# Constructing a Planning System for Responding to Natural Disaster Risks

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Abstract: Global climate change and rapid urbanization have intensified the compound and cascading characteristics of natural disasters, making it necessary to shift from engineering-dominated static prevention to full-cycle spatial governance. Grounded in complex systems theory and the theory of the production of space, this paper deconstructs the spatial attributes of natural disaster risks through a framework of material endowment, network organization, and dynamic response, and reveals the feedback mechanism of the human-land-disaster system. On this basis, six planning systems are proposed. Site-selection disaster prevention realizes risk isolation through rigid and flexible controls; structural pre-disaster planning strengthens system resilience through network optimization; capacity-control disaster reduction lowers exposure through development-intensity thresholds; strategic open-space reservation creates elastic buffers through planned reserves; connectivity-based disaster mitigation secures functional continuity through lifeline redundancy; and smart disaster control uses digital twins to improve precise prevention and control. The study forms a technical pathway deeply integrated with territorial spatial planning and provides theoretical support for resilient city building and the modernization of spatial governance.

Keywords: geological disasters; spatial attributes; planning response; system composition; spatial governance

The deep coupling of global climate change and rapid urbanization has made the natural-disaster risks facing cities more complex than ever. Urban construction is essentially a systematic intervention in the geological environment. In China in particular, high-intensity engineering activities have profoundly altered regional geostress fields and hydrogeological conditions, causing formerly stable geological systems to show compound effects such as the coupling of slope instability and land subsidence, cascading disaster chains, and sensitive spatiotemporal extension [1-4].

In the face of this new risk pattern, the limitations of traditional disaster prevention and reduction have become increasingly evident. First, engineering-led static prevention is poorly suited to dynamically evolving risks, because facility standards inferred from historical data often lag behind extreme climate change [5-7]. Second, sectorally fragmented governance struggles to address cascading disasters. Secondary fires caused by earthquakes and pipeline leakage often exceed the boundary of a single department, leading to superposed risks [1]. More critically, spatial thinking has remained underused in disaster prevention and reduction, which disconnects risk assessment from urban planning and construction [6]. It is therefore necessary to clarify planning as a core instrument for confronting disorderly forces and securing safe space, and to move beyond the path dependence of single-hazard defense, local engineering, and emergency response.

Global disaster-prevention thinking is undergoing a systemic transformation. The risk-disaster-causing factor-exposure-vulnerability framework has become an international consensus. Although related research in China started relatively late, it has expanded rapidly in recent years: theoretically, resilient-city thinking has been integrated with complex systems and spatial syntax [8-9]; in policy, the 14th Five-Year National Comprehensive Disaster Prevention and Reduction Plan requires stronger territorial spatial resilience; and technically, big data and artificial intelligence are being connected with disaster-prevention systems [10-13]. Existing studies still leave gaps. Many focus on the disaster itself or on a single technology, neglecting the interactive role of urban space as disaster carrier, risk amplifier, and prevention medium. The goal of safety and resilience has also not been deeply embedded in the territorial spatial planning system.

The 2025 Central Urban Work Conference emphasized accelerating resilient city construction and improving the urban safety prevention system. This creates an urgent need for a systematic theoretical framework that couples multiple hazards and covers the full prevention-control process. Accordingly, this paper deconstructs the complex interaction between natural-disaster risks and urban spatial systems, reveals the relationship among natural substrate, spatial organization, and planning response, and then proposes a six-dimensional urban planning system for responding to natural-disaster risks: site-selection disaster prevention, structural pre-disaster planning, capacity-control disaster reduction, strategic open-space reservation, connectivity-based disaster mitigation, and smart disaster control.

## 1 Urban spatial attributes of natural-disaster risks

Disasters are essentially nonlinear interactions between hazard-inducing factors and exposed bodies in specific spaces. During global urbanization, the expansion of construction land is positively associated with frequent disasters. Development in weak geological-structure zones, occupation of floodplains, and intensive use of coastal belts intensify earthquake-chain reactions, hydrological imbalance, and storm-surge damage, respectively. Deconstructing the urban spatial attributes of disaster risk is therefore essential for understanding disaster-formation mechanisms. From the perspectives of geographic location, hierarchical linkage, and process interaction, this paper divides these attributes into material spatial endowment, network spatial organization, and responsive spatial dynamics (Fig. 1).

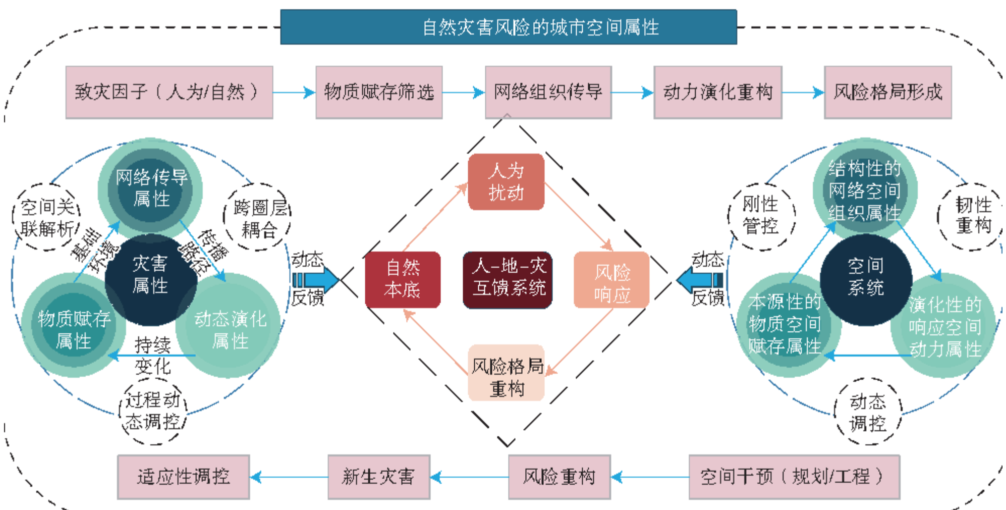



Fig. 1 Urban spatial characteristics of natural disaster risks.

### 1.1 Original material-spatial endowment attributes

Material spatial endowment attributes derive from the energy-material cycles of the Earth system and their spatiotemporal differentiation. They determine the macro-distribution and intensity spectrum of disaster risks, such as fault-zone distribution, meteorological disaster pathways, and river-system patterns. Under the dual disturbance of climate change and intensive human activities, geostress-field reconstruction and hydrological-cycle interference form a nonlinear feedback mechanism of natural substrate, anthropogenic disturbance, and risk response [4,14]. Disaster risk should therefore be understood as a spatial expression of the dynamic interaction between Earth systems and technological civilization, which requires a prevention-control logic based on energy-material circulation.

### 1.2 Structural network-spatial organization attributes

Network spatial organization attributes are rooted in the topology and systemic dependency of the built environment. As a risk carrier, the density-coupling-interface effects of urban space push modern disaster chains beyond a single scale, causing nonlinear amplification along building-city-region pathways. Social spatial organization further deepens this attribute. The spatial differentiation of population and economic agglomeration and governance capacity creates a vulnerable mosaic [15], producing selective paths of risk transmission. A three-dimensional coordination system of infrastructure resilience, social governance response networks, and ecological buffer barriers is therefore needed to interrupt cross-media risk transmission.

### 1.3 Evolving responsive spatial-dynamic attributes

Responsive spatial-dynamic attributes refer to the dynamic feedback process between urban spatial production and natural systems. Rapid urbanization has enhanced regional exposure and transferred old risks, while energy conversion or spatiotemporal delay can produce intergenerational risk transmission. The deeper contradiction lies in the externalities of human activities and the imbalance of risk distribution. Following the logic of risk space-technology, planning should use negative-list control and digital simulation to optimize the pattern, and on the basis of global risk sharing build a dynamic adaptation and development adaptation balance mechanism.
In sum, the spatial attributes of disaster risk are the compound product of natural geographic laws and human spatial practice. Material endowment provides the physical substrate of disaster occurrence, network organization defines the structural pathway of disaster transmission, and dynamic evolution drives the continuous transformation of risk patterns. Together, they form the spatial foundation for the complex urbanization of natural-disaster risks and guide planning from container thinking toward process thinking, leading the human-land-disaster system toward safety and balance.

## 2 Composition of a planning system for responding to natural-disaster risks

Based on complex systems theory and the theory of the production of space, this paper constructs a three-dimensional governance framework of spatial-process control, spatial-element allocation, and spatial-safety optimization. Through the production and transformation of spatial forms, it responds to the full chain of hazard induction, exposed-body aggravation, and vulnerability evolution. The core of this model is to reduce orderly load and orient system resilience by altering human-land-disaster relationships through spatial reconstruction. Six planning systems are proposed.

### 2.1 Site-selection disaster prevention based on disaster-substrate constraints

Site-selection disaster prevention is the source-control basis for urban planning responses to disaster risks. It identifies and avoids disaster constraints through site screening, forming a rigid and flexible constraint framework of risk identification, substrate constraint, and safe site selection. It incorporates disaster-sensitive areas into urban spatial access thresholds and planning regulation inventories (Fig. 2a). This system is rooted in the dialectical unity of physical geography and ecological civilization: it identifies disaster-energy transmission patterns through mountain-water-field-ecology analysis, clarifies how regional tectonics and hydrology shape the ground-surface spatial pattern, and provides deterministic natural constraints for urban space.
Technically, this paper builds an implementation framework of substrate analysis, site screening, and graded control. At the level of substrate analysis, integrated sky-space-ground-deep observation is used to interpret the geohazard-geomorphic-habitat coupling and disaster-chain sensitivity. In site screening, multisource data and evaluation technologies are combined to construct a regional database and establish multilevel disaster-substrate data at regional, urban, and site scales. In graded control, rigid constraints and flexible guidance are combined to integrate disaster constraints into project approval and monitoring, forming a closed loop of negative-list control, risk assessment, and dynamic correction.

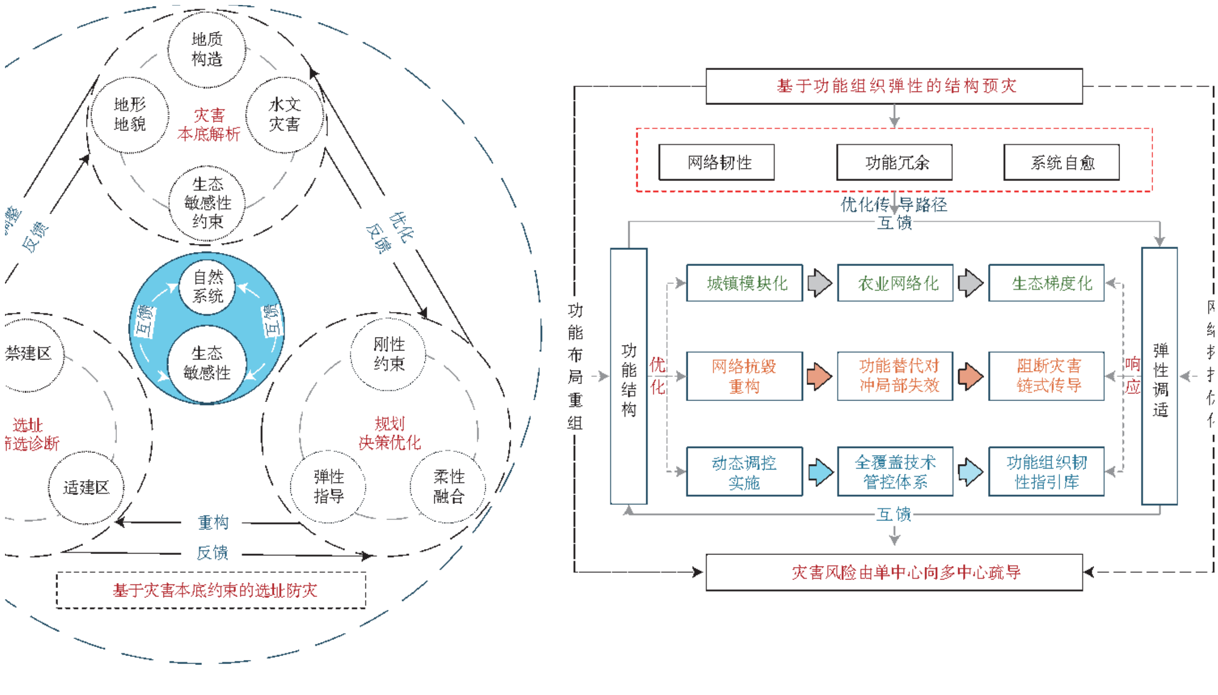



Fig. 2 Composition of the planning system for natural-disaster response.

**2.2 Structural pre-disaster planning based on functional-organization resilience**

Structural pre-disaster planning is the spatial-structure optimization path for responding to natural-disaster risks. It improves network topology and functional layout to form a multilevel resilient protection framework of network resilience, functional redundancy, and system self-healing (Fig. 2b). Drawing on complex adaptive systems theory and dissipative-structure theory, it stresses that disasters move along scale and functional interfaces. First, the functional unit-network structure-disaster substrate relationship is used to identify the mechanisms of functional reorganization and risk linkage [11,13]. Second, multicenter and group-based layouts distribute disaster risk and prevent functional failure in single centers. Finally, modular optimization redundancy is formed within spatial organization, so that facilities, agricultural space, ecological barriers, and emergency nodes maintain service efficiency.

The technical route for structural pre-disaster planning consists of functional optimization, network reconstruction, and dynamic adjustment. Functional-unit optimization identifies vulnerable points and reconstructs function through spatial syntax and multi-intelligent-body simulation. Network reconstruction strengthens the spatial capacity to endure interruptions by enhancing structural-resilience density and optimizing key-node redundancy. Dynamic adjustment then uses a simulation platform to conduct scenario projection, set endurance thresholds for key functions, and support adaptive response to sudden disaster transmission.

**2.3 Capacity-control disaster reduction based on development-intensity balance**

Capacity-control disaster reduction is the gradient-management handle for urban planning response to natural-disaster risks. It sets spatially differentiated development-intensity thresholds by coordinating urban-unit-ground parcel relationships, transforming safety-bearing capacity into the binding parameter of spatial development intensity (Fig. 3a). The approach requires the integration of disaster-system theory and capacity-gradient governance. It first identifies the multiscale disturbance characteristics of disasters and clarifies how excessive urban density and unit-level functional failure trigger the cascading amplification of risk. It then uses dual evaluation to establish a conversion pathway from risk zones to intensity-control grids. Finally, it anchors total development volume and establishes a stepwise intensity system of total-domain constraints, district adaptation, and parcel precision.

For capacity reduction, this paper develops a full-chain framework of threshold-plot matching and morphology-parameter optimization. In the urban safety-threshold layer, terrain, ecology, and disaster-history data are used to identify maximum regional development capacity and prevent overdevelopment from breaching the carrying threshold and causing systemic cascading failure. In the unit-land ratio layer, cellular automata and morphological models are used to build a disaster-sensitivity matrix, reveal risk transmission mechanisms, and optimize land-use proportions at the grid or community scale. In the site-form parameter layer, morphological safety-efficiency models and planning simulation are used to optimize layout ratios and building continuity, establishing refined controls for density, contour, spacing, height, and capacity.

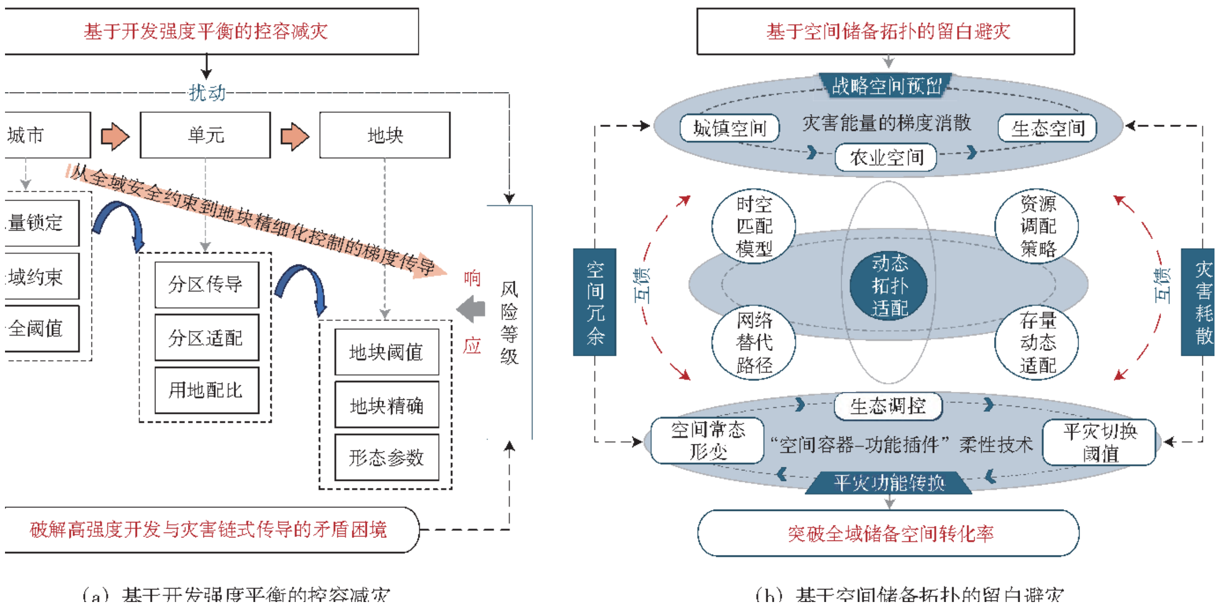



Fig. 3 Composition of the planning system for responding to natural disaster risks.

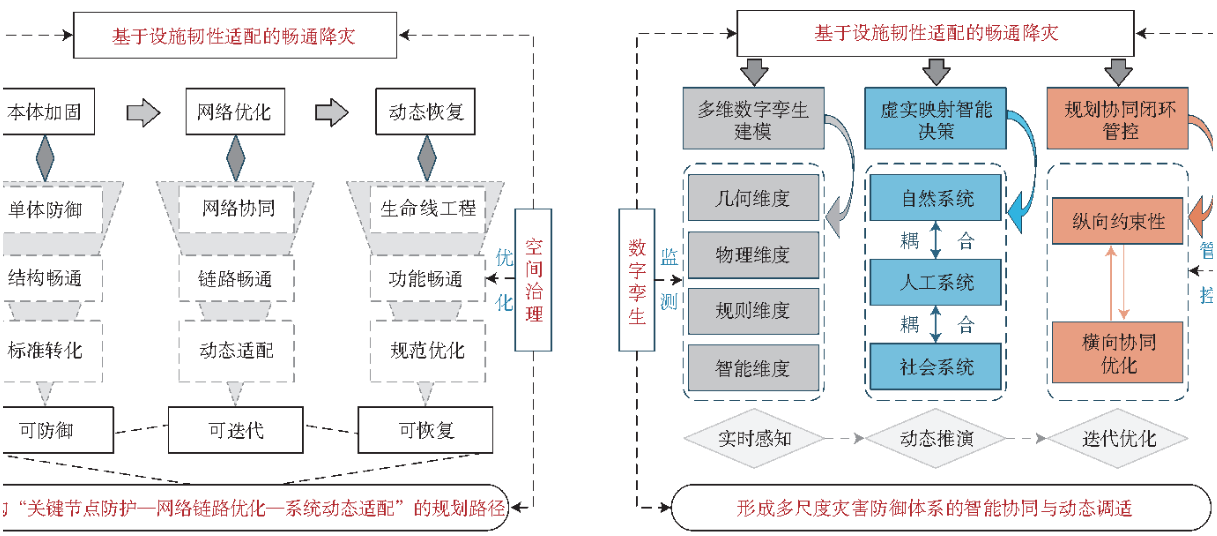
**2.4 Strategic open-space reservation based on spatial-reserve topology**

Strategic open-space reservation is the strategic spatial-reserve handle for urban planning response to disaster risks. It transforms resilient storage and release into the rate of spatial-resource allocation by optimizing urban-resilience nodes and topology, forming a mechanism of disaster conversion, energy buffering, and graded absorption (Fig. 3b). The system originates in the integration of resilient-city theory and topology. First, it converts spatial redundancy and functional resilience to strengthen uncertain-event response. Second, it introduces the logic of topology and disaster defense matching, responding to the mandatory regulatory need for important strategic reserve space. Third, through a spatial-reserve-intergenerational conversion design, township-level refuge layers become distributed resilient units, agricultural space is connected through forests, floodplains, and land resource allocation, and ecological space uses natural reserves to create large-scale disaster-energy absorption interfaces.

Technically, the system emphasizes spatial retention, topology generation, and entity conversion. At the strategic open-space level, it introduces solutions based on natural elements such as forest, field, water, and grassland, and converts multimodal network embedding into buffer belts. In township space, it constructs a core-ring-corridor three-level structure to absorb and store energy at different gradients. In agricultural and ecological spaces, field-ridge networks and protected landforms are transformed into large-scale energy-absorption networks. At the dynamic-topology adaptation stage, a spatiotemporal matching model identifies the best refuge and emergency-support nodes, optimizes network-substitution pathways and recovery-resource allocation, and determines the activation threshold and conversion sequence of reserve space through disaster scenario simulation.

### 2.5 Connectivity-based disaster mitigation through facility-resilience adaptation

Connectivity-based disaster mitigation is the infrastructure-guarantee handle for urban planning response to natural-disaster risks. It reconstructs engineering protection into a resilient-adaptation base for spatial governance by coordinating the lifeline-engineering physical system, network coordination, and dynamic recovery (Fig. 4a). This system is grounded in the coupling of resilient-infrastructure theory and spatial governance principles [12,19]. It first grades infrastructure through redundancy, adaptability, and recoverability, using ring-shaped topology and modular design to achieve high correspondence between facility functions and demand. Second, complex adaptive-systems theory is used to identify linkage-failure mechanisms, and a network dynamic-adaptation path based on single protection, networked repair, and system evolution is constructed. Finally, engineering protection requirements are translated into planning control indicators, and a resilient-infrastructure land-use classification is established to improve efficiency and shift passive defense toward active participation in spatial resilience.




（a）基于设施韧性适配的畅通降灾　　（b）基于数字孪生支撑的智慧控灾

Fig. 4 Composition of the planning system for natural-disaster response.

### 2.6 Smart disaster control supported by digital twins

Smart disaster control is the digital-governance hub for urban planning response to natural-disaster risks. It establishes a circular mechanism of virtual-real interaction, intelligent iteration, and integrated decision making through real-time perception, dynamic simulation, and iterative optimization (Fig. 4b). The system derives from the methodological innovation of digital twins and complex-systems science. It first constructs multidimensional mappings from geometric to dynamic simulation. It then integrates BIM, GIS, and IoT to create a coupled simulation environment of natural, artificial, and social systems, upgrading empirical decision making into algorithm-driven intelligent governance. Finally, it connects the digital platform with territorial spatial planning so that planning control, implementation monitoring, and assessment feedback form a complete intelligent closed loop.

In the implementation framework, smart disaster control proceeds through multidimensional modeling, virtual-real mapping, and closed-loop decision making. The digital-twin model provides bottom support through four-dimensional high-precision modeling of geometry, physics, rules, and intelligence. Virtual-real mapping maintains dynamic interpretation, constraint embedding, and evolutionary projection. The intelligent-decision link relies on real-time perception and multi-intelligent-body simulation to generate coordinated controls across vertical and horizontal dimensions, turning emergency response into precise intervention. At the planning-coordination level, a one-map platform supports multigoal optimization across predisaster simulation, in-disaster tracking, and postdisaster evaluation, forming an intelligent governance system of perception, inference, control, and iteration.

## 3 Conclusions and prospects

As a product of human transformation of nature, the city develops through constant interaction with natural laws. Disasters are not external disturbances to urban planning, but intrinsic contradictions embedded in the evolution of urban space. The capacity to respond scientifically and effectively to disaster risks is therefore a key measure of planning performance. Against the background of the deep coupling of global climate change and urbanization, this paper focuses on natural-disaster risks under the significant influence of human activities, deconstructs their spatial attributes, and constructs six major urban planning systems. The main conclusions are as follows.

### 3.1 Clarifying the urban-spatial logic of natural-disaster risks

The paper clarifies that the spatial attributes of urban natural-disaster risks are not a single geographic-location feature, but an integrated whole composed of origin, structure, and evolution. Material spatial endowment derives from the nonlinear differentiation of energy-material cycles in the Earth system. Plate movement and atmospheric circulation shape the risk substrate, while urban engineering activities create feedback between natural substrate, anthropogenic disturbance, and risk response. Network spatial organization relies on the topology of the built environment and social system, amplifies risk transmission through density, coupling, and interface effects, and produces nonlinear transmission across building, city, and region. Responsive spatial dynamics reflects the dynamic interaction between urban spatial production and natural systems, in which spatial development generates intergenerational effects through risk substitution and transfer, and the externalities of human activities intensify cross-scale and cross-media risk differentiation.

### 3.2 Constructing an urban planning system of source control, exposed-body protection, and capacity enhancement

Based on complex systems theory and the theory of the production of space, this paper translates the source-exposed body-disaster-reduction capacity framework of urban safety into six planning systems [6,19-20]. Site-selection disaster prevention identifies risk sources and realizes source isolation through disaster-avoidance siting. Structural pre-disaster planning targets the functional organization of exposed bodies and builds substitution and self-recovery mechanisms through network-topology optimization and functional redundancy. Capacity-control disaster reduction prevents excessive concentration of exposed bodies from magnifying risks through development-intensity thresholds. Strategic open-space reservation reserves strategic space and constructs physical buffers and refuge places. Connectivity-based disaster mitigation secures lifeline redundancy and network accessibility to maintain functions. Smart disaster control connects monitoring and prevention through digital twins and improves the precision and timeliness of intervention. Together, these systems integrate risk-source control, exposed-body protection, and disaster-reduction capacity enhancement into urban planning.

### 3.3 Exploring the integration path between territorial spatial planning and disaster prevention and reduction

To address the insufficient integration of safety-resilience goals, the paper proposes differentiated integration strategies. At the planning-transmission level, disaster-risk control lines should be incorporated into the rigid control system of three zones and three lines. At the technical-method level, sky-space-ground-deep collaborative monitoring, GIS spatial overlay analysis, and multi-intelligent-body simulation should be integrated to connect risk assessment with planning design. At the governance-performance level, graded control that combines rigid constraint, flexible guidance, and adaptive integration should balance ecological protection, safety prevention, and spatial-development needs.

Urban planning response to natural-disaster risks is a multidisciplinary and multilevel systems project. Future research should further integrate cross-disciplinary technical resources and collaborative innovation platforms, promote the transition of urban disaster prevention and reduction from postdisaster rescue to proactive prevention, from single-hazard defense to disaster-chain governance, and from experience-based decision making to intelligent regulation, thereby providing technical support for the modernization of urban spatial governance under the Peaceful China strategy.

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