Risk Coupling in Urban Space and Resilient Planning Responses

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Abstract. As urban populations and activities continue to concentrate at high density, cities face increasingly severe challenges from coupled risks. Urban risk has entered a "3.0 stage," in which normalized long-term pressures coexist and interact with sudden disturbances, making multi-risk coupling a major theme in urban resilience research. Against the challenges of future urban development, this paper reviews the characteristics and scenarios of multi-risk coupling, its spatial effects and mechanisms, and relevant planning practices. It then identifies key theoretical dimensions of resilience under coupled risks, including the interaction of ecological, social, engineering, and economic resilience; long and short resilience cycles; resilience thresholds; and cross-scale transmission. On this basis, the paper develops a framework for resilient territorial spatial planning and specifies resilience priorities for master, detailed, and specialized plans. Finally, it outlines future technical directions for plan preparation, including multi-source information acquisition and processing, risk overlay and coupling assessment, scenario deduction and simulation, and AI-assisted planning and implementation monitoring. The study provides a theoretical reference and methodological guidance for resilient-city planning and construction in the new era.

Keywords: urban spatial multi-risk; risk coupling; urban resilience; spatial planning

Chinese Library Classification: TU984 Document code: A DOI: 10.16361/j.upf.202405012 Article number: 1000-3363 (2024) 05-0088-10

* Supported by the General Program of the National Natural Science Foundation of China, "Spatial Effects, Resilience Mechanisms, and Planning Regulation of Multi-Risk Coupling in High-Density Urban Areas: A Case Study of Wuhan" (Project No. 52378057), and the Interdisciplinary Research Support Program of Huazhong University of Science and Technology, "Human-Land Feedback Mechanisms, Spatial Optimization, and Policy Regulation of Urban-Rural Systems under Extreme Flood Scenarios: A Case Study of the Wuhan Metropolitan Area" (Project No. 2023JCYJ020).

Uncertainty in urban risks is intensifying in China, and high-quality spatial development increasingly faces challenges of safety and resilience. Building resilient territorial space capable of coping with multiple risks has therefore become an important task through which spatial planning can contribute to Chinese modernization.

The evolution of spatial risk can be divided broadly into three stages (Figure 1). In Stage 1.0, the principal challenge to urban resilience was sustainable risk: how to address long-term internal pressures such as changes in land vegetation and ecological deterioration. These were relatively foreseeable "gray rhino" events. In Stage 2.0, resilience focused on extreme or sudden risks—"black swan" events—including natural disasters such as extreme rainfall and geological hazards, as well as human-induced disasters such as urban fires and hazardous-material accidents. China has now entered Stage 3.0, characterized by normalized risks. In the post-pandemic era, increasing urban density has brought long-term pressures and sudden disturbances into coexistence. Their temporal frequency is becoming normalized, while their spatial types are increasingly coupled. Multiple uncertain risks generate complex chain reactions: interactions among risk-inducing factors may transform a single hazard into systemic and cyclical harm, producing far greater losses.

Several scientific questions therefore require sustained attention in current and future spatial planning. First, what distinguishes the characteristics and regularities of multi-risk coupling in urban space? Second, what spatial effects and mechanisms does such coupling generate? Third, what are the principal theoretical elements of resilient response? Fourth, how can the current spatial planning system identify priority resilience content and technical directions? Following the sequence "research foundations of multi-risk coupling - urban resilience theory for coupled risks - resilient spatial planning and technical directions," this paper reviews concepts, scenarios, spatial effects, mechanisms, and planning practices, and proposes preliminary theoretical and planning responses for future research and practice.

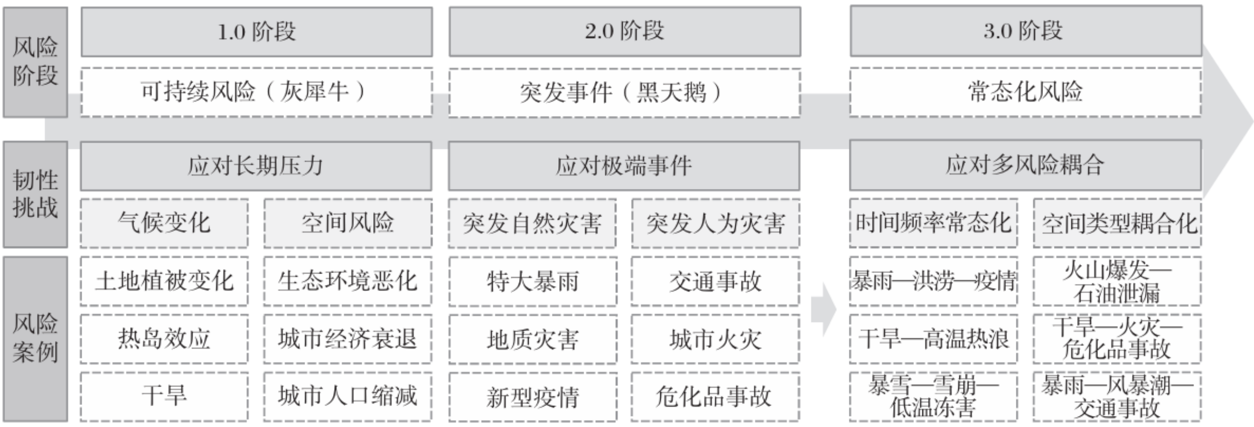

Figure 1. Three stages of urban risk development and their resilience challenges

1 Theoretical Foundations and Planning Experience Related to Multi-Risk Coupling in Urban Space

1.1 Conceptual Characteristics and Scenarios of Multi-Risk Coupling

The concept most closely related to risk is hazard, yet no full scholarly consensus exists on the distinction between the two. An urban hazard is a disturbance induced by a hazardous factor that causes physical losses within a defined spatiotemporal range. Urban risk, by contrast, refers to the probability that complex coupled relations among the natural environment, functional structure, human society, and other urban systems will generate damaging events [1]. A hazard therefore centers on the event, its evolution, and resulting losses; risk centers on the uncertainty of loss and can, to some extent, be quantified [2-3].

Researchers have long noted the coexistence of multiple risks in particular places and periods [4]. Urban spatial multi-risk describes a risk situation in which several hazard sources and multiple vulnerable elements overlap in time or space [5-6]. It is characterized by diversity across domains and coexistence across time (Table 1). Domain diversity includes natural, technological, economic, social, and political risks; temporal coexistence includes long-term pressures and sudden disturbances [7].

Interactions among multiple risks have attracted substantial attention over the past decade, and considerable progress has been made in understanding the evolution and characteristics of typical disaster chains [15-17]. Common chain reactions in Chinese cities include "typhoon - extreme rainfall - waterlogging/flooding," "earthquake - landslide/debris flow," "high temperature - drought - land degradation/pests and diseases," and "cold wave - snow disaster/biological freezing injury." From a spatial perspective, the urban environment largely determines pathways of risk transmission and forms of coupling, thereby amplifying the potential effects of disasters [18-19]. Because cities differ in hazard exposure and in the sensitivity of their spatial environments, the dynamic evolution of risk also varies. Disaster chains, hazard coincidence, cascading effects, induced effects, and domino effects are all manifestations of multi-risk coupling [18,20-23]. They reflect mutual influence and dependence among risk factors within a complex risk system, potentially intensifying risk evolution and prospective loss.

By mode of activation, multi-risk coupling can be divided into cumulative and sudden coupling. By risk type, it can be classified as natural-natural, human-induced, or natural-human coupling. Research on interactions between natural and human-induced risks remains comparatively limited, although natural-technological risks (Natech) and natural-social risks are strongly interconnected and may generate severe secondary losses [18]. Individual risk-inducing factors need not be extreme; their interaction may itself produce an extreme event. Scenarios in which multiple risk events occur simultaneously or successively are known as compound extreme events. Because of the inherent coupling among risks, the spatial effects of compound extremes often exceed the simple sum of separate extreme events and impose greater threats on the different components of urban lifeline systems [24-26].

Table 1. Concepts and meanings related to multi-risk

Concept	Definition	Sources
Hazard	A physical phenomenon that damages the urban economy, infrastructure, residents' lives, social services, or the ecological environment.	UNISDR, 2009; IPCC, 2012; Gallina et al., 2016.
Risk	A quantitative expression of the potential consequences of a hazard event for urban space, stated in probabilistic or semi-quantitative terms.	IPCC, 2012; Gallina et al., 2016.
Multi-hazard	Hazard events that threaten the same exposed elements and interact in different ways; hazards associated with the same place, occurring simultaneously, or following one another within a short period.	Saarinen et al., 1973; Carpignano et al., 2009; Marzocchi et al., 2012; Komendantova et al., 2014; Terzi et al., 2019.
Multi-hazard risk	Risk generated by multiple hazard-inducing factors, generally without considering correlations among levels of vulnerability.	Kappes et al., 2012; Ward et al., 2022.
Multi-risk	Risk generated by independent or interdependent hazard-inducing factors and multiple vulnerable elements that overlap in time and space. One risk changes the probability, frequency, or magnitude of another, and correlations among vulnerability levels are usually considered.	Carpignano et al., 2009; Kappes et al., 2012; Marzocchi et al., 2012; de Ruiter et al., 2020; Ward et al., 2022.

Source: compiled from references [5-6, 8-14].

1.2 Planning Practices for Multi-Risk Response

Multi-risk coupling has received attention in international urban spatial planning. Cities have proposed implementation strategies involving information platforms, resilient communities, urban infrastructure, and other dimensions. Some plans, including those of Los Angeles and London, distinguish long-term stresses from sudden shocks and organize risk prevention accordingly. Overall, however, theory and methods for multi-risk assessment and management remain insufficient, and existing spatial plans rarely examine the effects of risk coupling in depth (Table 2).

Since 2015, pilot programs for sponge cities and climate-adaptive cities have encouraged the gradual development of resilience-oriented spatial planning in China. Most cities now regard resilience and safety as major issues in master planning. The Beijing Specialized Spatial Plan for a Resilient City (2022-2035), for example, incorporates responses to multiple risks. Planning practice for coupled risks is still exploratory (Table 3).

Table 2. Representative spatial planning practices for multi-risk response worldwide

City	Resilience policy	Year	Typical risks	Goals and priority fields	Multi-risk response
Rotterdam	Rotterdam Resilience Strategy	2017	Sea-level rise, floods, extreme rainfall	Establish flood-control and drainage systems; improve secure urban-data sharing; encourage	Focuses on water-related natural hazards, particularly flooding, and on climate adaptation.

City	Resilience policy	Year	Typical risks	Goals and priority fields	Multi-risk response
				social innovation and participation.	
Los Angeles	Resilient Los Angeles	2018	Earthquakes, fires, debris flows, heat waves	Leadership and public participation; disaster preparedness and recovery; economic security; climate adaptation; infrastructure modernization.	Builds a resident-oriented multi-hazard information platform; reforms government collaboration; strengthens and protects communities to cope with unexpected catastrophic events and long-term latent stresses.
New York	OneNYC 2050: Building a Strong and Fair City	2019	Climate warming, flooding, storm surge, sea-level rise, urban heat waves	Address climate change over the long term; eliminate dependence on fossil fuels; power buildings, transport, and the economy with renewable energy.	Analyzes compound urban risks including climate crisis, economic risk, and social pressure.
London	London City Resilience Strategy 2020	2020	Persistent flooding, drought, extreme heat	Address sudden disasters and develop broader, longer-term urban capacity to withstand risk.	Examines risks over long and short time horizons; identifies shocks and stresses. Climate change is the principal shock, while inequality and lack of social integration are major stresses.
Singapore	Singapore Green Plan 2030	2021	Extreme rainfall, drought, epidemics	Five pillars: City in Nature, Energy Reset, Sustainable Living, Green Economy, and Resilient Future.	Strengthens resilience to environmental change and rainstorm/flood hazards through green-space development and measures such as the Cooling Singapore program.
Chicago	Chicago Climate Action Plan	2022	Hot summers, extreme winters, fog, floods, heavy rainfall, tornadoes	Reduce the effects of future uncertainty and adapt to climate change in a lasting and equitable manner.	Identifies risks jointly across municipal boundaries and with partners, and develops appropriate plans for floods, extreme winter weather, tornadoes, and other natural hazards.
Tokyo	Fundamental Plan for National Resilience	2023	Earthquakes, tsunamis, typhoons, floods, fires,	Protect human safety; maintain basic lifeline functions; reduce losses of national assets and	Strengthens local disaster-prevention capacity, actively applies digital and other new technologies, and improves

City	Resilience policy	Year	Typical risks	Goals and priority fields	Multi-risk response
			epidemics	public facilities; restore and rebuild rapidly.	both natural-hazard response and the implementation of national resilience.

Source: compiled from publicly available online materials.

Table 3. Examples of spatial planning practices for multi-risk response in China

City	Planning policy	Year	Typical risks	Goals and priority fields	Multi-risk response
Beijing	Beijing Master Plan (2016-2030)	2016	Flooding, forest fires, geological hazards	Proposes pathways for resilient-city planning from the perspectives of the urban system and resilience management.	Establishes a unified disaster-risk assessment, monitoring, and early-warning system.
Beijing	Guiding Opinions on Accelerating Resilient-City Development	2021	Flooding, forest fires, geological hazards	Coordinates the expansion of spatial resilience, strengthens engineering resilience, improves urban-management resilience, and cultivates social resilience.	Strengthens analysis of concurrent hazards and disaster-chain risks and improves urban risk maps.
Beijing	Beijing Specialized Spatial Plan for a Resilient City (2022-2035)	2024	Flooding, forest fires, geological hazards	Builds a safe, reliable, convertible, rapidly recoverable, organically organized, and future-adaptive spatial governance system for the capital.	Responds to complex extreme risks, promotes dual-purpose facilities for ordinary and emergency use, and uses disaster simulation to anticipate possible spatial measures.
Shanghai	Shanghai Master Plan (2017-2035)	2018	Typhoons, heat, flooding	Builds a more sustainable and resilient ecological city.	Improves monitoring and early-warning mechanisms for multiple urban hazards.
Shenzhen	Shenzhen Emergency Evacuation and Rescue Spatial Plan (2021-2035)	2023	Extreme rainfall, typhoons, earthquakes, geological hazards	Systematically analyzes risks from natural hazards, accidents, public-health emergencies, and social-security incidents.	Integrates routine and emergency needs, considers multiple hazards, and develops comprehensive multi-hazard responses.
Hong Kong	Hong Kong 2030+: Towards a Planning Vision and Strategy Transcending 2030	2021	Typhoons, extreme heat, flooding	Enhances blue-green resource systems to create a natural metropolis adapted to climate change and biodiversity.	Fully considers climate change, biodiversity, and related environmental factors, and incorporates climate-adaptive and climate-resistant design into new development and urban-renewal projects.

Source: compiled from publicly available online materials.

2 Theoretical Elements of Urban Resilience under Multi-Risk Coupling

Resilience originally meant “returning to the original state.” Its basic meaning concerns the capacity to respond to crises, recover, and sustain development [27-28]. Urban resilience extends this concept to cities and refers to the capacity of an urban system to absorb external disturbances while retaining its key characteristics, structure, and functions [29]. As the concept has developed, the objective of resilience has shifted from “restoring a steady state” to “shaping a steady state” and then to “continuous adaptation” [30]. In Risk Stage 3.0, the central task is continuous adaptation to normalized risk. Building on the preceding discussion, this section identifies the principal theoretical elements of urban resilience under coupled risks (Figure 2).

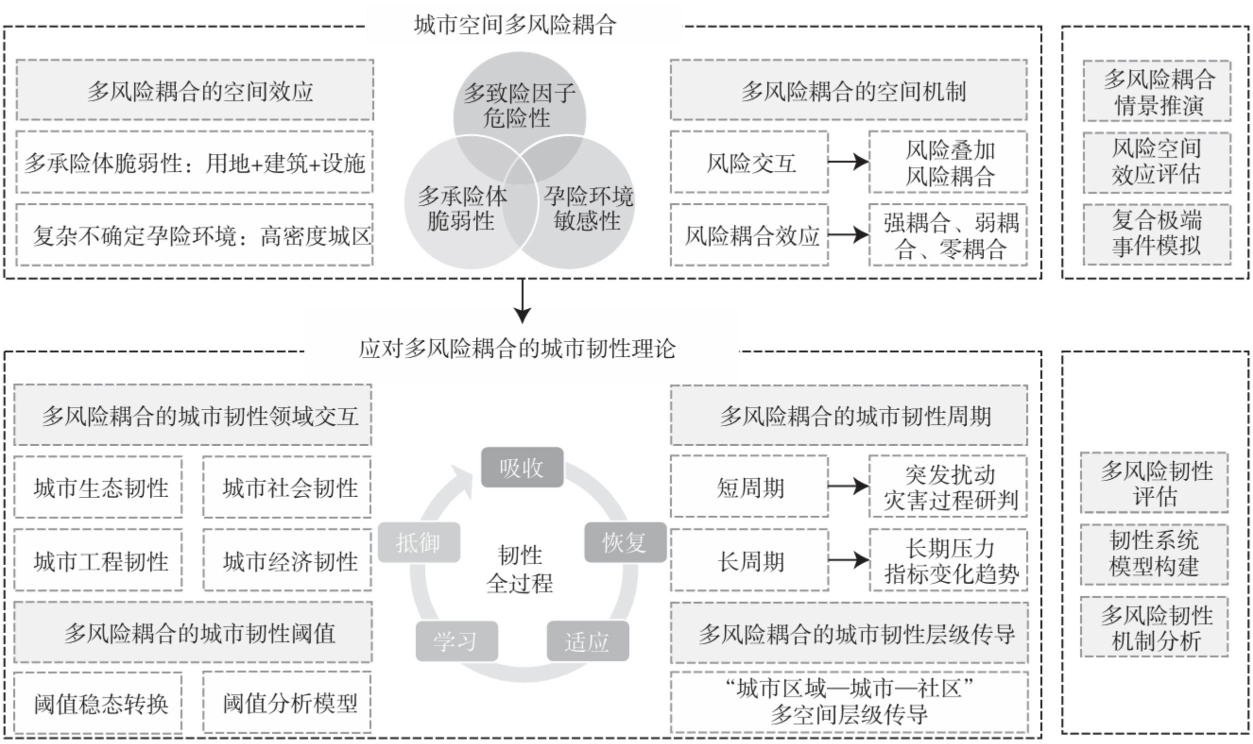

Figure 2. Theoretical elements of urban resilience in response to multi-risk coupling

2.1 Spatial Effects and Resilience Mechanisms of Multi-Risk Coupling

The urban risk-bearing system can be understood as three spatial subsystems: land use, buildings, and facilities. All are exposed to multi-risk impacts. The spatial effects of coupling are harmful outcomes produced by interactions between hazard intensity and the vulnerability of exposed elements within a risk-generating environment, including building collapse, transport interruption, and infrastructure damage. Central business districts, urban centers, and old urban neighborhoods [31-33] are major research objects because high-density areas are typical zones of risk coupling. Dense urban space may amplify interactions among risks and intensify their spatial consequences.

The diversity of hazard-inducing factors interacts with the complexity and uncertainty of urban spatial systems, giving rise to different compound mechanisms, particularly risk superposition and risk coupling. Superposition refers to the cumulative impact of several risks when there is no clear relationship among hazards, or when interrelations among their processes can reasonably be ignored. Existing planning studies have concentrated primarily on overlay analysis within specific times and places. From the perspective of a risk system, coupling includes both the coupling of risk-forming elements and the coupling of risk-evolution processes [21]. Interactions among risk factors in different systems may increase, reduce, or offset prospective losses [34-36], producing strong, weak, or zero coupling. These relations can be represented in a risk matrix (Figure 3). The internal mechanism of coupling lies in the time-space interdependence among hazard-inducing factors, risk-generating environments, and exposed elements, which jointly drive risk evolution and may generate more severe loss [18,37].

Resilience is expressed through the entire pre-disaster, during-disaster, and post-disaster process of resistance, absorption, recovery, adaptation, and learning [38]. It is closely related to life-cycle thinking and whole-process governance in emergency management. Before a disaster, cities should reduce the probability of risk or prospective loss; during a disaster, they should maintain operational stability and absorb and mitigate shocks; after a disaster, they should recover rapidly and use adaptation and learning to improve their capacity to address future risks.

Under multi-risk coupling, urban resilience can be analyzed through three dimensions: hazard intensity, sensitivity of the risk-generating environment, and vulnerability of exposed elements (Figure 4). Complexity and uncertainty within urban spatial systems make risk events more likely in certain environments. Coupling among hazard intensities may amplify threats to urban space, while exposed elements with different vulnerability profiles experience different coupling effects. In a specific risk-generating environment, resilience therefore concerns not only multiple hazards but also the vulnerability of multiple exposed systems.

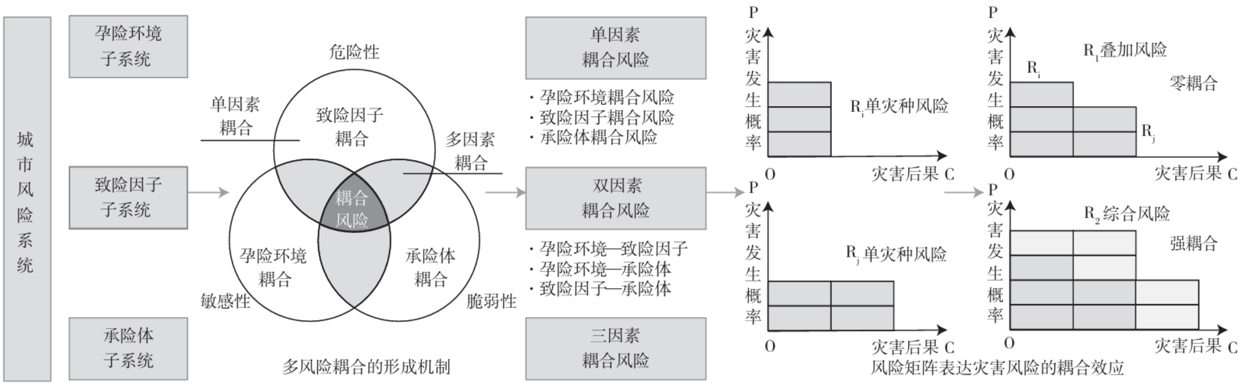

Figure 3. Internal effects of coupled urban risk

Source: redrawn from references [34-36].

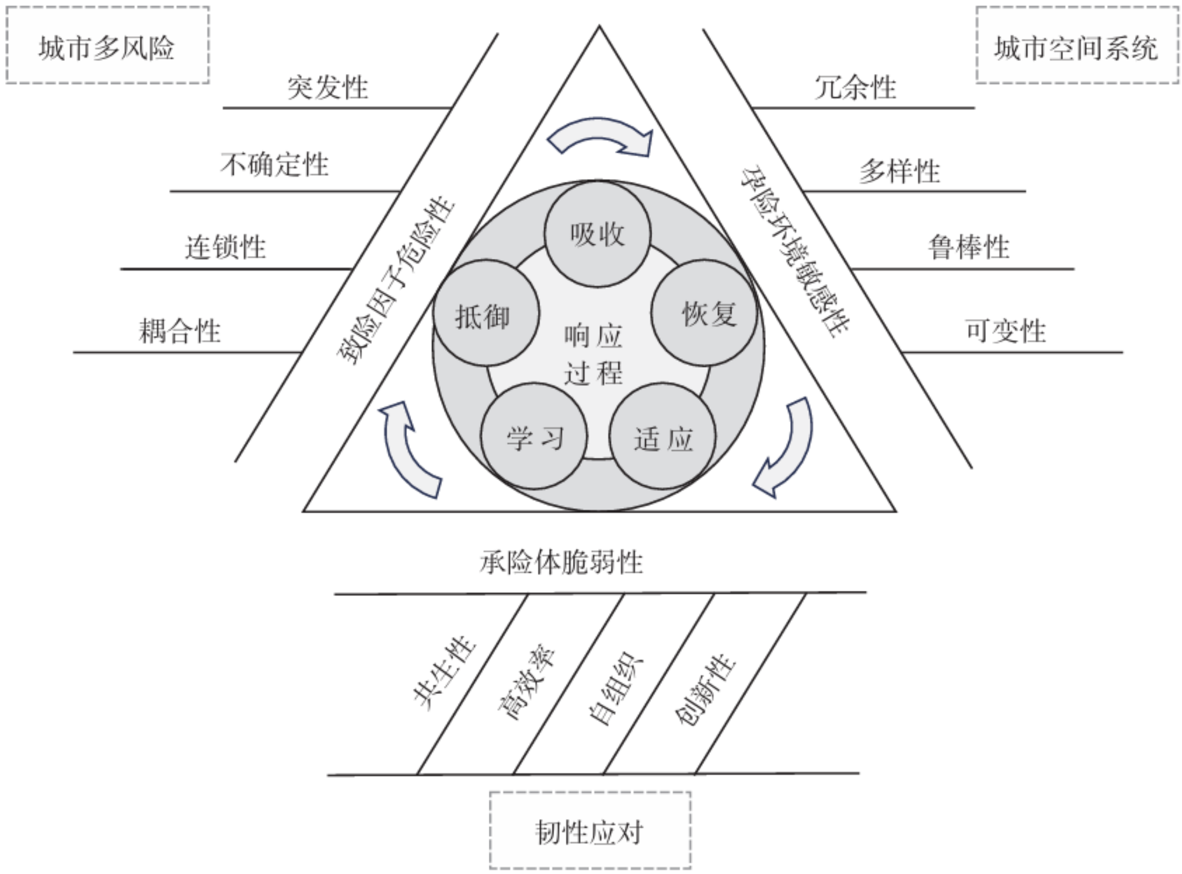

Figure 4. Characteristics of urban resilience under multi-risk coupling

2.2 Domains and Interactions of Resilience under Multi-Risk Coupling

Planning research on urban resilience began with the single dimension of ecological resilience and has expanded into four major domains: ecology, society, engineering, and economy [39]. In the ecological domain, normalized risks associated with urbanization and climate change place pressure on urban ecosystems and weaken their capacity to provide essential ecosystem services. Multi-risk coupling may drive ecological degradation, undermine ecosystem support for and feedback to human activity, and weaken regulatory functions related to flooding, microclimate, carbon emissions, and carbon sinks. Restoring ecological functions and maintaining urban structure under normalized risk are therefore central to ecological resilience [40-41].

In the social domain, human systems must increase their capacity to withstand coupled risks, and communities and residents must adapt to normalized risk. Social resilience emphasizes self-organization and learning, stronger social networks, community participation, cultural identity, and social equity and well-being [42-43]. In the engineering domain, the resilience assessment of urban infrastructure should explicitly incorporate multi-risk coupling. System redundancy in lifeline facilities can increase capacity to cope with compound extremes; improving the responsiveness of green infrastructure is especially important for reducing spatial effects [44-46]. In the economic domain, sudden disturbances require diverse industrial structures, connected factor networks, and secure and reliable industrial, supply, and innovation chains. Under long-term pressure, resilience depends on the capacity to respond to financial and other crises and on flexible structures that support economic recovery [7,47].

Different risks and their interactions affect not only resilience within each domain, but also relations among domains. Their temporal and spatial interaction can cause two types of damage: localized harm within a specific domain and cross-domain deterioration amplified by coupling. Elements inside each of the four domains influence one another to different degrees and jointly shape the evolution of urban resilience. Transport accessibility, for example, is a major control factor in engineering resilience. It directly influences spatial and industrial structures, changes directions and forms of urban development, and subsequently affects the division of labor and cooperation among industries. It is therefore fundamental to coordinated, sustainable operation under multiple risks and to maintaining endogenous momentum for resilience. Conversely, excessive spatial expansion and highly dense development may increase social instability and raise the demands placed on cities to maintain order and prevent unrest. Because control factors differ across domains, resilience planning should not only strengthen each domain internally but also identify key cross-domain relations and optimize synergies among them, thereby creating a mutually supportive urban spatial system capable of responding effectively to coupled risks.

2.3 Resilience Cycles and Thresholds under Multi-Risk Coupling

Urban resilience evolves cyclically [48-50]. The adaptive-cycle model is a classic explanation of resilience cycles [51-52], arguing that urban systems achieve regeneration and innovation through successive stages with different resilience characteristics, thereby producing a spiral pattern of cyclical evolution. In Risk Stage 3.0, cities are continuously affected by both long-term pressures and sudden disturbances, and resilience evolves simultaneously. Resilience under multi-risk coupling should therefore be examined through a dual-cycle perspective: a long cycle responding to sustained pressure and a short cycle responding to sudden disturbance.

Short-cycle change can be observed by identifying sudden coupled-risk events and interpreting disaster processes. Short-term evolution is not simply the sum of isolated events; it must incorporate the effects of coupling. A short cycle can be divided into a contraction phase during impact and an expansion phase during recovery. Resistance is dominant during contraction and reduces the spatial effects of multiple hazards. Recovery and adaptive capacity dominate during expansion, supporting restoration and potentially transformative development. A short-cycle perspective, however, may overlook long-term change across multiple events. Long-cycle resilience is the combined statistical expression of many coupled-risk events. It can be measured through long-term changes in multiple indicators, usually on an annual basis, to identify trends in resilience levels and growth rates, summarize long-cycle regularities, and support simulation and prediction. Short cycles assess resistance, recovery, and adaptation before and after specific shocks; long cycles use indicator systems to measure resilience in a domain or across the city. Their combination provides a fuller account of spatiotemporal evolution.

The resilience threshold is a critical concept for urban spatial multi-risk coupling. Cities are complex systems whose structure, functions, and state are jointly shaped by many factors. When certain indicators move beyond a given range, the system may become imbalanced, collapse, or degrade, and may no longer retain its previous state [53]. From a system-dynamics perspective, urban functions do not necessarily return to their initial state; they may stabilize at a lower or higher level. Analogous to regime shifts [54-55], a coupled-risk disturbance causes the resilience system to fluctuate; when disturbance intensity exceeds a threshold, the city leaves its existing steady state and transitions to another. Changes in thresholds under multi-risk impact are thus a form of regime shift.

Coupling may also cause resilience thresholds to deviate from the original system state and oscillate. From a dual-cycle perspective, both sudden disturbances and long-term pressures can breach the threshold. In a short cycle, uncertainty is high and fast variables may produce a powerful shock that changes the system almost instantaneously. In a long cycle, coupling acts more slowly, but persistent slow-variable pressure can directly alter the system once the threshold is crossed. The threshold can therefore be understood as the minimum resilience level at which urban functions continue to operate normally across long and short cycles, or as the maximum coupled event the system can absorb. Specific urban environments affect spatial consequences by altering this threshold. Figure 5 illustrates three possible coupling outcomes from two risk events: resilience improvement through learning, declining resilience through damage, or transition into an unstable state.

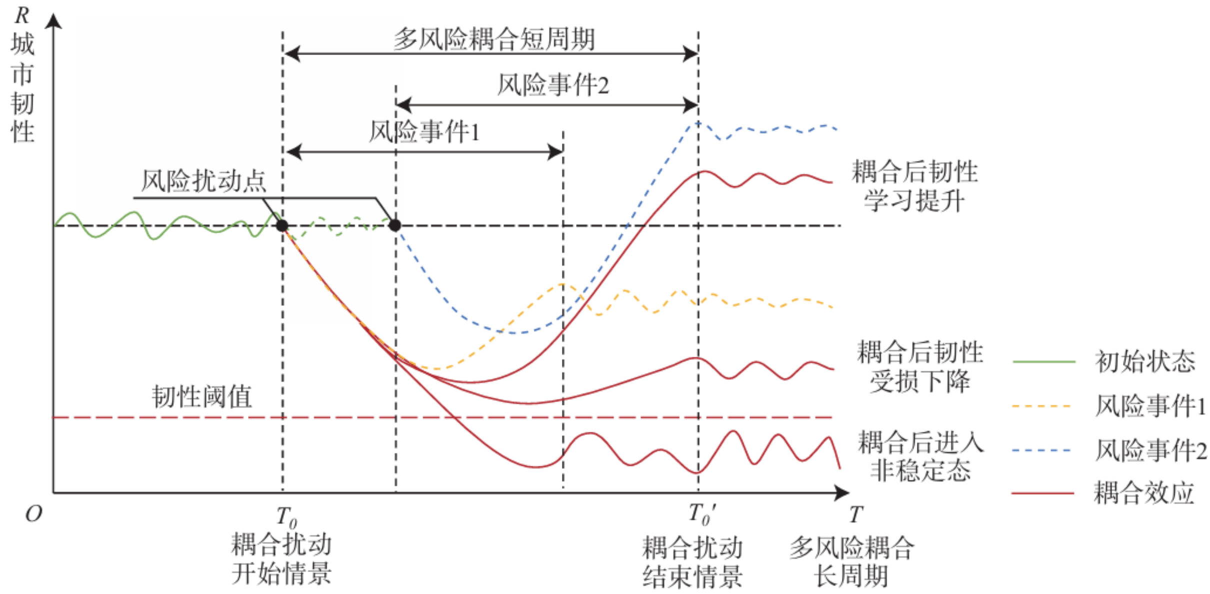

Figure 5. Theoretical model of resilience cycles in response to multi-risk

2.4 Resilience Levels and Cross-Scale Transmission under Multi-Risk Coupling

Urban resilience spans multiple spatial levels: the urban region (urban agglomeration or metropolitan area), the city, and the community. Each level has distinctive risks, resilience characteristics, and response strategies, and the levels interact in complex ways. External transport and logistics networks at the regional level, for example, enable cities to respond effectively to multiple risks. At the city level, emergency shelters and medical networks support communities. Resilient communities can use their organization and resources to assist neighboring communities, raising resilience across the city. Mutual influence and support within and among levels form the basis of systemic urban resilience.

Resilience transmission refers to the movement and diffusion of resilience within or between levels. In spatial terms, it is cross-level, multidirectional, systemic, and interconnected. From a complex-systems perspective, the interdependencies among levels change as urban systems evolve over long and short periods under coupled-risk events. Transmission provides support and buffering: when one level is affected, others can supply resources and assistance, accelerating recovery. Because urban resilience under multi-risk coupling involves spatial scales from the macro to the micro, analysis must consider the resilience characteristics and relationships of each level and how they jointly influence the system as a whole. Spatial planning can improve overall resilience by systematically identifying and strengthening resilience at each level and promoting cooperation and mutual support across scales.

3 Preparation of Resilient Spatial Plans for Multi-Risk Coupling

Urban resilience theory for coupled risks provides theoretical guidance for resilient spatial planning. It is therefore important to explore how the safety and resilience concept of multi-risk response can be incorporated into China’s territorial spatial planning system of “five levels and three plan types.” Figure 6 presents a preliminary framework.

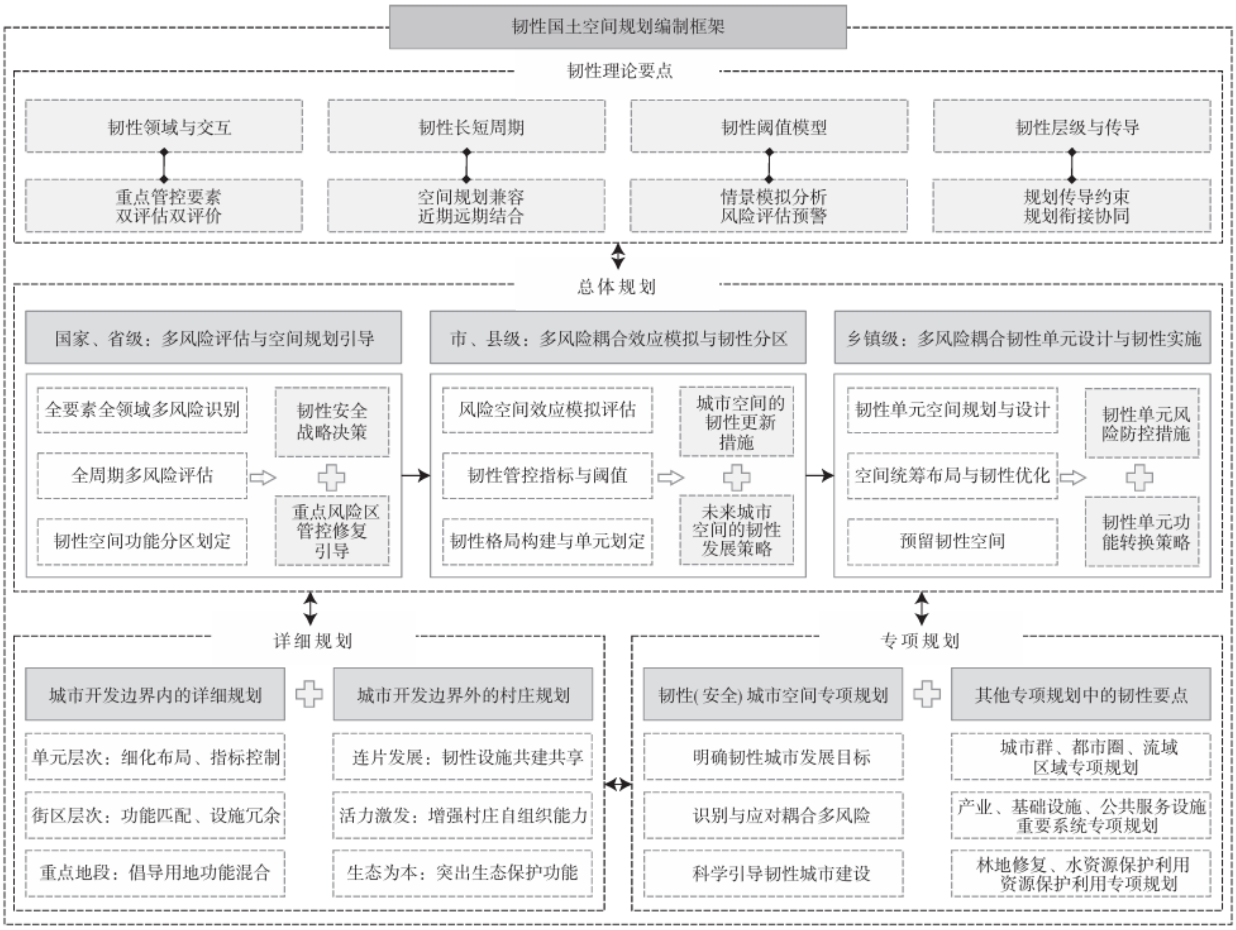

Figure 6. Framework for resilient territorial spatial planning

3.1 Resilience Priorities in Master Planning

Building resilient territorial space in response to normalized risk has become a major urban-planning principle. National and provincial master plans provide strategic guidance for resilient spatial development. In coordination with national resilience and security strategies, provincial plans should identify spatial risks and conduct dual evaluations of resource- and environmental-carrying capacity and development suitability. They should establish a resilient regional spatial pattern, delineate functional zones for territorial resilience and safety, and provide overall guidance for risk control and ecological restoration, especially in key risk areas.

Municipal, county, and township master plans should translate upper-level strategies into implementation. At municipal and county levels, resilient-city research should be undertaken where necessary. Plans should identify multi-risk coupling and evaluate resilience across all elements, domains, and cycles; construct a multi-risk urban safety base map; clarify bottom-line constraints and regulatory functions for resilience indicators; establish polycentric, networked patterns of spatial development and protection; create open, continuous, and connected ecological systems; and delineate resilience units. They should identify natural spaces capable of absorbing disasters, advance ecological restoration, improve regulatory ecosystem functions, and absorb or mitigate risk effects [56]. They should also improve the capacity of facilities to cope with multiple risks, enhance the adaptability and efficiency of infrastructure, and formulate strategies for resilient renewal of existing urban space and resilient development of future urban space. At township level, planning and design should be organized around resilience units, improve spatial-system organization, increase resource-use efficiency, coordinate production, living, and ecological spaces, reserve flexible space, and formulate routine risk-prevention measures and emergency functional-conversion strategies. Together, these actions form a multi-level, networked resilience system.

3.2 Resilience Priorities in Detailed Planning

In 2023, the Ministry of Natural Resources issued the Notice on Strengthening Territorial Spatial Detailed Planning, establishing new requirements for reform and practice. Detailed plans deepen and implement master plans by directly arranging land uses and the spatial layout of urban facilities. They are therefore a principal means of translating the resilient-city concept into the urban spatial system. Because spatial environments and resilience characteristics differ greatly inside and outside urban development boundaries, planning priorities also differ under normalized risk.

Within urban development boundaries, unit-level planning should use coupled-risk assessment to identify risk-prone zones and coupling hotspots, refine the spatial layout of shelters, civil-defense works, and other resilient-city facilities, and specify control indicators for resilience construction. At block level, plans should maintain a suitable relationship among population, development intensity, and urban form; provide adequate infrastructure, public-management and public-service facilities, green spaces, and squares; reasonably increase redundancy in resilience facilities; and ensure the implementation of emergency infrastructure. In key areas, greater spatial diversity and transformability should be encouraged, together with mixed land use in urban-renewal districts, public-activity centers, and mountain or waterfront landscapes.

Outside urban development boundaries, rural areas are comparatively weak links in resilient space. Multi-village planning can encourage joint construction and sharing of resilience facilities and strengthen horizontal transmission among places at the same level. Villages designated for agglomeration and upgrading or suburban integration should stimulate vitality through industrial upgrading and environmental improvement, strengthen self-organization, and reserve flexible development space. Villages designated for distinctive conservation or relocation and consolidation should emphasize ecological protection and human-settlement improvement. National parks, protected areas, major water-source areas, agricultural land, and other ecological or productive spaces requiring detailed plans should be screened for fire, geological, and seismic risks, with priority given to maintaining complete ecosystem-service functions.

3.3 Resilience Priorities in Specialized Planning

In China, ideas of resilience under multi-risk coupling are currently dispersed across specialized plans for sponge cities, comprehensive disaster prevention and mitigation [57], public-service facilities, transport, green systems, and related sectors. At the new stage of resilience development, urban resilience offers a theoretical framework and technical means for addressing safety. Whole-process, multi-domain, and cross-level resilience can be integrated into urban disaster prevention and mitigation through a specialized spatial plan for a resilient or safe city. Building on planning explorations in Beijing and elsewhere, Figure 7 presents an initial framework.

A specialized resilient-city spatial plan should address the common questions of Risk Stage 3.0: What are the development goals of a resilient city? How should normalized risks be managed to enhance resilience? How should the spatial pattern of a resilient city be guided? The plan can include five tasks: (1) integrate risk data from multiple departments, systematically identify potential urban multi-risks, conduct resilience assessment, and clarify weak links; (2) formulate forward-looking development goals based on long-term urban development and safety needs, adapting to uncertain future coupling; (3) allocate resources rationally, improve resilient spatial structure, layout, and zoning, coordinate dual-purpose public infrastructure for routine and emergency use, and create an organically integrated resilience system; (4) propose refined ecological, social, engineering, and economic measures and specify strategies for different risk scenarios; and (5) establish a clear implementation schedule and responsible actors, regularly evaluate effectiveness, and update plan content.

Because Chinese cities vary greatly in geography and scale, plans should be tailored to specific contexts. Geographically, planning should identify typical coupling types—for example, typhoon-rainfall risks in southeastern coastal cities or earthquake-geological-hazard risks in seismic zones—and formulate specialized measures that reconcile ordinary and emergency requirements and enable rapid conversion. Smaller cities and county seats have relatively simple spatial environments and hazard profiles; their priority is to reduce the prospective impact of common coupled risks and strengthen community resilience. Large cities are more complex and require identification of key resilience units and simulation of multiple scenarios, with guidance across the levels of “whole territory - central urban area - key spatial unit - community.” Megacities and super-large cities have highly concentrated populations and factors in their cores. They should strengthen co-construction and co-governance at the urban-regional scale, improve resilience transmission through urban-agglomeration and metropolitan coordination, prepare strategically for complex interactions between extreme climate events and severe emergencies, arrange spatial functional conversion and resource-flow patterns under extreme scenarios, and use digital twins and other new technologies to strengthen multi-risk perception, response, and governance under both long-term pressure and sudden shocks.

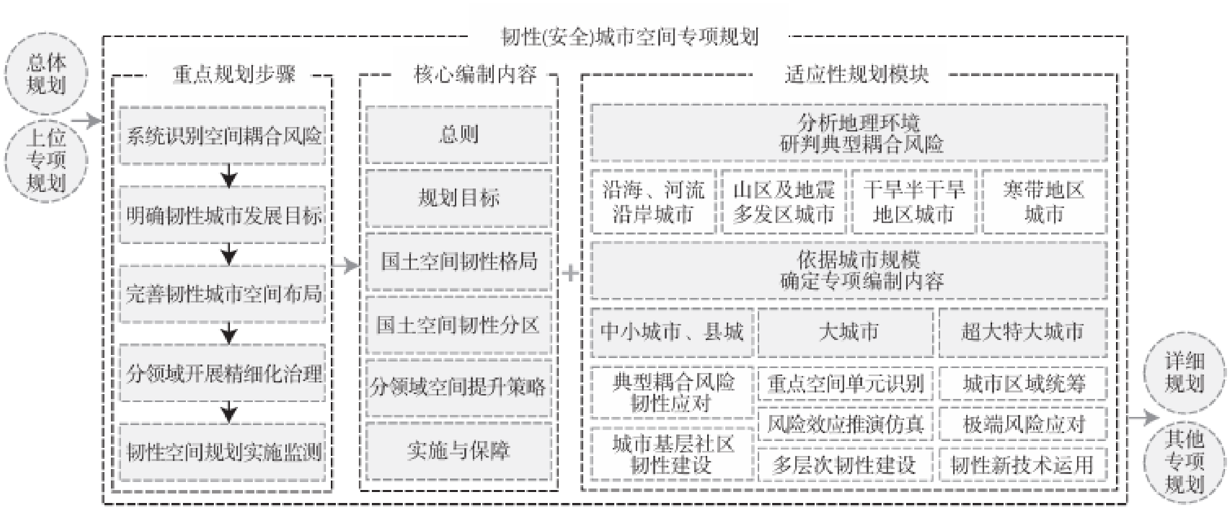

Figure 7. Preliminary framework for a specialized spatial plan for a resilient (safe) city

4 Technical Directions for Resilient Spatial Plan Preparation

The preceding resilience priorities indicate that the full planning process requires planners to collect multi-source urban spatial data, reveal complex risks, and simulate risk effects through integrated information and artificial intelligence technologies. Wu Zhiqiang and colleagues [58] argue that AI is making planning intelligent from multiple perspectives while also creating new challenges in the relationship between AI and cities. Peng Zhongren and colleagues [59] envision four stages in the development of urban-planning AI: assistance, augmentation, automation, and autonomy. Key technical directions for resilient plan preparation include spatial-information acquisition and processing, risk overlay and coupling assessment, scenario deduction and simulation, and intelligent planning and implementation monitoring.

4.1 Spatial-Information Acquisition and Processing

Remote sensing, the Internet of Things, and the Internet are widely used to collect and process urban spatial and risk data. Wider use of diverse urban flow data and improved data quality will substantially expand the dimensions of multi-risk resilience research and increase the efficiency of plan preparation. AI has significant advantages in mining urban big data, and the involvement of new technologies in urban analysis is becoming a major trend. Machine-learning algorithms can relate, fuse, and integrate historical and real-time risk data and support automated urban-model construction [58]. Digital empowerment of resilient planning should therefore emphasize the expansion and quality improvement of big-data applications, deep data mining, and multi-source integration. AI can support automated information processing, text and graphic generation, and model construction for complex urban systems, improving both planning efficiency and quality and enabling data-driven, intelligent urban resilience.

4.2 Risk Overlay and Coupling Assessment

Risk overlay and coupling assessment is an important direction in disaster-risk research and a critical component of resilient spatial planning. Assessment techniques are shifting from "single-hazard assessment" and "multi-factor integration" toward "multi-risk coupling" in complex urban systems. Models have been developed using disaster-risk system theory, trigger- relationship rules, pressure-state-response frameworks, multi-agent models, and other approaches [17,60-62]. Existing planning techniques can be divided into two categories by output: multi-risk level assessment, which classifies risk indices to reveal spatial distributions; and probabilistic multi-risk assessment, which examines coupling relations in depth and calculates probabilities and losses at the event scale.

As urbanization increases the complexity of spatial systems, assessment that focuses only on individual risks and ignores relationships among them will no longer meet future needs and may underestimate actual risk. Greater attention must be given to identifying and evaluating spatial effects in urban environments. Future multi-risk assessment can combine remote sensing with richer spatial information to produce high-resolution risk maps and identify potential urban hotspots. Machine learning and deep learning can support mathematical coupling models and urban-network models, enabling finer and even dynamic assessment, identification of risk patterns, investigation of complex relationships and formation mechanisms, and evaluation of the sensitivity and vulnerability of territorial space.

4.3 Scenario Deduction and Simulation

Planning for multi-risk coupling should conduct scenario deduction for typical urban risks. Starting from diverse risk data, it should construct systems of risk elements, determine key coupling scenarios in urban space, build evolutionary models through probabilistic assessment, and identify the functional state of spatial elements. According to the regularities of scenario evolution, natural-language models can be used to build knowledge graphs, construct scenarios, analyze multi-risk processes, and extract risk factors and spatial elements. Bayesian networks, Petri nets, hydrodynamic models, and other methods can then support spatiotemporal deduction of risk processes [63-66], identify spaces of prospective damage, and assess spatial effects on exposed elements.

Resilience mechanisms can be explored with system-dynamics models and simulations that capture complex interactions among risks and explain relations among influencing factors. Future urban simulation can combine intelligent methods to construct multi-risk models and capture threshold effects in spatial evolution [58]. Virtual reality, digital twins, and related technologies can further reveal relations between urban risk and spatial regularities, support multi-scenario simulation of coupled risks, and help select effective resilience policies and measures.

4.4 Intelligent Planning and Implementation Monitoring

Intelligent technologies are already providing practical support for plan generation, implementation, and monitoring. Genetic algorithms can simulate natural selection and mutation to identify optimal solutions for resilient spatial patterns. Intelligent image recognition can analyze urban data collected through remote sensing and IoT devices, monitor implementation, and provide spatial feedback.

Intelligent natural-language processing can automatically monitor and analyze social-media text during emergencies, evaluate the effects of resilience plans, and provide social feedback on implementation.

AI also makes adaptive dynamic planning possible. Generative AI enables planners to make intelligent resilience-design decisions and rapidly produce high-quality text and graphic outputs [58,67]. Chinese researchers have proposed the use of deep reinforcement learning in urban community planning [68], allowing plans to be adjusted and updated dynamically. In the future, intelligent adaptive guidance can support implementation under uncertain and changing urban conditions.

5 Conclusion

As urban risk management enters Stage 3.0, the theory of urban resilience under multi-risk coupling requires deeper development. Planning for normalized coupled risks is an inevitable direction in the new era and an important means of enhancing resilience and coordinating routine and emergency functions. Beginning with the risk challenges of future urban development, this paper reviewed the research foundations and planning experience of urban spatial multi-risk coupling, explored relevant resilience theory and applications, and identified priorities for resilient plan preparation and future technical development.

Three issues deserve particular attention. First, from the perspective of risk itself, the characteristics and regularities of typical urban risks must be clarified, with a specific focus on coupling. Second, from the perspective of the relationship between risk and the city, research should examine spatial effects and mechanisms, determine how land-use, facility, and building systems respond to multiple risks, and investigate resilience mechanisms through human-land interaction. Third, from the perspective of the relationship between risk and planning, resilient spatial plans should incorporate coupling-scenario analysis for specific multi-risk objects and formulate targeted planning and design measures. The study is intended to provide a theoretical reference and methodological guidance for planning and constructing safe, resilient cities in Risk Stage 3.0.

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Revised: June 2024

AI-assisted translation